NATURAL RESOURCES MANAGEMENT PLAN FOR THE UH MANAGEMENT AREAS ON MAUNA KEA

A Sub-Plan of the Mauna Kea Comprehensive Management Plan

September 2009

SUSTAINABLE RESOURCES GROUP INTN'L, INC.

EXHIBIT A-10

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ACKNOWLEDGEMENTS

This Natural Resources Management Plan (NRMP) was funded by the Office of Mauna Kea Management (OMKM). Stephanie Nagata, OMKM Interim Director, was instrumental in setting up and overseeing all aspects of the contract with Sustainable Resources Group Intn'l, Inc. (SRGII), as well as providing information and feedback relating to the history and operations of OMKM and facilitating information gathering from others. She, along with the Mauna Kea Management Board (MKMB) Environment Committee are recognized for their initiative in identifying a need for this plan and providing valuable review and comment on draft documents.

Numerous individuals were consulted in the development of this plan, from resource managers to research scientists to members of the public. Many of the communications with these individuals are acknowledged directly in the references. SRGII and OMKM are grateful for the participation of, and input from, attendees of the community consultation meetings. Ron Koehler provided information regarding maintenance operations overseen by Mauna Kea Observatories Support Services (MKSS). The Visitor Information Center and ranger staff provided insight into the variety of activities occurring on the UH Management Areas. Dawn Pamarang of OMKM and the OMKM librarians assisted by providing data and resource materials consulted in the preparation of the plan.

EXECUTIVE SUMMARY

The development of the *Mauna Kea Natural Resources Management Plan* (NRMP) was initiated as a project of the Mauna Kea Management Board (MKMB) Environment Committee. Completion and approval of the NRMP was a conditional requirement made pursuant to approval of the *Mauna Kea Comprehensive Management Plan* (CMP) by the Board of Land and Natural Resources (BLNR) in April 2009.

The NRMP is unique because it is the first plan to focus on the protection and preservation of natural resources in the UH Management Areas on Mauna Kea (Mauna Kea Science Reserve (MKSR), Summit Access Road, and Hale Pōhaku). While the CMP provides an overview and major recommendations pertaining to natural resources, the NRMP provides detailed information on the status of and threats to natural resources and development of a management program to conserve these resources. A list cross-referencing CMP management actions to related sections in the NRMP is provided in Table 3 to aid managers tasked with implementing both plans. The sections listed provide background information related to, or other pertinent information in support of, the CMP management actions.

The NRMP is based on a scientific framework that includes comprehensive review of existing scientific studies, biological inventories, and historical documentation that identifies the current state of knowledge of resources and management activities and the effectiveness of current management actions. Community consultation was also part of the process, with surveys, email and phone interviews, and meetings held in Hilo and Honolulu to gather input from scientific experts, natural resource managers, and concerned members of the public. The NRMP examines human uses of the area, with particular emphasis on their current and potential impacts on natural resources. This plan offers specific management actions to reduce the identified threats to natural resources and to guide adaptive responses to future threats. It also details a process for establishing and implementing a natural resources management program. The implementation plan reflects the input of multiple stakeholders, each of which sees different challenges and opportunities related to the management of Mauna Kea's natural resources.

The traditional Hawaiian culture and belief system in which the natural and spiritual realms are intertwined provides a framework for integrated management of cultural and natural resources. In most cases, the cultural, spiritual, and religious aspects cannot be examined separately from the physical or scientific aspects. Within this context it was hoped that stakeholder involvement and cooperation by both cultural and natural resource practitioners would result in the development of a plan that resulted in the long-term protection of all resources. The information and recommendations contained in the NRMP are considered in a broader context, including opportunities and constraints presented by policy, operational and cultural resource considerations.

The overarching goal of this NRMP is to help OMKM achieve its mission by providing natural resource management goals, objectives, and activities that protect, preserve, and enhance the natural resources of Mauna Kea. The NRMP was developed with the following concepts in mind:

1. The high elevation areas of Mauna Kea represent a unique global resource that should be preserved for future generations.
2. Natural resource management planning will be based on the ecosystem approach, rather than conducted species by species.
3. Management activities will be focused on limiting the impacts of human activities on natural resources.

4. The planning and execution of natural resource management programs will involve input from the larger community (e.g., managers, scientists, educators, volunteers, the public).
5. Long-term global environmental factors such as climate change must be taken into account when planning natural resource management activities.

The Mauna Kea Natural Resources Management Plan is organized into five main sections.

Section 1, Introduction, provides background and setting, including a discussion of the principles of natural resources management and scientific framework, an overview of management area, and a description the management environment. Management principles utilized in the development of the NRMP include adaptive management, ecosystem management, and traditional ecological knowledge. The NRMP is one component of the overall management strategy being implemented for the UH Management Areas on Mauna Kea to allow for multiple uses of the mountain while protecting the resources, providing a detailed discussion of environmental issues and potential management solutions.

Section 2, Natural Resources Environment, details the current state of knowledge of the abiotic and biotic resources, including historical observations, current status, existing surveys and data, information gaps, and threats. The areas covered in the NRMP include some of Hawai'i's unique and rare alpine ecosystems. The MKSR and the upper portions of the Summit Access Road mostly fall into the alpine community, while the mid-level facilities at Hale Pōhaku and the lower portion of the Summit Access Road fall within the subalpine community. Although the biotic communities in these areas differ, they are linked by a common hydrology, geology, and by general ecosystem processes. The aeolian ecosystem found on the summit likely depends on the productivity of the areas downslope to sustain its globally unique organisms. These fragile ecosystems are valuable resources to the citizens of Hawai'i and to the global community.

Section 3, Activities and Uses, describes the existing human environment, including activities, infrastructure, use levels and patterns, and changes over time that have, or may have, an impact on Mauna Kea's natural resources. In addition to presenting information on the current and historical status, this section describes potential impacts and threats to natural resources associated with human use of the area. The primary concerns relating to human use are evaluating their potential threats and managing activities and access. Existing conditions are discussed by "use type" including astronomical research and facilities, scientific research, recreational and tourism activities, commercial activities, and cultural and religious practices. Since many of the threats and impacts result from more than one type of user, the discussion is organized by type of impact or threat.

Section 4, Component Plans is the information, analysis, and management section, which is divided into five major components. The goals of the component plans are summarized in Table 2.

Section 4.1 Natural Resource Inventory, Monitoring and Research Component Plan, describes the development of an Inventory, Monitoring and Research (IM&R) program and identifies data gaps and information needs for the natural resources found within UH Management Areas. IM&R needs are prioritized according to current understanding of the resources and data gaps. Science-based natural resource management requires quality data about the status of biological and physical resources. Comprehensive and well-designed IM&R programs allow managers to determine the status of natural resources, track changes in resources over time, identify new threats, measure progress towards meeting management objectives, and plan future research and management. Data collected from IM&R programs can assist managers with identifying at-risk areas, to prevent habitat loss or degradation; identifying areas that can be restored and preserved; prioritizing management actions based on geographic area and sensitivity; and informing stakeholders of management successes or issues of concern, with the aim of increasing public trust and support for management actions.

Executive Summary

The IM&R program is divided into three components that examine the status of natural resources in the UH Management Areas: baseline inventories, long-term monitoring, and research. The baseline inventory, or initial survey, establishes the status of the area under management at the beginning of a natural resources management program. To date, only limited baseline data has been collected on natural resources in UH Management Areas.[1] Many of the decisions and paths taken by the management program will follow from the results of the baseline inventory. Long-term monitoring begins after the completion of the baseline inventory and tracks selected resources over time. Decisions on what resources to monitor over the long term will be based on the results of the baseline inventory and the objectives of the management program, including adhering to any legal requirements. Research answers questions and fills data gaps that are beyond the scope of the inventory and monitoring program but that are necessary to understand and manage the resources and advance the body of knowledge. Research programs may begin after the baseline inventory is completed, or at any time during long-term monitoring. High priority resources to include in the IM&R program are identified in Table 1.

Table 1. High Priority Natural Resources to Include in IM&R Program

Resource Category	Hale Pōhaku	MKSR
	Physical	
Soils	Erosion inventory	Site-specific contamination of substrate
Hydrology	N/A	Summit groundwater hydrology and connection to downslope water resources (Lake Waiau, aquifers, seeps and springs)
	Biological	
Plants	T&E* Species (including silverswords)	T&E Species (including silverswords)
	Māmane woodlands	Stone desert
	Invasive plants	Invasive plants (along road)
Invertebrates	Native pollinators (bees, moths)	Summit arthropods
	Invasive wasps and ants	Invasive arthropods
Birds	Hawaiian Petrel, Palila, and native honeycreepers	Hawaiian Petrel
Mammals	T&E native species (Hawaiian hoary bat)	N/A (No native species found in MKSR)
	Herbivores (sheep, goats)	Herbivores (sheep, goats)
	Predators (cats, mongoose, rats)	Arthropod Predators (rats, mice)
	Seedeaters (mice, rats)	Seedeaters (mice, rats)

*Threatened and endangered

Section 4.2, Threat Prevention and Control Component Plan, describes the development of a Threat Prevention and Control plan for natural resources management within UH Management Areas. A review of current and potential threats to the natural resources is provided, and a range of management actions are presented and prioritized to deal with identified threats.

Threat prevention and control is an important part of ecosystem management. For many threats, the magnitude of the impact will depend on the types of activities that occur on the land and the level of use. Because of this, a threat or impact to a natural resource that may be minimal in one area may be of greater consequence in another. In other cases, such as with global climate change, the threat is less

[1] A cultural resources (archeological) inventory has been completed for the Mauna Kea Science Reserve (McCoy et al. 2009).

directly tied to local land use and activity levels. While it is important to view the management areas on the ecosystem level, some management activities to control or prevent threats will by necessity be focused primarily in areas of high impact. Uses and activity levels vary within the UH Management Areas, and potential impacts of human uses are of different magnitude and importance. This means that there will be no one-size-fits-all type of management action or level of management effort to deal with most threats to natural resources.

Section 4.3, Natural Resources Preservation, Enhancement, and Restoration Component Plan, describes and prioritizes management activities to protect the sustainability of native plant and animal communities and their habitats. The actions of preserving, enhancing, and restoring natural resources are part of a continuum of management activities. The level of intervention and kinds of management activities necessary to protect the natural resources determine whether preservation, enhancement, or restoration actions are needed.

Section 4.4, Education and Outreach Component Plan, describes the continued development of OMKM's educational and outreach efforts, and provides recommended education and outreach activities to improve understanding of the unique natural resources found within UH Management Areas. Education and outreach are necessary to provide visitors to the mountain and observatory personnel with the information they need to understand and protect the natural resources. Increasing use of Mauna Kea brings with it the potential for increased negative impacts on the fragile subalpine and alpine ecosystems and cultural resources. It is easy for visitors, observatory personnel, and support staff to overlook many of these elements because, to many, the barren landscape appears lifeless. To address this, the OMKM education and outreach program should be expanded to include natural resources. Additionally, educators and researchers should be encouraged to utilize Hale Pōhaku and the Science Reserve for educational and scientific research programs, to better increase understanding of the unique ecosystems found there.

Section 4.5, Information Management Component Plan, describes the activities needed to successfully manage information collected during inventory, monitoring, research, threat prevention and control, preservation, enhancement, restoration, education, and outreach activities. Data obtained from the baseline inventory, records of user activity levels, long-term monitoring, and spatial depiction of the distribution of threats and natural resources will help inform the natural resources manager where to conduct various management activities. Recommendations include establishment of a geographic information system (GIS) system at OMKM, maintaining data properly, and continued support and improvement of the OMKM library.

Section 5, Implementation and Evaluation Plan, describes the resources necessary to implement the proposed management actions, along with a methodology for evaluating and updating the NRMP. The Implementation Plan describes the steps and recommended activities necessary for establishing and implementing a successful Natural Resources Management Program. Topics covered include obtaining sufficient funding, staffing, training, equipment and facilities needs, coordination with other agencies, and ongoing review and evaluation of program successes and failures. Natural resources management on Mauna Kea requires collaboration and cooperation among the various stakeholders because there are overlapping jurisdictions and because ecosystems do not recognize political or property boundaries.

The Evaluation Plan provides a methodology for evaluating the success of the program and for determining any need for changes in management strategies. Topics include monitoring NRMP implementation and a process for review and revision of the NRMP. Since the true status of the natural resources on the UH Management Areas is not fully understood and because conditions change over time, it is important to allow for flexibility in natural resource management activities and management plans. Both day-to-day resource management activities and natural resource management plans must be able to respond appropriately to changes in conditions or to the discovery of new information. This is accomplished using adaptive management and ecosystem management principles (see Section 1.2).

Table 2. NRMP Component Plan Goals

4.1	**Natural Resource Inventory, Monitoring and Research**
	– Determine baseline status of the natural resources (baseline inventories) – Conduct long-term monitoring to determine the status and trends in selected resources, to allow for informed management decisions – Conduct research projects to fill knowledge gaps about natural resources that cannot be addressed – Create efficient, cost effective Inventory, Monitoring and Research programs – Measure progress towards performance goal of preserving, protecting, and restoring Mauna Kea ecosystems – Increase communication, networking, and collaborative opportunities, to support management and protection of natural resources
4.2	**Threat Prevention and Control**
	– Provide early warning of undesirable changes to Mauna Kea's high-elevation ecosystems – Minimize habitat alteration and disturbance – Maintain high level of air quality – Prevent migration of contaminants to the environment – Minimize accelerated erosion – Reduce impacts of solid waste – Maintain current levels of background noise – Prevent establishment of new invasive species and control established invasive species – Maintain native plant and animal populations and biological diversity – Limit impacts to natural resources from scientific research and sample collection – Prevent fires – Manage ecosystems to allow for response to climate change
4.3	**Natural Resources Preservation, Enhancement, and Restoration**
	– Preserve sensitive habitats and unique high-elevation ecosystems – Enhance existing native communities and unique habitats – Mitigate or repair damage to sensitive ecosystems – Restore damaged ecosystems
4.4	**Education and Outreach**
	– Educate and involve the public to support and enhance conservation of Mauna Kea's natural resources.
4.5	**Information Management**
	– Maintain accessible, relevant information to meet management, educational, and research needs for Mauna Kea

Since this is the first NRMP for the UH Management Areas on Mauna Kea, its scope is deliberately broad and comprehensive. It will be the task of the managers to use this document as guidance, in concert with other management directives, to prioritize and implement relevant parts of the NRMP. For many elements, a variety of management actions are presented. It is not the intent of this plan that all of these be implemented, but rather the best actions be chosen depending on the management priorities, situation, availability of funding, and the results of baseline inventories and long-term monitoring. An adaptive management approach will ensure that the management strategies reflect input received from inventory, monitoring and research activities in order to preserve and protect the natural resources of Mauna Kea.

Table 3. Mauna Kea CMP Management Actions Cross-Referenced to Sections in the NRMP

Mauna Kea CMP Management Action		NRMP Section
CMP Section 7.1.1: Native Hawaiian Cultural Resources		
General Management		
CR-1	Kahu Kū Mauna shall work with families with lineal and historical connections to Mauna Kea, cultural practitioners, and other Native Hawaiian groups, including the Mauna Kea Management Board's Hawaiian Culture Committee, toward the development of appropriate procedures and protocols regarding cultural issues.	3.1.5, 5.1.1
CR-3	Conduct educational efforts to generate public awareness about the importance of preserving the cultural landscape.	4.4.2
CMP Section 7.1.2: Natural Resources		
Threat Prevention and Control		
NR-1	Limit threats to natural resources through management of permitted activities and uses.	4.2.3
NR-2	Limit damage caused by invasive species through creation of an invasive species prevention and control program.	4.2.3.7
NR-3	Maintain native plant and animal populations and biological diversity.	4.2.3.8
NR-4	Minimize barriers to species migration, to help maintain populations and protect ecosystem processes and development.	4.2.3.11
NR-5	Manage ecosystems to allow for response to climate change.	4.2.3.11
NR-6	Reduce threats to natural resources by educating stakeholders and the public about Mauna Kea's unique natural resources.	4.4
Ecosystem Protection, Enhancement, and Restoration		
NR-7	Delineate areas of high native diversity, unique communities, or unique geological features within the Astronomy Precinct and at Hale Pōhaku and consider protection from development.	4.1, 4.2.3.1
NR-8	Consider fencing areas of high native biodiversity or populations of endangered species to keep out feral ungulates (applies to areas below 12,800 ft elevation).	4.2.3.7, 4.3
NR-9	Increase native plant density and diversity through an outplanting program.	4.3, 4.4
NR-10	Incorporate mitigation plans into project planning and conduct mitigation following new development.	4.3
NR-11	Conduct habitat rehabilitation projects following unplanned disturbances.	4.3
NR-12	Create restoration plans and conduct habitat restoration activities, as needed.	4.3
Program Management		
NR-13	Increase communication, networking, and collaborative opportunities, to support management and protection of natural resources.	4.1.3.3, 4.3, 5.1.3
NR-14	Use the principles of adaptive management when developing programs and methodologies. Review programs annually and revise any component plans every five years, based on the results of the program review.	1.2, 5.2
Inventory, Monitoring and Research		
NR-15	Conduct baseline inventories of high-priority resources, as outlined in an inventory, monitoring, and research plan.	4.1
NR-16	Conduct regular long-term monitoring, as outlined in an inventory, monitoring, and research plan.	4.1
NR-17	Conduct research to fill knowledge gaps that cannot be addressed through inventory and monitoring.	4.1.2.3
NR-18	Develop geo-spatial database of all known natural resources and their locations in the UH Management Areas that can serve as baseline documentation against change and provide information essential for decision-making.	4.1, 4.5
CMP Section 7.1.3: Education and Outreach		
EO-1	Develop and implement education and outreach program.	4.4
EO-2	Require orientation of users, with periodic updates and a certificate of completion, including but not limited to visitors, employees, observatory staff, contractors, and commercial and recreational users.	4.4.2

	Mauna Kea CMP Management Action	NRMP Section
EO-3	Continue to develop, update, and distribute materials explaining important aspects of Mauna Kea.	4.4
EO-4	Develop and implement a signage plan to improve signage throughout the UH Management Areas (interpretive, safety, rules and regulations).	4.4.2
EO-5	Develop interpretive features such as self-guided cultural walks and volunteer-maintained native plant gardens.	4.3, 4.4.2
EO-6	Engage in outreach and partnerships with schools, by collaborating with local experts, teachers, and university researchers, and by working with the ʻImiloa Astronomy Center of Hawaiʻi.	4.4.2
EO-7	Continue and increase opportunities for community members to provide input to cultural and natural resources management activities on Mauna Kea, to ensure systematic input regarding planning, management, and operational decisions that affect natural resources, sacred materials or places, or other ethnographic resources with which they are associated.	4.4.2
EO-8	Provide opportunities for community members to participate in stewardship activities.	4.4.2
CMP Section 7.1.4: Protection of Astronomical Resources		
AR-2	Prevent light pollution, radio frequency interference (RFI) and dust.	2.1.6.2, 4.2.3.2
CMP Section 7.2.1: Activities and Uses		
General Management		
ACT-1	Continue and update managed access policy of 1995 Management Plan.	1.4.1.5, 4.2, 4.4
ACT-2	Develop parking and visitor traffic plan.	3.1.1.2
ACT-3	Maintain a presence of interpretive and enforcement personnel on the mountain at all times to educate users, deter violations, and encourage adherence to restrictions.	5.1.2
ACT-4	Develop and enforce a policy that maintains current prohibitions on off-road vehicle use in the UH Management Areas and that strengthens measures to prevent or deter vehicles from leaving established roads and designated parking areas.	3.2, 4.2.3.1
Recreational		
ACT-5	Implement policies to reduce impacts of recreational hiking	4.2.3.1
ACT-6	Define and maintain areas where snow-related activities can occur and confine activities to slopes that have a protective layer of snow.	4.2.3.1
ACT-7	Confine University or other sponsored tours and star-gazing activities to previously disturbed ground surfaces and established parking areas.	6.2.3
ACT-8	Coordinate with DLNR in the development of a policy regarding hunting in the UH Management Areas.	3.1.3.5, 3.2.12,
Commercial		
ACT-9	Maintain commercial tour permitting process; evaluate and issue permits annually.	3.1.4
ACT-10	Ensure OMKM input on permits for filming activities	3.1.4.2
ACT-11	Seek statutory authority for the University to regulate commercial activities in the UH Management Areas.	1.4.2.3
Scientific Research		
ACT-12	Ensure input by OMKM, MKMB, and Kahu Kū Mauna on all scientific research permits and establish system of reporting results of research to OMKM.	4.2.3.1, 4.2.3.7, 4.2.3.9
CMP Section 7.2.2: Permitting and Enforcement		
Laws and Regulations		
P-1	Comply with all applicable federal, state, and local laws, regulations, and permit conditions related to activities in the UH Management Areas.	1.4.3
P-2	Strengthen CMP implementation by recommending to the BLNR that the CMP conditions be included in any Conservation District Use Permit or other permit.	1.4.2.3
P-3	Obtain statutory rule-making authority from the legislature, authorizing the University of Hawaiʻi to adopt administrative rules pursuant to Chapter 91 to implement and enforce the management actions.	1.4.2.3

Mauna Kea CMP Management Action		NRMP Section
P-4	Educate management staff and users of the mountain about all applicable rules and permit requirements.	4.4
Enforcement		
P-5	Continue coordinating with other agencies on enforcement needs.	5.1
P-6	Obtain legal authority for establishing, and then establish, a law enforcement presence on the mountain that can enforce rules for the UH Management Areas on Mauna Kea.	1.4.2.3, 3.1.3.2, 5.1
P-7	Develop and implement protocol for oversight and compliance with Conservation District Use Permits.	1.4.2.3
P-8	Enforce conditions contained in commercial and Special Use permits.	3.1.4
CMP Section 7.3.1: Infrastructure and Maintenance		
Routine Maintenance		
IM-2	Reduce impacts from operations and maintenance activities by educating personnel about Mauna Kea's unique resources.	4.4
IM-4	Evaluate need for and feasibility of a vehicle wash station near Hale Pōhaku, and requiring that vehicles be cleaned.	4.2.3.7
IM-5	Develop and implement a Debris Removal, Monitoring and Prevention Plan.	4.2.3.5
IM-6	Develop and implement an erosion inventory and assessment plan.	3.2.4, 4.1.4.2, 4.2.3.4
Infrastructure		
IM-8	Assess feasibility of paving the Summit Access Road.	4.2.3
IM-9	Evaluate need for additional parking lots and vehicle pullouts and install if necessary.	3.1.1.2.2
IM-10	Evaluate need for additional public restroom facilities in the summit region and at Hale Pōhaku, and install close-contained zero waste systems if necessary.	3.1.3.1, 3.2.3, 4.2.3.3
Sustainable Technologies		
IM-13	Conduct feasibility assessment, in consultation with Hawaii Electric Light Company, on developing locally-based alternative energy sources.	3.1.1.2.3
IM-14	Encourage observatories to investigate options to reduce the use of hazardous materials in telescope operations.	4.2.3.3
CMP Section 7.3.2: Construction Guidelines		
General Requirements		
C-1	Require an independent construction monitor who has oversight and authority to insure that all aspects of ground based work comply with protocols and permit requirements.	3.2, 4.2
Best Management Practices		
C-2	Require use of Best Management Practices Plan for Construction Practices.	4.2.3
C-3	Develop, prior to construction, a rock movement plan.	4.2.3.1
C-7, EO-2	Education regarding historical and cultural significance	4.4
C-8, EO-2	Education regarding environment, ecology and natural resources	4.4
C-9	Inspection of construction materials	4.2.3.7
CMP Section 7.3.3: Site Recycling, Decommissioning, Demolition and Restoration		
SR-1	Require observatories to develop plans to recycle or demolish facilities once their useful life has ended, in accordance with their sublease requirements, identifying all proposed actions.	4.3.3.4.1
SR-2	Require observatories to develop a restoration plan in association with decommissioning, to include an environmental cost-benefit analysis and a cultural assessment.	4.3.3.4.1
SR-3	Require any future observatories to consider site restoration during project planning and include provisions in subleases for funding of full restoration.	4.3.3.4.1

Mauna Kea CMP Management Action		NRMP Section
CMP Section 7.3.4: Consideration of Future Land Use		
Facility Planning Guidelines		
FLU-1	Follow design guidelines presented in the 2000 Master Plan.	5.1.1
FLU-2	Develop a map with land-use zones in the Astronomy Precinct based on updated inventories of cultural and natural resources, to delineate areas where future land use will not be allowed and areas where future land use will be allowed but will require compliance with prerequisite studies or analysis prior to approval of Conservation District Use Permit.	4.3.3.1
FLU-4	Require project specific visual rendering of both pre- and post-project settings to facilitate analysis of potential impacts to view planes.	4.1.4.11
FLU-5	Require an airflow analysis on the design of proposed structures to assess potential impacts to aeolian ecosystems.	4.1.4.4
FLU-6	Incorporate habitat mitigation plans into project planning process.	4.3.3.3
FLU-7	Require use of close-contained zero-discharge waste systems for any future development in the summit region, from portable toilets to observatory restrooms, if feasible.	3.1.1.2.6
CMP Section 7.4.1: Operation and Implementation of the CMP		
OI-2	Develop training plan for staff and volunteers.	5.1
OI-3	Maintain and expand regular interaction and dialogue with stakeholders, community members, surrounding landowners, and overseeing agencies to provide a coordinated approach to resource management.	5.1
CMP Section 7.4.2: CMP Monitoring, Evaluation and Updates		
MEU-1	Establish a reporting system to ensure that the MKMB, DLNR, and the public are informed of results of management activities in a timely manner.	4.1.3.3
MEU-2	Conduct regular updates of the CMP that reflect outcomes of the evaluation process, and that incorporate new information about resources.	5.2

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ACRONYMS

AM	Arbuscular Mycorrhiza
APHIS	U.S. Animal and Plant Health Inspection Service
ATV	All-Terrain Vehicles
BIISC	Big Island Invasive Species Committee
BLNR	Board of Land and Natural Resources
BOR	Board of Regents
CARA	California Association for Research in Astronomy
CCA	Candidate Conservation Agreement
CDUP	Conservation District Use Permit
CFHT	Canada-France-Hawaii Telescope
CMP	Mauna Kea Comprehensive Management Plan
CZM Program	Coastal Zone Management Program
CRMP	Cultural Resources Management Plan
CSO	Caltech Submillimeter Observatory
CWRM	Commission on Water Resource Management, State of Hawai'i
DHHL	Department of Hawaiian Home Lands, State of Hawai'i
DLNR	Department of Land and Natural Resources, State of Hawai'i
DOCARE	Division of Conservation and Resource Enforcement, DLNR
DOFAW	Division of Fish and Wildlife, DLNR
DOH	Department of Health, State of Hawai'i
EA	Environmental Assessment
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
Gemini	Gemini North Telescope
GIS	Geographic Information System
GPS	Global Positioning System
HRS	Hawai'i Revised Statutes

Acronyms

IFA	Institute for Astronomy, UH
IM&R	Inventory, Monitoring and Research
IPIF	Institute of Pacific Islands Forestry, U.S. Department of Agriculture, Forest Service
IRTF	Infrared Telescope Facility, NASA
IT	Information Technology
JCMT	James Clerk Maxwell Telescope
JNLT	Japan National Large Telescope
KECK I	W.M. Keck Observatory (1992)
KECK II	W.M. Keck Observatory (1996)
LIDAR	Light Detection and Ranging
MK	Mauna Kea
MKMB	Mauna Kea Management Board
MKSR	Mauna Kea Science Reserve
MKSS	Mauna Kea Observatories Support Services
MOU	Memorandum of Understanding
NASA	National Aeronautics and Space Administration
NAR	Natural Area Reserve, DLNR
NARS	Natural Area Reserves System, DLNR
NEPA	National Environmental Policy Act
NGO	Non-governmental Organization
NHPA	National Historic Preservation Act
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NRCS	Natural Resources Conservation Service, U.S. Department of Agriculture
NRHP	National Register of Historic Places
NRC	Natural Resources Coordinator
NRM Program	Natural Resources Management Program
NRMP	Natural Resources Management Plan
NSF	National Science Foundation
NWS	National Weather Service
OCCL	Office of Conservation and Coastal Lands, DLNR
OMKM	Office of Mauna Kea Management, UH

Acronyms

PCSI	Pacific Consulting Services, Inc.
PTA	Pōhakuloa Training Area
QA/QC	Quality Assurance/Quality Control
RCRA	Resource Conservation and Recovery Act
RFP	Request for Proposal
SEPO	Science Education and Public Outreach Program
SHPD	State Historic Preservation Division, DLNR
SHWB	Solid and Hazardous Waste Branch, Department of Health, State of Hawai'i
SMA	Submillimeter Array
SODAR	Sound Detection and Ranging
SRGII	Sustainable Resources Group Intn'l, Inc.
Subaru	Subaru Telescope
T&E	Threatened and Endangered
TEK	Traditional Ecological Knowledge
TMA	Three Mountain Alliance
UKIRT	United Kingdom Infrared Telescope
USDA	U.S. Department of Agriculture
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
UH	University of Hawai'i
VIS	Visitor Information Station
VLBA	Very Long Baseline Array

1 Introduction

1.1 Planning Approach

Mauna Kea is the tallest mountain in the Hawaiian Islands and one of the most diverse environments on earth. It is a representative of a tropical island alpine environment that is rare on the planet. From ocean to peak, it encompasses nearly all of the major vegetation zones of Hawai'i (Cuddihy 1988; Ziegler 2002).

The areas encompassed by the *Mauna Kea Natural Resources Management Plan* (NRMP) include some of Hawai'i's unique and most treasured ecosystems. The Mauna Kea Science Reserve (MKSR) and the upper portions of the Summit Access Road mostly fall into the alpine community, while the mid-level facilities at Hale Pōhaku and the lower portion of the Summit Access Road fall within the subalpine community (see Section 2.2.1). Although the biotic communities in these areas differ, they are linked by a common hydrology, geology, and by general ecosystem processes. Much of the unique alpine ecology of Mauna Kea is controlled by the geology and climate of the area; thus, engineering limits and impacts to natural resources were examined in the context of natural hydrologic and geologic processes. The aeolian ecosystem found on the summit likely depends on the productivity of the areas just downslope to sustain its globally unique organisms (Ziegler 2002). These fragile ecosystems are valuable resources to the citizens of Hawai'i and to the global community.

The *Mauna Kea Natural Resources Management Plan* was initiated as a project of the Mauna Kea Management Board (MKMB) Environment Committee. Past management planning for the Mauna Kea area has focused on master planning (i.e., *2000 Mauna Kea Science Reserve Master Plan* (2000 Master Plan) (Group 70 International 2000)) and guiding use of the area (i.e., *1995 Revised Management Plan for the UH Management Areas on Mauna Kea* (1995 Management Plan) (DLNR 1995), which focused on public access). The *Mauna Kea Comprehensive Management Plan* (CMP) (Ho'akea LLC dba Ku'iwalu 2009) was developed to provide a guide for managing existing and future activities and uses, while ensuring ongoing protection of Mauna Kea's cultural and natural resources. Upon approval of the CMP in April 2009, BLNR attached a condition requiring completion of a Natural Resources Management Plan (see Section 1.4.1.9). This NRMP meets BLNR's requirement and is the first plan to focus on the protection and preservation of natural resources in the UH Management Areas of Mauna Kea. The NRMP is based on a comprehensive review of existing scientific studies, biological inventories, and historical documentation that identify the current state of knowledge of resources and management activities and the effectiveness of current management. Community consultation was also part of the process, with surveys, email and phone interviews, and meetings held in Hilo and Honolulu to gather input from local scientific experts, natural resource managers, and concerned members of the public. A draft version of the report was made available for public review and comment. Open houses were held in Waimea, Kona, and Hilo to share the results of the report with the community and obtain feedback.

The NRMP highlights knowledge gaps and evaluates the status of natural resources, and it provides clear management recommendations based on the best available science. The plan prioritizes information-gathering to fill data gaps on a number of natural resources (see Section 4.1). This baseline information is needed to better understand the status of the natural resources and to prioritize management actions to protect and enhance these resources. The NRMP also examines human uses of the area, with particular emphasis on their current and potential impacts on natural resources. Several of the threats to Mauna Kea's ecosystems had been identified prior to the current plan. These include feral ungulate grazing, human disturbance, and invasive species. In the 21st century, threats to the high-altitude ecosystems of Mauna Kea include impacts on species composition and ecosystem processes resulting from introduced diseases and global climate change. This plan offers specific management actions to reduce the identified threats to natural resources and to guide adaptive responses to future threats. The implementation plan reflects the input of multiple stakeholders, each of which sees different challenges and opportunities related to the management of Mauna Kea's natural resources.

An important component in natural resource management is the human community. For generations, Mauna Kea has been a sacred site to the Native Hawaiian community, and it remains so today (Maly 1999; Maly and Maly 2005). More recently, Mauna Kea has served as an important astronomical site, educational facility, and recreation area. These human uses of the environment often directly conflict with the protection of natural resources. At the outset, this study recognized that Mauna Kea's special place in both the cultural and biological spheres could lead to stakeholder cooperation in the long-term management of Mauna Kea's natural resources. As a result, this plan offers a process for education and community consultation with the Office of Mauna Kea Management (OMKM) in the ongoing management of the UH Management Areas (see Section 4.4).

Wherever feasible, this NRMP has been designed to complement the *Mauna Kea Comprehensive Management Plan* (Ho'akea LLC dba Ku'iwalu 2009), the *Cultural Resources Management Plan for the UH Management Areas on Mauna Kea* (McCoy et al. 2009) and the *Mauna Kea Science Reserve Master Plan* (Group 70 International 2000), in order to provide a comprehensive approach to resource management planning. This NRMP recognizes that the telescope facilities exist in natural and cultural environments that may have competing needs. Having a NRMP that describes the existing environment and current and potential impacts will facilitate future analysis of proposed projects and activities by providing a larger context for management. Comprehensive planning is necessary in order to ensure the on-going protection of resources in the area for future generations.

1.1.1 Plan Organization

The Mauna Kea Natural Resources Management Plan is organized into five main sections.

Section 1, Introduction provides background and setting, including a discussion of the principles of natural resources management and scientific framework, an overview of management area, and a description the management environment.

Section 2, Natural Resources Environment details the current state of knowledge of the physical and biotic resources, including historical observations, current status, existing surveys and data, information gaps, and threats.

Section 3, Activities and Uses provides information on the range of activities that take place in the management areas and their potential impacts on, and threats to, natural resources.

Section 4, Component Plans is the information, analysis, and management section, which is divided into five major components.

4.1 Natural Resource Inventory, Monitoring and Research Component Plan

4.2 Threat Prevention and Control Component Plan

4.3 Natural Resources Preservation, Enhancement, and Restoration Component Plan

4.4 Education and Outreach Component Plan

4.5 Information Management Component Plan

Section 5, Implementation and Evaluation Plan describes the resources necessary to implement the proposed management actions, along with a methodology for evaluating and updating the NRMP.

1.1.2 OMKM Mission Statement and NRMP Management Goals

OMKM's mission, as an organization, is to achieve harmony, balance, and trust in the sustainable management and stewardship of the Mauna Kea Science Reserve through community involvement and programs that protect, preserve, and enhance the natural, cultural and recreational resources of Mauna Kea while providing a world class center dedicated to education, research, and astronomy.

The overarching goal of this NRMP is to help OMKM achieve its mission by providing natural resource management goals, objectives, and activities that protect, preserve, and enhance the natural resources of Mauna Kea. The NRMP was developed with the following concepts in mind:

1. The high elevation areas of Mauna Kea represent a unique global resource that should be preserved for future generations.
2. Natural resource management planning will be based on the ecosystem approach, rather than conducted species by species (see Section 1.2).
3. Management activities will be focused on limiting the impacts of human activities on natural resources.
4. The planning and execution of natural resource management programs will involve input from the larger community (e.g., managers, scientists, educators, volunteers, the public).
5. Long-term global environmental factors such as climate change must be taken into account when planning natural resource management activities.

As described above, the management recommendations developed in this NRMP are presented in Section 4, which is composed of five component plans. Each component plan has its own set of goals (see Table 1-1). These goals can be thought of as the major steps to be taken to meet the overarching goal of the NRMP and to support OMKM's mission statement. Each goal has its own set of objectives and actions to help meet these goals.

Table 1-1. Natural Resource Management Plan Goals

Program Goals		Section
Inventory, Monitoring and Research Component Plan		
Goal IMR-1	Determine baseline status of the natural resources (baseline inventory)	4.1.2.1
Goal IMR-2	Conduct long-term monitoring to determine the status and trends in selected resources, to allow for informed management decisions	4.1.2.2
Goal IMR-3	Conduct research projects to fill knowledge gaps about natural resources that cannot be addressed through inventory and monitoring	4.1.2.3
Goal IMR-4	Create efficient, cost effective Inventory, Monitoring and Research programs	4.1.3.1
Goal IMR-5	Measure progress towards performance goal of preserving, protecting, and restoring Mauna Kea ecosystems	4.1.3.2
Goal IMR-6	Increase communication, networking, and collaborative opportunities, to support management and protection of natural resources	4.1.3.3
Threat Prevention and Control Component Plan		
Goal TPC-1	Provide early warning of undesirable changes to Mauna Kea's high-elevation ecosystems	4.2.2
Goal TPC-2	Minimize habitat alteration and disturbance	4.2.3.1
Goal TPC-3	Maintain high level of air quality	4.2.3.2
Goal TPC-4	Prevent contaminant migration to the environment	4.2.3.3
Goal TPC-5	Minimize accelerated erosion	4.2.3.4
Goal TPC-6	Reduce impacts of solid waste	4.2.3.5
Goal TPC-7	Maintain current levels of background noise	4.2.3.6

Program Goals		Section
Goal TPC-8	Prevent establishment of new invasive species and control established invasive species	4.2.3.7
Goal TPC-9	Maintain native plant and animal populations and biological diversity	4.2.3.8
Goal TPC-10	Limit impacts to natural resources from scientific research and sample collection	4.2.3.9
Goal TPC-11	Prevent fires	4.2.3.10
Goal TPC-12	Manage ecosystems to allow for response to climate change	4.2.3.11
Natural Resource Preservation, Enhancement, and Restoration Component Plan		
Goal PER-1	Preserve sensitive habitats and unique high-elevation ecosystems	4.3.3.1
Goal PER-2	Enhance existing native communities and unique habitats	4.3.3.2
Goal PER-3	Mitigate or repair damage to sensitive ecosystems	4.3.3.3
Goal PER-4	Restore damaged ecosystems	4.3.3.4
Education and Outreach Component Plan		
Goal EO-1	Educate and involve the public to support and enhance conservation of the Mauna Kea's natural resources	4.4.2
Information Management Component Plan		
Goal IM-1	Maintain accessible, relevant information to meet management, educational, and research needs for Mauna Kea	4.5.2

1.2 Principles of Natural Resources Management

A science-based natural resources management plan provides the foundation for making the best management decisions possible, provides the flexibility for modifying them, and fosters confidence and consensus from a public that must co-exist with the resource management decisions. A scientific framework also provides consistency to the planning and management process, over time and staff changes. The key components of science-based planning are a collaborative approach to setting goals and priorities, developing strategies or hypotheses to address those goals, measuring and evaluating results, and then revisiting the process to address any new or on-going issues. The dynamic process of incorporating science-based results into ongoing resource protection and enhancement is called *adaptive management*. This NRMP utilizes key concepts from adaptive management, ecosystem management, and traditional ecosystem knowledge in the development of science-based natural resource management recommendations.

1.2.1 Adaptive Management

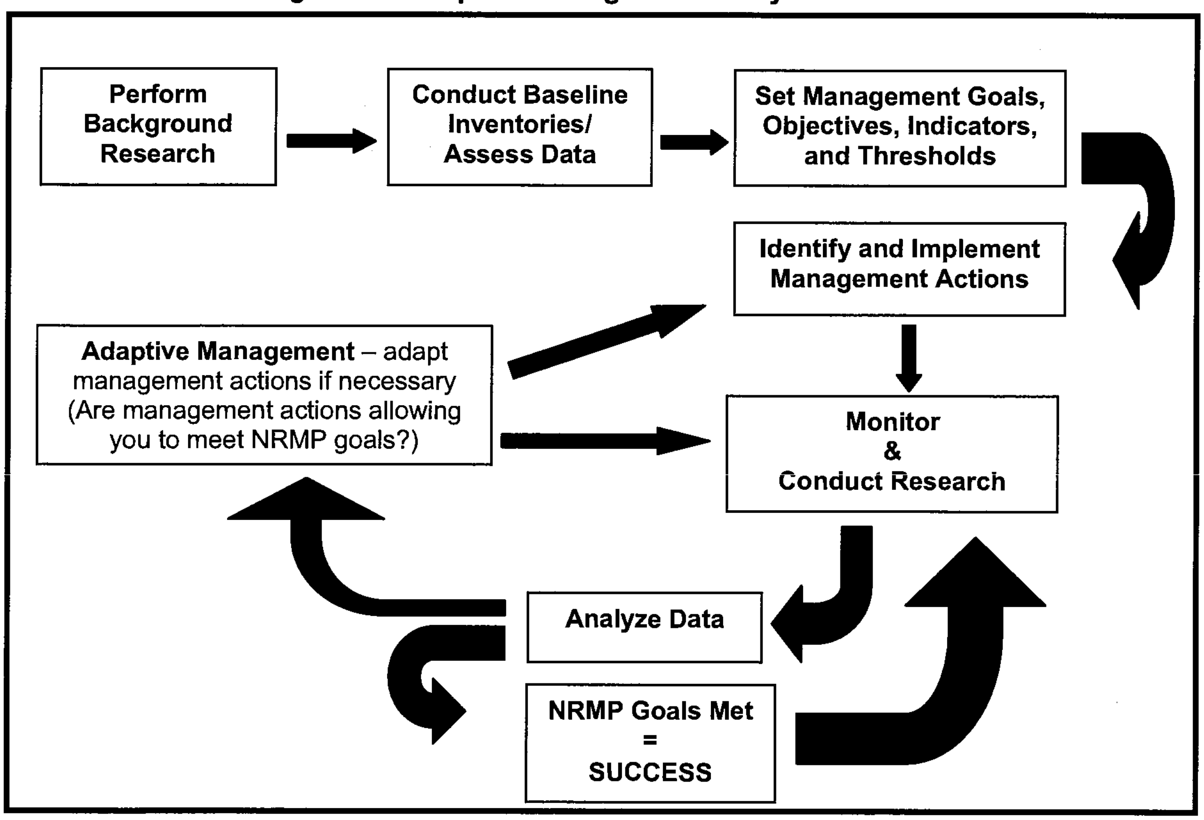
Adaptive management is defined as a systematic process for continually improving management policies and practices by learning from the outcomes of past and current management activities. Adaptive management recognizes that there is a level of uncertainty about the 'best' policy or practice for a particular management issue, and therefore requires that each management decision be revisited in the future to determine if it is providing the desired outcome. The cyclic activity of adaptive management is demonstrated in Figure 1-1.

Adaptive management adopts the same iterative approach as scientific inquiry, an approach in which knowledge is continually being updated and built upon. In managing natural resources and ecosystems, the best methodologies for achieving goals and objectives are rarely well defined, and techniques for managing problems such as alien plants or climate change vary, depending on location, species composition and microhabitat. Similar to the scientific process, adaptive management builds upon prior results, both positive and negative, and allows managers to continually reassess and incorporate new knowledge into their management practices.

Management actions in a natural resources plan guided by adaptive management can be viewed as hypotheses and their implementation as tests of those hypotheses. *A priori* planning and test design can allow managers to better determine if actions are effective at achieving a management objective. For example, surveys before and after treatment might assess the effectiveness of an eradication method, or plots with a certain eradication technique might be compared to plots with no action (control plots). Once an action has been completed, the next, equally important, step in an adaptive management protocol is the assessment of the action's effectiveness (results). A review and evaluation of the results allows managers to decide whether to continue the action or to change course. This experimental approach to resource management means that regular feedback loops guide managers' decisions and ensure that future strategies better define and approach the objectives of the management plan.

True adaptive management is a powerful way to approach protection, enhancement and restoration of natural resources, but it is also time and personnel intensive. Designing a plan that incorporates adaptive management takes more time initially, but can lead to shorter implementation times and greater efficiency. An adaptive management plan requires an extensive review of current scientific literature and existing management practices and consultations with experts in the field. It also requires that the implementation of management actions and evaluation protocols be thoughtfully designed, and it must include feedback mechanisms for reassessing management strategies and changing them, if necessary. These actions were incorporated during the development of this NRMP, and the results are presented in the following sections (2 through 5). As described throughout, the NRMP is a living document that will benefit from regular review and updating, to remain current and to support effective management.

Figure 1-1. Adaptive Management: A Cyclic Process



1.2.2 Ecosystem Management

An ecosystem-level approach is increasingly being incorporated into natural resources management planning (Christensen et al. 1996). Management at the ecosystem level approaches the protection, enhancement, and restoration of natural resources from the perspective that ecosystems are structural wholes. It also recognizes that people, policies, and politics are as much a part of an ecosystem as are silverswords and Palila. This inclusive view of ecosystems comprises the following eight elements (adapted from Christensen et al. 1996):

1. ***Sustainability***: Emphasis on intergenerational sustainability of management decisions
2. ***Goals***: Measurable outcomes
3. ***Sound ecological models and understanding***: Emphasis on scientific research performed at all levels of ecological organization
4. ***Complexity and connectedness***: Recognition that biological diversity and structural complexity strengthen ecosystems against disturbance and supply the genetic resources necessary to adapt to long-term change
5. ***The dynamic character of ecosystems:*** Recognition that change and evolution are inherent in ecosystem sustainability
6. ***Context and scale:*** Recognition that ecosystem processes operate over a wide range of spatial and temporal scales
7. ***Humans as ecosystem components:*** Recognition that humans play an active and valuable role in achieving sustainable management goals
8. ***Adaptability and accountability***: Recognition that current knowledge and paradigms of ecosystem function are provisional, incomplete, and subject to change. Management approaches must be viewed as hypotheses to be tested by research and monitoring programs (adaptive management)

The five general goals of ecosystem management plans, according to (Grumbine 1994), are:
1. Maintaining viable populations
2. Having a representation of all ecosystem types on the landscape
3. Maintaining ecological processes, notably natural disturbance regimes
4. Protecting the evolutionary potential of species and ecosystems, and
5. Accommodating human uses of the landscape

The above elements and goals have been incorporated into the natural resources management actions found throughout this NRMP, in particular, the component plans in Section 4 and the programmatic recommendations found in Section 5.1. Because ecosystems do not recognize political or property boundaries, many of the proposed natural resources management actions require collaboration and cooperation between various landowners and federal and state agencies (see Sections 4 and 5).

1.2.3 Traditional Ecological Knowledge

Traditional knowledge of ecosystems is based on the practical adaptation of technique, technology, and institutions within the local environment that have been passed down from generation to generation. Traditional ecological knowledge (TEK) does not represent a single body of knowledge; rather it is a cumulative body of knowledge, practice and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and their environment (Berkes 2008). Even though there is no clear delineation between

TEK and science (Agrawl 1995), the recognition of traditional knowledge as a legitimate type of knowledge is significant. Gathering traditional knowledge is important because it is site specific and because, as time passes, the *kūpuna* (elders) who hold this knowledge are slowly passing away.

Natural resource management in Hawai'i has a rich tradition and long history to draw upon. Traditionally, Hawaiians lived by the principle *malama 'aina,* or respect, conserving, and caring for their resources, which was further expressed in the traditional practice of taking from the land or sea only what was needed. The relationship between the land and the sea was understood by the ancient Hawaiians through the ahupua'a system and its basic concept of land divisions that extend from the mountain to the sea. Ahupua'a management is similar to the western concept of watershed management, but also integrates cultural, human, and spiritual concerns. Among traditional Hawaiian contextual beliefs, there were other items that were unfamiliar and not practiced in modern Western thought (Gon 2003):

- relationship between humans and natural objects or living things (e.g., 'aumakua)
- that rights and responsibilities apply to all things in the natural world
- consciousness of the natural world and its elements that humans may speak directly to those elements of interest
- that environmental ethics include asking permission for resources
- giving something when taking anything of significance.

Advantages of integrating components of TEK into a management strategy include: location-specific knowledge; increased knowledge of environmental linkages; and local capacity building and power sharing. The principals of ecosystem management and ahupua'a management are compatible and result in a similar set of management actions and goals. The concepts of *malama 'aina* and ahupua'a management are integrated into the management recommendations presented in this NRMP.

Recent work documenting the cultural and historical landscapes of Mauna Kea has compiled a significant amount of historical material and provides valuable resources describing Native Hawaiian traditions; traditional and customary practices and beliefs; early descriptions of the landscape, land use and access; changes in the environment; efforts at conserving the mountain landscape; and the events leading to the development of observatories on Mauna Kea (Maly 1999; Maly and Maly 2005). This information provides an essential baseline for ongoing management of Mauna Kea's resources and can be incorporated into management strategies including resource analysis and education.

1.3 Overview of Management Area

1.3.1 Location and Description

Mauna Kea is one of five volcanoes that make up the Island of Hawai'i, the southernmost island in the Hawaiian Archipelago. It is located in the north-central part of the island (Figure 1-2). Mauna Kea is currently dormant but may erupt again. It is the tallest mountain in the island chain, and due to its great height, it encompasses a wide variety of ecosystems. In 1964, Mauna Kea lands were placed within the state's conservation district. Management of the two million acres of conservation district land in Hawai'i is the responsibility of the Department of Land and Natural Resources (DLNR) and the Board of Land and Natural Resources (BLNR) and is guided by a number of federal and state laws, statutes, and rules (see Section 1.4.3.2).

The management area covered by this plan begins at approximately 9,200 ft (2,804 m) on Mauna Kea and extends to the summit, at 13,796 ft (4,205 m), encompassing three distinct areas: the Mauna Kea Science

Reserve (MKSR), the mid-level facilities at Hale Pōhaku, and the Summit Access Road (see Figure 1-3). These areas are collectively referred to as the 'UH Management Areas.'

The largest of these areas is the Mauna Kea Science Reserve (MKSR) (TMK: (3) 4-4-15:09), which was established in 1968 through a 65-year lease (General Lease No. S-4191) between BLNR and the University of Hawai'i (UH).[1] Originally, the MKSR encompassed approximately 13,321 ac (5,931 ha), but in 1998, 2,033 ac (823 ha) were withdrawn as part of the Mauna Kea Ice Age Natural Area Reserve (NAR) (see Section 1.3.3.1). The MKSR now encompasses 11,288 ac (4,568 ha) of state land above approximately 11,500 ft (3,505 m) elevation, which, according to the lease is to be used "as a scientific complex." The University's 2000 Master Plan for the Mauna Kea Science Reserve designated 525 ac (212 ha) of the leased land as an "Astronomy Precinct," where development is to be consolidated to maintain a close grouping of astronomy facilities and support infrastructure. The remaining 10,763 ac (4,356 ha) are designated a Natural/Cultural Preservation Area in order to protect natural and cultural resources within the MKSR (Group 70 International 2000).

Situated at an elevation of about 9,200 ft (2,804 m), the mid-level facilities at Hale Pōhaku (TMK (3) 4-4-15:12) also fall under the area of management responsibility of this plan. Hale Pōhaku comprises 19.3 ac (7.8 ha) on the south slope of Mauna Kea.

The third management area, the Summit Access Road, extends from Hale Pōhaku to the boundary of the MKSR, at approximately 11,500 ft (3,505 m). Although the Grant of Easement (No. S-4697) includes only the Summit Access Road, the 1995 Management Plan added an easement approximately 400 yards (366 m) wide on either side of the road, except for portions inside the Mauna Kea Ice Age Natural Area Reserve (NAR) on the western side of the road, to the UH Management Area.

While this management plan has been developed specifically for the UH Management Areas, it is impossible to constrain attributes of the natural environment within these boundaries. Often the scope of the discussion will necessarily incorporate features within the general landscape boundaries of approximately 9,000 ft (2,700 m) elevation to the summit, including adjacent lands such as the Mauna Kea Ice Age NAR and the Mauna Kea Forest Reserve, both properties managed by DLNR. Management actions for working with other agencies are provided in Sections 4 and 5.

1.3.2 Activities and User Groups

Mauna Kea, especially the summit region is, to this day deeply significant in Native Hawaiian culture and religion. Beliefs and cultural practices of many contemporary Native Hawaiians are associated with Mauna Kea, as are ancient myths and traditional gods and goddesses. In ancient times, the upper elevations of the mountain would have been used primarily for resource procurement and for religious and healing purposes, but those elevations were too cold for habitation and agriculture. The Mauna Kea Adze Quarry may have been the largest source of high-quality stone for adze making in all of Polynesia. Other uses of the higher elevations of Mauna Kea included catching birds for food and feathers. The very highest reaches of the mountain, were probably rarely approached, because of their extreme sacredness. From time to time, after the arrival of Europeans in the Islands, Westerners traveled to the summit of Mauna Kea as sightseers and naturalists. Today Mauna Kea welcomes a range of users from astronomers to tourists to cultural practitioners to researchers (see Section 3).

[1] The lease requires the university to "maintain the land in a clean and orderly condition, use the land as a scientific complex, and obtain prior written approval from the department before subleasing or making improvements. It may be terminated at any time by the lessee or for cause by the lessor. The department's (DLNR's) reserved rights include hunting and recreation, and trails and access" (Office of the Legislative Auditor 2005).

Figure 1-2. Location Map: Mauna Kea on the Island of Hawai'i

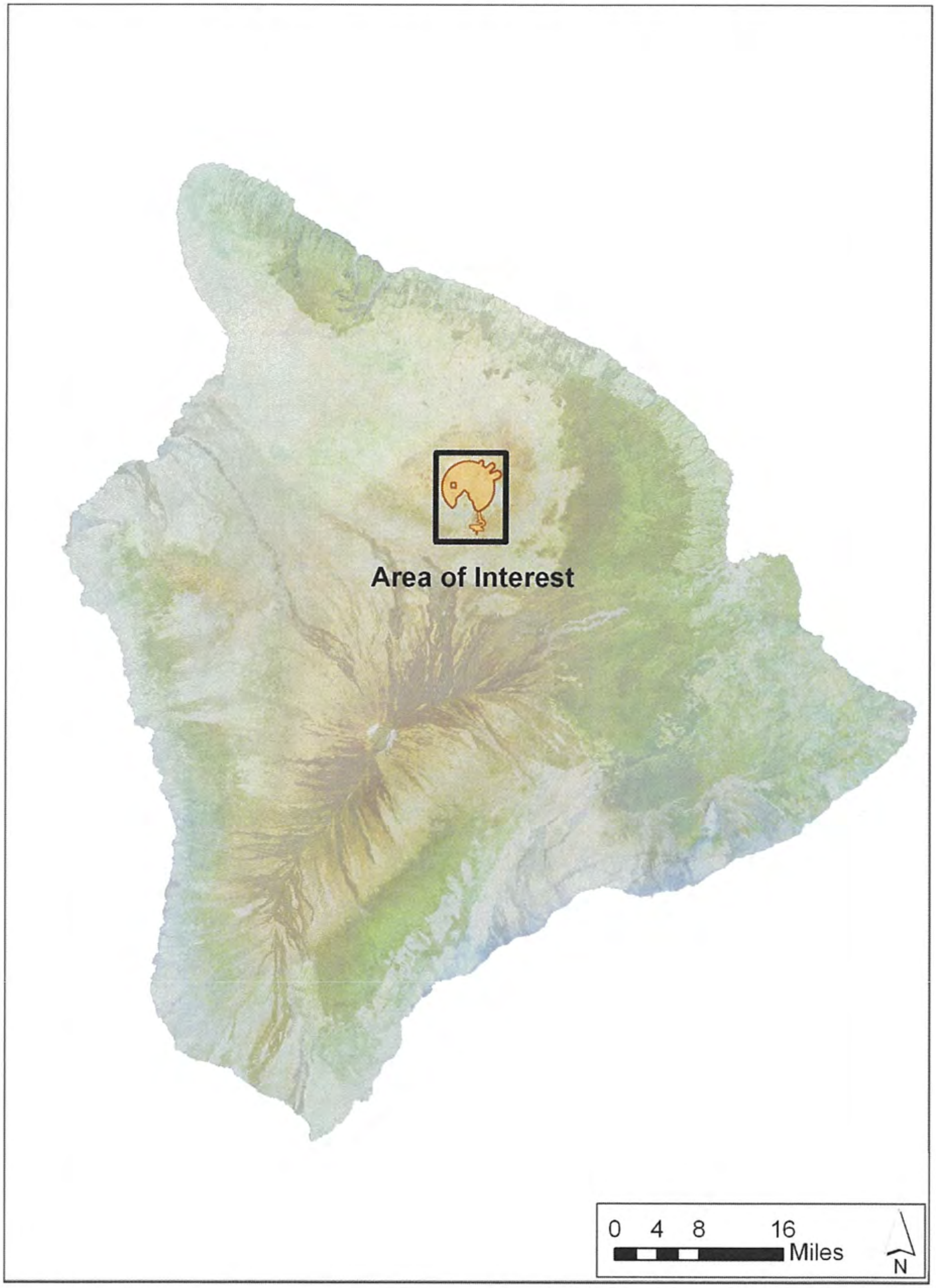
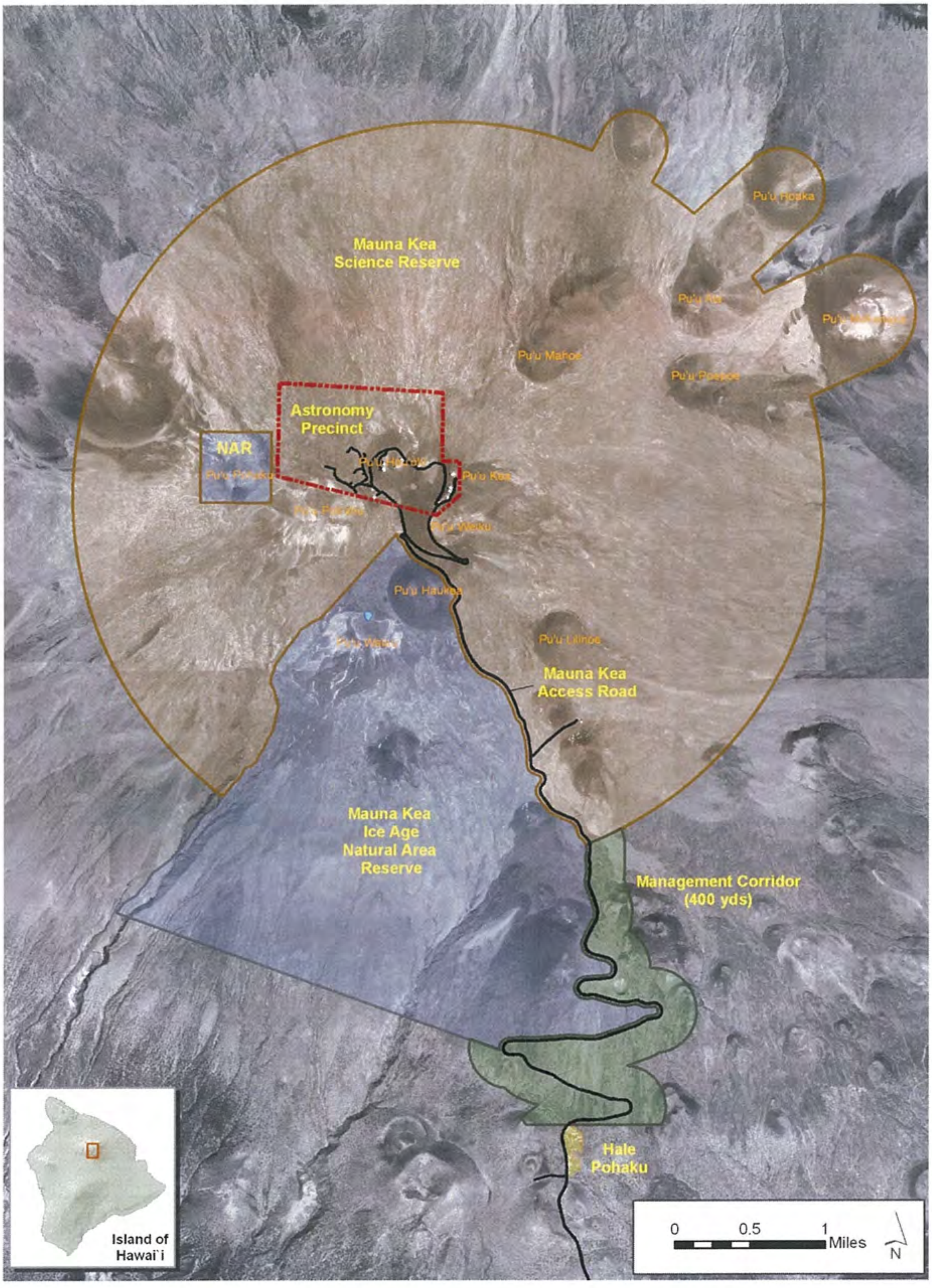


Figure 1-3. UH Management Areas on Mauna Kea



Mauna Kea Science Reserve. Activities occurring in the MKSR include scientific research, cultural and religious activities, and recreation. The best known and most prominent activity in the MKSR is astronomical research. With its high-elevation location in the middle of the Pacific Ocean, far from sources of atmospheric pollution and usually free of clouds, the summit of Mauna Kea is one of the best viewing locations anywhere in the world. Twelve observatories are located within the Astronomy Precinct, within the MKSR. The Very Long Baseline Array Antenna Facility is located outside the Precinct, at an elevation of 12,200 ft (3,719 m). Other types of scientific research occur within the MKSR, including geology, meteorology, and biology, and the summit also provides a natural laboratory for the study of the effects of altitude on human health. User groups involved in scientific research at the summit come from Hawai'i and around the world. In addition to those directly involved in research, individuals involved in various support services related to the observatories also travel to the summit, and during periods of construction contractor company employees also work there.

For many Native Hawaiians, Mauna Kea is a sacred place for connection with nature and the spiritual world. The sacredness is believed to increase with elevation. Cultural and religious practices associated with the mountain include prayer, burial, and other rituals, and construction of small shrines. In the traditional Hawaiian belief system, spirituality is associated with the very land itself, and on Mauna Kea, with trails and certain topographic features, and vistas (Maly and Maly 2005; McCoy et al. 2009).

Recreational activities in the UH Management Areas include sightseeing, skiing and snow play, hiking, and in surrounding areas, hunting. Visitors come for the natural beauty, scenic vistas, and accessible high peaks. Out-of-town visitors, including cruise ship passengers frequently come to the mountain on commercial tours. The operation of commercial vehicles is overseen by OMKM, which issues permits, sets rules, and collects fees from the nine commercial tour companies that operate on the mountain.

Hale Pōhaku. The Ellison Onizuka Center for International Astronomy, at Hale Pōhaku, offers a place for astronomers and technicians working at the summit to acclimate before going up, and to live while working. The observatory support facilities include dormitories, dining facilities, and recreational areas. The Visitor Information Station (VIS), a 950 sq ft facility, houses an interpretive center and a rest stop for visitors on their way to the summit. The VIS also offers tours to the summit and nightly stargazing. A dirt access road and fire break that circles the mountain is also accessible from Hale Pōhaku, although this is used mainly by hunters. Access routes to designated hunting areas in the vicinity of Hale Pōhaku and higher on the mountain are marked by signage. Hale Pōhaku is also within federally designated critical habitat of the Palila (*Loxioides bailleui)*, an endangered native bird.

1.3.3 Regional Land Use

Because living things, ecosystem processes, and cultural practices are not usually confined by administrative boundaries, it is important for the NRMP for the UH Management Areas to consider the user activities, management issues and regulations (or lack thereof) on lands adjacent to the focus area. The diversity of land divisions and land uses on Mauna Kea (see Figure 1-4) requires coordinated management. This section describes the variety of land uses on Mauna Kea that are not part of the UH Management Areas and which agencies are responsible for their management (see Section 1.4.2 for agency responsibilities and regulations and Section 5.1.3 for recommendations for improving agency coordination).

1.3.3.1 Mauna Kea Ice Age NAR

The Mauna Kea Ice Age Natural Area Reserve (NAR), established in 1981, comprises two parcels that are surrounded by, and are adjacent to, the MKSR. The NAR is under the jurisdiction of the DLNR

Natural Area Reserves Commission. A square 143.5 ac (58 ha) parcel around Pu'u Pohaku, is located west of the summit area. Fossil ice left behind by glaciations has been found within its boundaries. The larger, 3,750 ac (1,518 ha) triangular-shaped parcel extends from approximately 10,070 ft (3,069 m) up to 13,230 ft (4,033 m), at the upper tip of the parcel. Within this piece are several special features: the Mauna Kea Adze Quarry; Lake Waiau – the only high elevation lake in the state; and geomorphic features created by glaciers such as moraines and glacial till. In addition to the lake, the NAR includes another rare ecological community, the invertebrate-dominated aeolian desert. Special-status species found in the NAR include the federally listed, endangered Mauna Kea silversword and the wēkiu bug, a candidate for federal listing as endangered. Currently, management is focused on wēkiu bug surveys and research, education and on-site management of recreational and cultural users, and public hunting for non-native ungulate control in the surrounding Mauna Kea Forest Reserve (Mitchell et al. 2005a). In order to work more closely on cross-boundary management issues, in 2008 OMKM developed a cooperative agreement with DLNR, Division of Forestry and Wildlife (DOFAW)-NARS. Under the agreement, OMKM provides visitor assistance using OMKM rangers, engages in joint research and educational efforts with NAR staff, and reports violations occurring in the NAR.

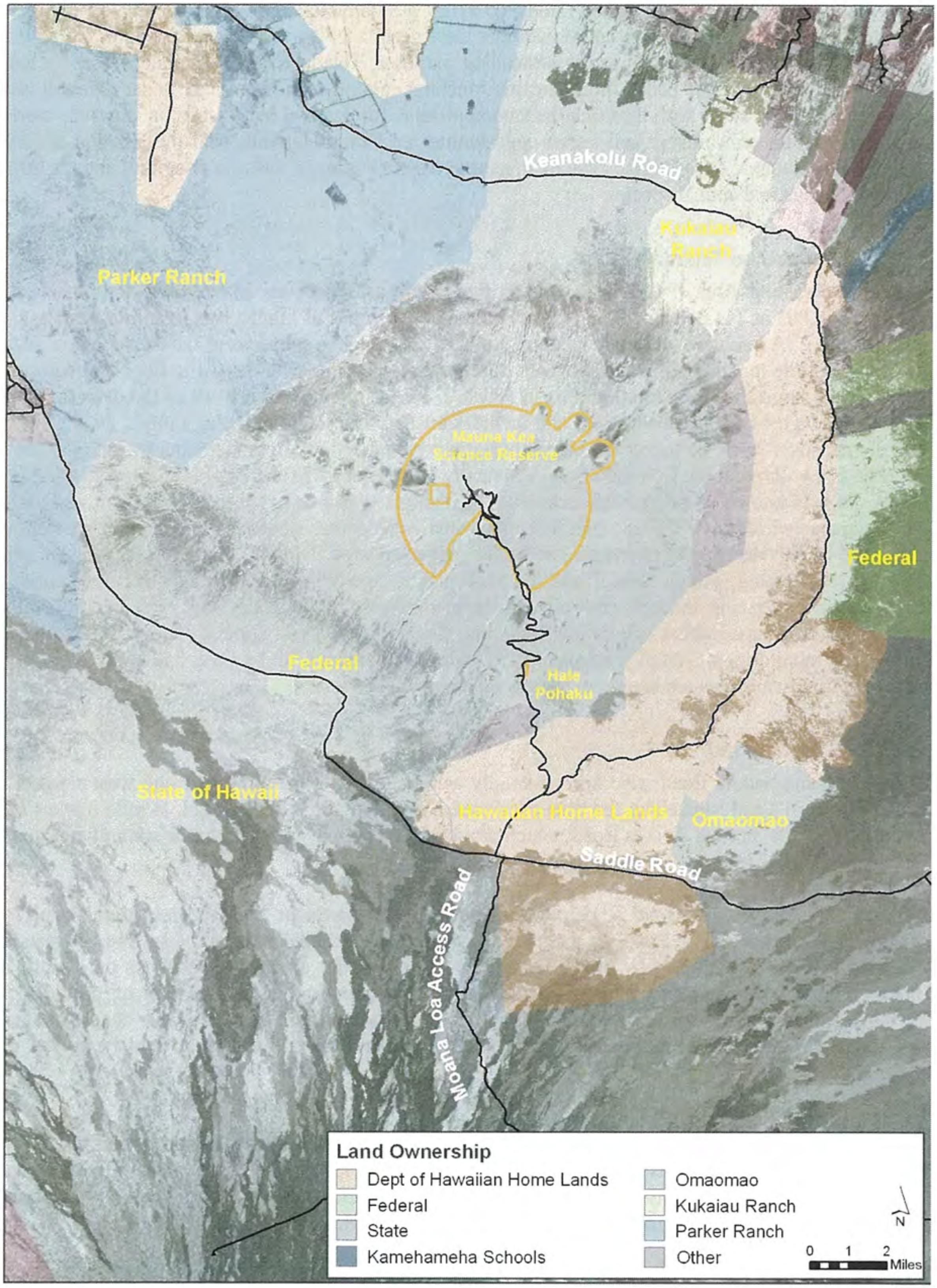
1.3.3.2 Mauna Kea Forest Reserve

Mauna Kea Forest Reserve lands encompass approximately 52,500 ac (21,246 ha) above 7,000 ft (2,134 m), surrounding the UH Management Areas and Mauna Kea Ice Age NAR. The lower-elevation boundary of the forest reserve is bordered by state lands, Hawaiian Home Lands, the Parker Ranch, and the Kukaiau Ranch. The forest reserve is under the jurisdiction of the DLNR Division of Forestry and Wildlife (DOFAW). The forest reserve contains māmane (*Sophora chrysophylla*) forest, critical habitat for the federally listed endangered Palila bird. The māmane forests on Mauna Kea contain the entire known world population of Palila. Management issues include browsing by introduced ungulates (e.g., sheep, mouflon, feral pigs, and goats), increasing populations of invasive plant and exotic animal species, and wildfires (see Sections 2.2.1 and 2.2.3). In an effort to curb degradation of this habitat, DOFAW conducts ungulate control, and recreational hunting is permitted year-round (see Section 3.1.3.5).

1.3.3.3 Hakalau Forest Unit, National Wildlife Refuge

The Hakalau Forest National Wildlife Refuge consists of two units: The Hakalau Forest Unit, which was established in 1985 and which encompasses 33,000 ac (13,355 ha) on the eastern slope of Mauna Kea, and the Kona Forest Unit, which was established in 1997 and which encompasses 5,300 ac (2,145 ha) on the western slope of Mauna Loa. The refuge, established to protect endangered forest birds and their habitat, is under the jurisdiction of the U.S. Fish and Wildlife Service. The Hakalau unit occupies an area between 2,500 ft and 6,600 ft (762 m and 2,012 m) and contains native-dominated montane rainforest, mixed native/exotic forest areas and grasslands dominated by exotic plants. At least nine federally listed endangered plant species, eight federally listed endangered bird species, and one federally listed endangered bat species have been confirmed in this area. Only the Upper Maulua area is open to public use, for hiking and wildlife observation, but access requires permission and the combination to a locked gate. Due to the remote location and poor roads, the refuge receives very few visitors. Some of the main threats to this habitat include browsing by introduced ungulates, competition from invasive exotic plant species, competition and predation from exotic animals, and wildfires. Ongoing management efforts include the control and removal of feral and exotic animals, control of invasive plant species, and restoration of native forest. Although the unit does not abut the UH Management Areas, its proximity, biological importance, and management issues underscore the idea that all areas within the vicinity of the focus area must be taken into account.

Figure 1-4. Regional Land Use on Mauna Kea



1.3.3.4 Hawaiian Home Lands

The Department of Hawaiian Home Lands (DHHL) has jurisdiction over approximately 53,000 ac (21,448 ha) of the lands of Humu'ula Mauka that were designated by the Hawaiian Homes Commission Act of 1920 to be made available for homesteading purposes. This land was held under leases by Parker Ranch from 1914 to 2002. Today, limited cattle ranching continues on Humu'ula, under a permit issued by DHHL. DHHL, along with beneficiaries and applicants for pastoral lease lands, is currently working on a plan for land stewardship and lessee opportunities on Humu'ula lands near the junction of Saddle Road and the Summit Access Road. The main natural resource issue in this area is control and eradication of invasive plant and animal species.

1.3.3.5 Pōhakuloa Training Area

Pōhakuloa Training Area (PTA) is located in the saddle area between Mauna Loa and Mauna Kea. Totaling 108,863 ac (44,055 ha), PTA extends up the lower slopes of Mauna Kea to approximately 6,800 ft (2,073 m). PTA lands are within the general, limited, and resource subzones of the conservation district. PTA is under the jurisdiction of DLNR, with a large portion having been leased to the U.S. Army since 1956. As the largest military training area in Hawai'i, PTA is used for nearly all of the diverse types of training conducted by the armed forces and includes artillery impact areas, firing ranges, an airfield, and vehicle maneuver areas. Resource management initiatives and actions are undertaken by both DLNR and the U.S. Army, through the Colorado State University Center for Environmental Management of Military Lands. PTA is known to contain 15 federally listed threatened and endangered plants, three federally listed endangered bird species, and one federally listed endangered bat species. An area in the northeast portion of PTA is designated as critical habitat for the endangered Palila. The main threats to this habitat include over-grazing, competition from invasive plants, and wildfires. Management is focused on decreasing over-grazing through controlled hunting of feral sheep, goats, and pigs and by building exclusionary fencing. Habitat restoration, including the eradication and control of invasive exotic plant species and monitoring of endangered species is also a management priority. Over 343 archaeological and culturally significant sites are known to be located within PTA.

1.3.3.6 Saddle Road

The Ala Mauna Saddle Road, also known simply as Saddle Road, links the east and west sides of the Island of Hawai'i and runs along the base of Mauna Kea. Along the Saddle Road, at mile marker 28, is the turnoff for the Summit Access Road, which provides the only paved access to the summit area and the UH Management Areas.

In 2001 the BLNR approved a permit for the state Department of Transportation to perform improvements to the Saddle Road. At this time the project is scheduled to have the section between mile markers 11 and 42 completed by 2011. Timing for the remainder of the road depends on permits and funding. The paving and expansion of Saddle Road was proposed in anticipation of providing for increased traffic, both locals and visitors. The improved condition will provide easier access to Mauna Kea and potentially result in increased visitors to the summit and other areas open to public use.

1.3.3.7 Population Centers

The County of Hawai'i, population approximately 173,000, encompasses the entire Island of Hawai'i. The land area of the County is approximately 4,028 sq mi (10,433 sq km). Two of the largest towns on the island are Hilo and Kailua-Kona. Hilo, located on the east side of Hawai'i, has a population of approximately 47,500 and is the location of the University of Hawai'i at Hilo. Kailua-Kona, located on the west side of Hawai'i has a population of approximately 10,000. Both towns have ports large enough to accommodate cruise ships, and each has an airport, by which most tourists visiting the island enter.

1.4 Management Environment

1.4.1 History of Planning and Management

This section summarizes the history of planning and management for the UH Management Areas, including site and master planning documents for the astronomy complex and more recent documents focusing on the area's important cultural and natural resources. See Table 1-2.

Table 1-2. History of Planning and Management for the UH Management Areas

1977 Mauna Kea Plan - Created five management areas - Identified management objectives and permitted uses - Addressed protection of the *māmane-naio* forest ecosystem at Hale Pōhaku
1980 Hale Pōhaku Complex Development Plan - Not officially adopted, used as an advisory document - Provided guidance for development of the Hale Pōhaku area
1982 Research and Development Plan for the Mauna Kea Science Reserve (RDP) - Programmatic master plan for the continued development of the Science Reserve
1983 Mauna Kea Science Reserve Complex Development Plan - Provided a physical planning framework to implement the RDP - Accompanied by an environmental impact statement - Not submitted to BLNR for approval
1985 Management Plan (CDUA HA-1573) - Revised management plan to address concerns from DLNR and the public - UH responsible for protection of resources and control of access - Criticized because although BLNR was to retain management control over commercial activities, permitting and use were not addressed
1995 Revised Management Plan for the UH Management Areas on Mauna Kea - Addressed commercial uses in the summit area - Transferred formal management responsibilities of public use, such as *recreational, educational, cultural and commercial activities,* back to DLNR - UH retained responsibility for management related directly to astronomical facilities and the Summit Access Road
1998 Audit of Management of Mauna Kea and the Mauna Kea Science Reserve - Highlighted deficiencies in the management of Mauna Kea by UH and DLNR
2000 Mauna Kea Science Reserve Master Plan - Contains recommendations for management of access, natural and cultural resources, education, research and recreation - Established "Astronomy Precinct" - Adopted by UH Board of Regents as a policy framework, approval never sought from BLNR
2005 Audit of the Management of Mauna Kea and the Mauna Kea Science Reserve - Called for updated management plan of UH managed areas - Included recommendations related to management for both UH and DLNR
2009 Mauna Kea Comprehensive Management Plan (CMP) - Provides a guide for managing existing and future activities and uses to ensure ongoing protection of Mauna Kea's cultural and natural resources
2009 Cultural Resources Management Plan (CRMP) - Contains archaeological survey of MKSR - Presents management recommendations for the protection of historical and cultural resources

1.4.1.1 The Early Years

As early as 1909, the summit of Mauna Kea was recognized as a prime site for astronomical observation (Office of the Legislative Auditor 1998). In 1964, researchers from the University of Hawai'i conducted tests that substantiated earlier opinions that conditions for viewing were exceptional, and the Lunar and Planetary Station constructed atop Pu'u Poliahu started operation. Also in 1964, Mauna Kea lands were placed within the state's Conservation District, giving management authority to BLNR. In 1965 and 1966, the University further explored the potential for astronomy at the summit and contracted with the National Aeronautics and Space Administration (NASA) to design and build an 88-in (2.24 m) telescope. The University established the Institute for Astronomy (IfA) in 1967, and that same year began development of the first of the 13 telescopes now located at the summit. In June 1968, the University of Hawai'i secured a 65-year lease from BLNR for more than 13,321 ac (5,931 ha) at the summit of Mauna Kea for the land known as the Mauna Kea Science Reserve (MKSR). The MKSR was a new construct not previously defined by DLNR's mandate, and did not have its own set of rules or an administrative support structure within DLNR. While the BLNR retained general regulatory authority over the MKSR and some broad responsibilities were given to the University, permitted and prohibited activities were not defined. During this early period, the summit and the MKSR were managed by the University and DLNR.

By 1974, with three telescopes in place on the summit, local groups, including hunters and environmentalists, voiced concerns about further development on the mountain. As a result, the state sought to better plan and manage development of future facilities, and a memorandum issued by then Acting Governor George Ariyoshi, directed DLNR to develop and promulgate a master plan for all of Mauna Kea above Saddle Road.

1.4.1.2 1977 DLNR Mauna Kea Plan; 1980 Hale Pōhaku Complex Development Plan

In 1977, after two years of planning, study and public hearings, BLNR approved *The Mauna Kea Plan* (DLNR 1977). This plan created five management areas and indicated the management objectives and permitted uses for each. Responsibility for the management and upkeep of Mauna Kea Science Reserve and the astronomy facilities at Hale Pōhaku were deemed to be the responsibility of the University of Hawai'i. Management and upkeep of the Hale Pōhaku park facilities was assigned to DLNR. Management and upkeep of the Summit Access Road from the Saddle Road to the Summit were assigned to the state Department of Transportation. The 1977 plan indicated that development of any mid-level facilities at Hale Pōhaku should ensure that the impacts to the surrounding māmane-naio forest ecosystem were minimal, and DLNR was directed to create a master plan specific to this area. The *Hale Pōhaku Master Plan* was issued in 1980 (Group 70 1980), but BLNR never officially adopted it, and the plan remained merely an advisory document (Office of the Legislative Auditor 1998).

1.4.1.3 1982 Research and Development Plan for the Mauna Kea Science Reserve; 1983 Mauna Kea Science Reserve Complex Development Plan

In 1982 the *Research and Development Plan (RDP) for the Mauna Kea Science Reserve and Related Facilities* was approved by the University of Hawai'i Board of Regents (University of Hawaii Institute for Astronomy 1981). This plan was created as a programmatic master plan for the continued development of the MKSR (Office of the Legislative Auditor 1998). The following year, the UH Board of Regents approved a second plan that was designed to facilitate the implementation of the specific research facilities identified in the RDP. The *Mauna Kea Science Reserve Complex Development Plan* was a complex development plan to provide the physical planning framework to implement the RDP (Group 70 1983a). The objective was to guide and control development, in order to preserve the scientific, physical, and environmental integrity of the mountain. Incorporated into this document was a proposal for managing resources and for monitoring and controlling visitor use. The plan made the University responsible for managing and monitoring its leased areas. Accompanying the plan was an environmental impact statement (Group 70 1983b) that evaluated the potential general impacts of implementing the actions proposed in the complex development plan and which proposed actions to mitigate potential negative impacts. The *Mauna Kea Science Reserve Complex Development Plan* was not submitted to BLNR for approval as an overall management plan. This plan was amended in 1987 to address the development of the Very Long Baseline Array (VLBA).

1.4.1.4 1985 Management Plan

In 1985, the BLNR approved the University of Hawai'i *Mauna Kea Management Plan* (also referred to as CDUA HA-1573) (University of Hawaii 1985). The plan was a revised version of the 1983 *MKSR Complex Development Plan,* amended to address management concerns voiced by DLNR and the public (Office of the Legislative Auditor 1998). One criticism of the 1985 plan was that it still lacked components to manage commercial use. It stated that the BLNR would retain management control over commercial activities, but that permitting and use would be addressed at a later date. Although this plan was amended in 1987 to address the development of the Very Long Baseline Array, management of commercial use was still not addressed (Group 70 1987).

1.4.1.5 1995 Revised Management Plan for the UH Management Areas on Mauna Kea

In 1995 the BLNR approved the *Revised Management Plan for the UH Management Areas on Mauna Kea* (1995 Management Plan) (DLNR 1995). This is the most recently approved management plan for these areas. One of the subjects this plan discusses in detail is which public use activities are permitted within the UH Management Areas. These include recreational, educational, cultural, and commercial activities. In general, recreational activities such as hiking, sight-seeing, amateur astronomy, snow sports, and hunting are permitted but may be controlled or restricted. Cultural activities that do not involve physical impacts are permitted. Commercial activities that are permitted include skiing and sledding tours, hiking tours, and sight-seeing tours. Other commercial activities that are allowed but require special permission include ski meets or races, tours of the telescope facilities, film-making and night use of the Visitor Information Station at Hale Pōhaku. Recreational use of off-road vehicles and commercial hunting tours are prohibited.

One of the major tasks of the 1995 Management Plan was to address the lack of management over commercial use (Office of the Legislative Auditor 1998). To that end, all management responsibilities, except those related directly to astronomical facilities or the Summit Access Road, were transferred back to DLNR. In addition, the plan incorporated management controls for permitted commercial uses. The plan states that the DLNR is responsible for issuing permits, setting and collecting fees, and enforcement for the activities of commercial operators. The University has the right to review and comment on these, as well as a responsibility to help monitor the activities of these operators. The University maintains the right to control visitor activities around the astronomy facilities, to manage access to MKSR, and to restrict access under certain conditions. The University also has the right to ask other agencies to assist in visitor management when DLNR enforcement officers are not available and to require a waiver of liability before allowing access to the upper elevations. The plan outlines a couple of commercial rights of the University itself, such as the right to operate concessions within the UH Management Area and the right to contract a shuttle service to take visitors to the summit for various activities.

The 1995 Management Plan was approved by BLNR subject to certain conditions. One of these was that a historic preservation plan be completed and implemented by the UH Institute for Astronomy. Other conditions included education of Mauna Kea Observatories Support Services (MKSS) staff on the details of the plan and instruction on reporting violations; prohibition of tampering with all historic, archaeological and cultural sites; upon completion of biological and archaeological reports, staff shall report back to the BLNR to review whether any modifications to the plan are warranted; posting of additional signage and subject to funding, the VIS should be open seven days a week.

1.4.1.6 1998 Audit of Management of Mauna Kea and the Mauna Kea Science Reserve

In 1998, at the request of the legislature, the state auditor conducted an audit of the management of Mauna Kea and the Mauna Kea Science Reserve (Office of the Legislative Auditor 1998). The audit found a number of deficiencies in the management of Mauna Kea by the University and by DLNR. The audit charged that the University focused on developing astronomical facilities at the expense of protecting the mountain's resources. With the DLNR, the audit found inadequate monitoring and enforcement of permitting requirements that put state resources at risk. Overall the audit found that although protection controls had been established by management plans, these controls were poorly implemented, leading to inadequate protection of cultural, historic, and natural resources. The audit concluded with a list of recommendations.

1.4.1.7 2000 Mauna Kea Science Reserve Master Plan

In 1998, in an effort to improve management of the MKSR and the facilities at Hale Pōhaku, and to assist with the planning of future development, the University created the Mauna Kea Advisory Committee. The committee met from June 1998 through August 1999 and, with representatives from Group 70 International, consultant to the University, held a series of public meetings at various sites around the Island of Hawai'i. Issues concerning better management of the mountain's resources and limiting development of observatories were raised at the meetings. Representatives of Group 70 also discussed recommendations for a master plan with community members.

In 2000, with consideration of issues raised in the public meetings and the state audit, the University released the *Mauna Kea Science Reserve Master Plan* (2000 Master Plan) (Group 70 International 2000). The 2000 Master Plan called for 525 ac (212 ha) of the leased land to be designated an "Astronomy Precinct." To help protect natural and cultural resources within the science reserve (and to protect the astronomy facilities from outside impacts), all astronomy facilities would be confined to this area. A significant portion of the 2000 Master Plan is dedicated to what are referred to as "issues and opportunities for management." This section, complete with recommendations, addresses management authority, access, natural resources, cultural resources and practices, education and research, and recreation. Two specific issues addressed that were not covered in previous plans were provisions for wēkiu bug management and an appendix containing a geological resources management plan for the MKSR (Lockwood 2000).

The 2000 Master Plan sought to include community involvement in the management of the MKSR and proposed three new management entities to assume direct responsibility: the Office of Mauna Kea Management, the Mauna Kea Management Board (MKMB), and Kahu Kupuna (the predecessor of Kahu Kū Mauna). The 2000 Master Plan was adopted by the UH Board of Regents to serve as the policy framework for the responsible stewardship and use of University managed lands on Mauna Kea and the aforementioned entities have been established (see Section 1.4.2.1).

1.4.1.8 2005 Audit of the Management of Mauna Kea and the Mauna Kea Science Reserve

A follow-up audit, conducted by the State in 2005, recognized that the University and DLNR had implemented many of the recommendations of the 1998 audit, but found that more needed to be done (Office of the Legislative Auditor 2005). The audit praised implementation of the 2000 Master Plan—specifically the establishment of the astronomy precinct, the implementation of the ranger program, and increased community involvement through the three new management entities—but stated that management plans for the MKSR need to be updated to reflect its current use and management and to provide transparency and accountability to the University (Office of the Legislative Auditor 2005).

One of the management challenges described is that while the University is responsible for the protection of cultural and natural resources within its jurisdiction, it lacks authority to establish and enforce administrative rules. The audit recommended that the University obtain rule-making authority and develop, implement, and monitor a comprehensive management plan for natural, cultural, and historic resources of the summit and Hale Pōhaku area. It also recommended that the University implement and enforce a permit and sublease monitoring system for observatories.

For DLNR, the audit recommended revising and updating leases and permits, implementing and enforcing a permit monitoring system, and increasing communication between the divisions involved in the management of Mauna Kea. It also recommended that DLNR support OMKM's completion of the historic management plan for Mauna Kea, complete a management plan for the Mauna Kea Ice Age NAR, and seek a written legal opinion from the Department of Attorney General regarding the transfer of commercial permitting to the University.[2]

1.4.1.9 2009 Mauna Kea Comprehensive Management Plan

A 2005 audit of the management of Mauna Kea found that the existing, and inconsistent, management plans for Mauna Kea were an impediment to effective management (Office of the Legislative Auditor 2005). The University acknowledged the need for a management plan that reflects the current and potential future operating conditions, with a focus on resource protection. The Mauna Kea Comprehensive Management Plan (CMP) for UH Management Areas (Ho'akea LLC dba Ku'iwalu 2009) is an integrated planning tool for resource management that reflects the most recent available information. Development of the CMP included extensive community engagement. The CMP is intended to provide a guide for managing existing and future activities and uses, and to ensure ongoing protection of Mauna Kea's cultural and natural resources, many of which are unique. The CMP was approved by BLNR in April 2009. One of the conditions of the approval was the completion and approval of a *Natural Resources Management Plan* within one year or prior to the submittal of a Conservation District Use Application, whichever occurs first. This document addresses this requirement.

1.4.1.10 2009 Cultural Resources Management Plan

Cultural resource management issues were addressed to some extent in all of the plans prepared between the 1970s and 2000. The earliest plans identified management areas and assigned management responsibilities, but provided little or no direction apart from the need to protect the natural and cultural environment. The *Draft Cultural Resources Management Plan for the UH Management Areas on Mauna Kea* (CRMP) builds on a partially completed historic preservation plan prepared in 2000 combined with inventories, reports, studies and collaborations with Native Hawaiians and other community groups that

[2] Transfer was completed in January 2007. See Section 3.1.4.

have occurred since that time (McCoy et al. 2009).[3] As part of the CRMP, a complete archaeological survey of the MKSR was conducted between 2005 and 2008. The objective of the CRMP is to ensure that the mandate to preserve and protect the cultural resources of the UH Management Areas is fulfilled by the University. The plan outlines the historical and cultural significance of Mauna Kea, presents management objectives and actions, and discusses implementation of recommended policies and procedures. It acknowledges that management plans are not static and outlines processes and procedures for revisiting the plan.

1.4.2 Management Responsibilities

Given that several entities share management responsibilities for Mauna Kea, coordinated management of the mountain has been a challenge. Differing rules and regulations govern the different jurisdictional areas (e.g., Conservation District, Natural Area Reserve, Forest Reserve, Science Reserve), and management units do not correspond to ecosystem boundaries (see Section 1.2.2). Currently there is no mechanism for integrated or coordinated management of Mauna Kea's resources (including lands outside of the UH Management Areas). Although most of the summit of Mauna Kea has been designated as a science reserve and the lands protected as part of a conservation district, management of the mountain has primarily focused on supporting astronomy facilities. Presently, both DLNR and the University are responsible for managing the UH Management Areas (see Table 1-3). Both have a number of agencies or organizations within them, which are assigned certain responsibilities based on state regulations, stipulations of the lease, or by the 1995 Management Plan and the 2000 Master Plan. DLNR shares certain responsibilities for management of the mountain, however the department continues to be a noticeably absent on the mountain and from involvement in management planning and enforcement. The IfA has responsibility for managing the observatories and their operations, but is not a land manager. Since its establishment, OMKM has taken on that responsibility for the UH Management Areas, but lacks rule making authority.

The 2000 Master Plan acknowledged that joint management by DLNR and the University, and layers of management requirements and recommendations outlined in historical leases, plans, permits and written or verbal commitments, have created a complex and often confusing pattern of management responsibility (Group 70 International 2000). A similar short-coming was detailed in the 2005 audit – that the ability to ensure the ongoing protection of natural and cultural resources through comprehensive management is compromised by unclear management and lack of enforcement (Office of the Legislative Auditor 2005). No regular meetings are held between the governmental agencies with management responsibilities for Mauna Kea—in particular involving OMKM and the various divisions of DLNR. Significantly, because there is so little interaction between the various state agencies responsible for the management of Mauna Kea, applicable rules and regulations in the Science Reserve are little enforced.

1.4.2.1 University of Hawai'i

As the lessee, the University has responsibility for managing the UH Management Areas. The UH Board of Regents and the President have retain project approval and design review authority over all major projects in the UH Management Areas (see Section 5.1.1). The acceptance of the 2000 Master Plan by the UH Board of Regents prompted the creation of three new management entities, the Office of Mauna Kea

[3] The need to develop and implement an historic preservation plan was identified for the first time in the 1995 Management Plan, the responsibility for which was assigned to IfA. SHPD, with the aid of IfA, prepared a draft historic preservation plan which, to some extent, was incorporated into the 2000 Master Plan. This plan, which was written concurrent with the preparation of the 2000 Master Plan and before OMKM was established, was in some respects a conceptual plan.

Management, the Mauna Kea Management Board, and Kahu Kū Mauna. These entities operate in conjunction with several advisory committees and the UH IfA.

Office of Mauna Kea Management. OMKM was established in 2000 and is responsible for the day-to-day management of the cultural and natural resources of the UH Management Areas. OMKM is housed within and funded by the UH-Hilo, and the OMKM staff report directly to the Chancellor of UH Hilo. Included within OMKM's charge is the responsibility to "protect, preserve and enhance the natural, cultural, and recreational resources of Mauna Kea"; a significant piece of this mandate is coordination with other stakeholders, public and private. OMKM also works with other agencies on issues that are related to the mountain but outside OMKM's jurisdiction. In addition, OMKM establishes management policies and oversees the ranger program (see Section 3.1.3.2). OMKM continues its program development as it defines its responsibilities and expands its services as the entity overseeing the management of the UH Management Areas on Mauna Kea.

Mauna Kea Management Board. The Mauna Kea Management Board (MKMB) comprises seven members of the community who are nominated by the UH Hilo Chancellor and approved by the UH Board of Regents. The MKMB advises the Chancellor and OMKM. The volunteer members represent a cross section of the community and serve as the community's main voice, advising on activities, uses, operations, and development planned for Mauna Kea. MKMB works closely with Kahu Kū Mauna.

Kahu Kū Mauna. Kahu Kū Mauna (Guardians of the Mountain), is a nine-member council whose members are approved by the MKMB. Kahu Kū Mauna advises the MKMB, OMKM, and the UH Hilo Chancellor on Hawaiian cultural matters affecting the UH Management Areas. The council comprises individuals from the Native Hawaiian community. Members are selected on the basis of their awareness of Hawaiian cultural practices, traditions and significant landforms as applied to traditional and customary use of Mauna Kea, and their sensitivity to the sacredness of Mauna Kea.

Advisory Committees. Other committees have been formed to advise OMKM and the MKMB on specific topics. They include the MKMB Environment Committee; the Wēkiu Bug Scientific Committee; the Hawaiian Cultural Committee; and the Public Safety Committee. These committees are coordinated by OMKM.

Institute for Astronomy. The IfA, based at UH Mānoa, conducts state-of-the-art astronomical research. Its faculty and staff are also involved in astronomy education, and in the development and management of the observatories on Haleakala and Mauna Kea. IfA oversees the conduct and coordination of astronomical research in the MKSR, including long-term planning and visioning.

Mauna Kea Observatories Oversight Committee. The Mauna Kea Observatories Oversight Committee is composed of representatives from all of the observatories and IfA. Each observatory pays into an account housed at IfA that is used to fund MKSS activities including road maintenance, snow removal, facilities maintenance and management at Hale Pōhaku, common utilities and the VIS.

Mauna Kea Observatories Support Services. Mauna Kea Observatories Support Services (MKSS) operates under the direction of the observatories through the Mauna Kea Observatories Oversight Committee funds and oversees the general maintenance and logistical services to all Mauna Kea observatories and the facilities at Hale Pōhaku. MKSS also supports, under the direction of OMKM, ranger services. The 2000 Master Plan recommended that most of MKSS' services be transferred to OMKM, but no deadline was specified. The MKMB recently passed a motion approving the transfer of the management and oversight of MKSS to OMKM, however the issue continues to be discussed.

Table 1-3. University of Hawai'i Entities with Management Responsibilities for Mauna Kea

University of Hawai'i	Lessee of the management areas on Mauna Kea; UH Board of Regents responsible for of approval of various plans
Office of Mauna Kea Management (OMKM)	Reports to the Chancellor of UH Hilo; Responsible for day-to-day management of cultural and natural resources of the UH management areas
Mauna Kea Management Board (MKMB)	Seven members nominated by UH Chancellor and approved by UH Board of Regents; Serve as community's voice advising on activities, uses, operations and development for Mauna Kea
Kahu Kū Mauna	Nine member council approved by MKMB; Advises MKMB, OMKM and UH on Hawaiian cultural matters affecting the UH management areas
Other Advisory Committees	Established to advise OMKM and MKMB: Wēkiu Bug Scientific Committee, Hawaiian Cultural Committee, Public Safety Committee
Institute for Astronomy	Based at UH Mānoa; Oversees conduct and coordination of astronomical research in the MKSR, including long-term planning.
Mauna Kea Observatories Oversight Committee	Representatives from all observatories and IfA; Manages account used to pay for MKSS activities and utilities; Account funded by observatories
Mauna Kea Observatories Support Services	Oversees general maintenance and logistical services to the observatories and facilities at Hale Pōhaku; Supports ranger services

1.4.2.2 Hawai'i State Agencies

Department of Land and Natural Resources. DLNR is headed by the BLNR and manages the state's public lands. Several divisions within DLNR share management responsibility for Mauna Kea, including the Division of Aquatic Resources, the Division of Conservation and Resources Enforcement, the Division of Forestry and Wildlife, the Natural Area Reserves Commission, the Land Division, the Office of Conservation and Coastal Lands, and the State Historic Preservation Division.[4]

Division of Aquatic Resources. The Division of Aquatic Resources (Commission of Water Resources Management) (DAR) has as its mission to manage, conserve and restore the state's unique aquatic resources and ecosystems for present and future generations. This agency sets overall water conservation, quality and use policies; defines beneficial and reasonable uses; protects ground and surface water resources, watersheds and natural stream environments; establishes criteria for water use priorities while assuring appurtenant rights and existing correlative and riparian uses and establishes procedures for regulating all uses of Hawai'i's water resources.

Division of Conservation and Resource Enforcement. The Division of Conservation and Resource Enforcement (DOCARE) is responsible for enforcing all laws and rules that apply to all lands managed under DLNR. This includes protecting and conserving the state's lands and natural resources, investigating complaints and violations, and monitoring all leases, permits, and licenses issued by DLNR. Pursuant to Act 226 Session Laws of Hawai'i 1981, the DOCARE's enforcement officers have full police

[4] This information taken primarily from the DLNR website (http://hawaii.gov/dlnr/) and the 2005 audit report (Office of the Legislative Auditor 2005).

powers to execute all state laws and rules within all State lands. The division's Hawai'i branch includes Mauna Kea in the East Hawai'i district, although they do not maintain a regular presence on Mauna Kea.

Division of Forestry and Wildlife. The Division of Forestry and Wildlife (DOFAW) is charged with protecting and managing watersheds, protecting natural resources, protecting and managing outdoor recreation resources and forest product resources. It is also charged with public education and develops and manages statewide programs on forest and wildlife resources as well as natural area reserves and trail and access systems. The division also manages outdoor recreation programs and activities, including hunting, that occur on state-owned lands on Mauna Kea.

Natural Area Reserves Commission. The Natural Area Reserves Commission is administratively attached to DLNR; its staff is in DOFAW. It establishes criteria that are used in determining whether an area is suitable for inclusion within the reserves system. The commission also establishes policies and criteria for the management, protection, and permitted uses of the reserves system. The statewide reserves system was established with the mandate of protecting the best remaining examples of native ecosystems and geological sites on state managed lands. The system currently comprises 19 reserves, including the Mauna Kea Ice Age NAR (see Section 1.3.3.1).

Table 1-4. Hawai'i State Agencies with Management Responsibilities for Mauna Kea

Department of Land and Natural Resources Responsible to the Board of Land and Natural Resources; Several divisions within DLNR have responsibilities related to management of UH management areas on Mauna Kea
DLNR Division of Aquatic Resources Sets overall water conservation, quality and use policies with the goal of protecting and regulating Hawai'i's water resources
DLNR Division of Conservation and Resource Enforcement Responsible for enforcing laws and rules that apply to all lands managed under DLNR; DOCARE enforcement officers have full police powers within State lands.
DLNR Division of Forestry and Wildlife Responsible for the management and protection of watersheds, natural resources, outdoor recreation and forest product resources; Manages hunting activities
DLNR Natural Area Reserves Commission Establishes policies and criteria for the management, protection, and permitted uses of the lands within the Natural Area Reserves system
DLNR Land Division Manages state-owned lands; Serves as custodian for all official transactions relating to public lands
DLNR Office of Conservation and Coastal Lands Develops administrative rules for conservation districts; Regulates and enforces land use within conservation districts; Processes conservation district land use requests; Investigates complaints and violations for lands within the conservation districts; Monitors all leases, permits and licenses issued by DLNR for lands within the conservation districts
DLNR State Historic Preservation Division Carries out responsibilities outlined in the National Historic Preservation Act; Manages programs to promote the use and conservation of historic properties

Land Division. The Land Division is responsible for managing state-owned lands in ways that will promote the social, environmental, and economic well-being of Hawai'i's people and for ensuring that these lands are used in accordance with the goals, policies, and plans of the state. Lands that are not set aside for use by other government agencies come within the direct purview of the Land Division, as do the management and enforcement of leases, permits, executive orders, and other encumbrances for public lands. The division also investigates local land problems, maintains data for the State Land Information

Management System, and serves as custodian for all official transactions relating to public lands, and maintains a central repository of all government documents dating back to the "Great Māhele" of 1848.

Office of Conservation and Coastal Lands. DLNR reorganized the Land Division in 2002, creating the Office of Conservation and Coastal Lands (OCCL). The office regulates and enforces land use for approximately two million acres of private and public lands that lie within the state's conservation district, including Mauna Kea. OCCL is also responsible for processing conservation district use land use requests and violations and for developing administrative rules for the conservation district, investigating complaints and violations, and monitoring all leases, permits and licenses issued by the DLNR.

State Historic Preservation Division. The State Historic Preservation Division (SHPD) helps to carry out the responsibilities outlined in the National Historic Preservation Act (NHPA) (see Section 1.4.3.1). The division is guided by the Statewide Historic Preservation Plan (2001) and the rules and regulations set forth in Chapter 6E of the Hawai'i Revised Statues (see Section 1.4.3.2).The goal of the NHPA is to preserve and protect historical and culturally significant properties. SHPD manages several programs to promote the use and conservation of historic properties, including those on Mauna Kea. SHPD also reviews proposed development projects to ensure minimal effects of change on historic and cultural assets.

1.4.2.3 Rules, Regulations, and Enforcement

OMKM's management strategy must incorporate appropriate rule-making, permit compliance, and enforcement. Successful management and stewardship of Mauna Kea will come, in part, from balancing development and public access and enforcement of rules. Some of the management actions identified in this plan are contingent on the University of Hawai'i obtaining rule-making authority, developing rules, and having the authority to enforce those rules. The inability to obtain this authority will continue to impede the University's ability to protect Mauna Kea's natural resources.

Administrative Control. OMKM lacks administrative control to develop, implement and enforce rules and regulations for public activities within the MKSR, including access and development in the summit area and at Hale Pōhaku. Establishing OMKM as the authority to enforce rules and cite violators would give it the ability to, for example:

- Manage public access to summit (e.g., vehicle type, weather, limit numbers, hours of operation)
- Manage public access to biologically, geologically and culturally sensitive areas
- Register visitors (currently the rangers do not register visitors, attributing this decision to the University's lack of authority to promulgate administrative rules (Office of the Legislative Auditor 2005))
- Require mandatory educational and safety information for visitors
- Regulate observatory vehicles (e.g., number of trips)
- Enforce speed limits
- Cite violators of conservation district rules (e.g., for intentional removal of artifacts)
- Continue management of commercial permits and activities (see Section 3.1.4)
  - Evaluate and monitor commercial operations and permit compliance
  - Enforce penalties for non-compliance

Conservation District Use. UH and DLNR share responsibility for monitoring activities (UH) and enforcing regulations and permit conditions (DLNR) on Mauna Kea. Conservation district use permit (CDUP) conditions apply primarily during construction of astronomy facilities, though the permits contain a continuing requirement for compliance with conservation district use regulations. The state now includes environmental protection requirements as permit conditions. To date, neither entity has fully accepted or acted upon its responsibilities, resulting in weak monitoring and enforcement (Office of the Legislative Auditor 2005). Under the terms of its lease, UH is responsible for monitoring the activities of the tenant observatories for conformance with the conditions of their CDUPs (see Section 1.4.3.2). OMKM has been designated the entity responsible for monitoring holders of tenant-permits, and twice a year, rangers inspect each observatory for compliance with its CDUP. It is the OCCL that is ultimately responsible for enforcing conservation district regulations and permit conditions.

OMKM Ranger Program. The ranger program has been successful in providing a presence on the mountain for operational and visitor support (see Section 3.1.3.2). If and when OMKM receives the authority to promulgate rules, they will need enforcement personnel, and rangers may be able to perform these duties. One potential option would be for the rangers to be cross-deputized as DLNR DOCARE officers. It may not be necessary for all rangers to have enforcement responsibilities; the program could support a mix of enforcement and interpretive rangers.

1.4.3 Natural Resources Management Mandates and Regulatory Context

Natural resources management must include adherence to applicable federal and state laws, regulations, and other directives.[5] In addition to those specifically addressing natural resources, a natural resources manager must also be familiar with those related to cultural resources.[6]

1.4.3.1 Federal Level

There are a number of Federal acts and programs that affect management decisions for Mauna Kea and UH managed lands on Mauna Kea.

Clean Air Act (42 USC 7401 et seq.). The Clean Air Act (CAA) governs the nation's air quality. The CAA prohibits new and existing sources of air pollution from emitting pollution that exceeds ambient air quality levels designed to protect public health and welfare. New sources are subject to more stringent control technology and permitting requirements. Hazardous air pollution and visibility impairment are also addressed by the CAA.

Clean Water Act (33 USC 1251 et seq.). The Clean Water Act (CWA) is the major federal legislation concerning improvement on the nation's water resources. The Act was amended in 1987 to strengthen enforcement mechanisms and to regulate stormwater runoff. The Act provides for the development of municipal and industrial wastewater treatment standards and a permitting system to control wastewater discharges to surface waters.

Coastal Zone Management Act of 1972 (16 USC §145 et seq.). The Coastal Zone Management Act of 1972, as amended, requires that, to the maximum extent practicable, federal actions affecting any land or water use or coastal zone natural resource be implemented consistent with the enforceable policies of an approved state management program.[7] The Act authorizes states to administer approved coastal nonpoint pollution programs. Advance concurrence from the state coastal commission is required prior to taking an

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[5] Federal regulations apply to federally funded projects (e.g., some of the telescopes).

[6] These are presented in detail in the *Cultural Resources Management Plan for the UH Management Areas on Mauna Kea* (McCoy et al. 2009).

[7] Due to the small land area and extensive amount of coastline, the State of Hawai'i Coastal Zone Management Program (CZMA) encompasses the entire State.

action affecting the use of land, water, or natural resources of the coastal zone. Excluded from the coastal zone are lands solely subject to, or held in trust by, the federal government, its officers, or its agents.

Endangered Species Act (16 USC §1531 et seq.). The Endangered Species Act is implemented by 50 CFR 402 and 50 CFR 17. This Act requires all federal agencies to carry out programs to conserve federally listed endangered and threatened plants and wildlife and the habitat on which they depend. Development and implementation of these programs must be carried out with the consultation and assistance of the Departments of the Interior and Commerce. A biological assessment may be required to determine whether formal consultation with the USFWS or the National Marine Fisheries Service (NMFS) is necessary, and it may also serve as a basis for a USFWS or NMFS biological opinion. USFWS and NMFS also maintain a listing of candidate species and species of concern.[8] While there are no legal requirements to consider candidate species and species of concern, it is prudent for managers to regard these species as if they were listed, while their status is being reviewed. Section 2.2 details federally listed species found or potentially found at Hale Pōhaku and MKSR.

National Environmental Policy Act (42 USC §4321 et seq.). The National Environmental Policy Act (NEPA) requires consideration of environmental concerns during project planning and execution. The Act requires Federal agencies to prepare an environmental assessment or environmental impact statement for federal actions that have the potential to significantly affect the quality of the human environment, including both natural and cultural resources. NEPA is implemented by regulations issued by the Council on Environmental Quality (40 CFR 1500). The Act establishes procedures for use by federal agencies for preserving important natural aspects of the national heritage and enhancing the quality of renewable resources. A NEPA analysis can have one or more of several outcomes: a determination of categorical exclusion (CatEx) where an action can be categorically excluded from further environmental analysis; the preparation of an Environmental Assessment (EA) if the action cannot be categorically excluded or is not a "major federal action"; the EA can result in a "finding of no significant impact" (FONSI), or in the decision to conduct an Environmental Impact Statement (EIS) study because the action has been found to be a major federal action through NEPA analysis.[9]

National Registry of Natural Landmarks (Program 15.9100 § 62.2). The National Registry of Natural Landmarks is administered by the National Park Service, under the Department of the Interior. The landmarks registered under this program are not intended for acquisition by the federal government, but rather, voluntary maintenance and preservation is encouraged. This designation is given to sites thought to best exemplify the geological and ecological history of the United States. The program goal is that acknowledgment of these areas may increase public appreciation for the natural heritage of the United States. Mauna Kea was designated a natural landmark in November 1972 (NPS 1994).

National Historical Preservation Act, Section 106 (16 USC §470). The National Historic Preservation Act was created to support efforts to identify and protect sites, buildings, and objects that have historic, architectural, archeological, or cultural significance. The purpose is to ensure that the historical and cultural foundations of the nation are preserved. This act specifies that there should exist a National Register of Historic Places (NRHP), an Advisory Council on Historic Preservation, individual state historic preservation offices and a review process for assessing potential impacts to sites as described in Section 106. The NRHP designation is used to identify areas and properties that are due consideration with regard to planning and development and worth preservation, whether by private, state, or federal

[8] Candidate species and species of concern are those that are being monitored but, due to insufficient information, have not been placed on the endangered and threatened species lists.

[9] Any future project within the UH Management Areas conducted with federal funds that has the potential to have an adverse impact will require the preparation of an EA or EIS under NEPA.

agencies. Section 106 requires that a review process be conducted for all federally funded projects that may impact a site that is listed or eligible for listing on the NRHP. If it is determined that there would be an adverse effect, the agency conducting the project is required to seek ways to avoid, minimize, or mitigate that effect, as well as to consider alternative plans. Section 106 dictates that the views of the public should be solicited and considered throughout the process. The Advisory Council on Historic Preservation has made it possible to combine the NEPA and Section 106 processes, and the implementing regulations for Section 106 encourage this approach to project planning. While the statute broadly defines the requirements for Section 106, the implementing regulations, at 36 CFR Part 800, describe the process by which historic properties by which historic properties are identified and handled during an undertaking.

National Register of Historic Places. The Adze Quarry, located in the Mauna Kea Ice Age NAR, has been listed on the National Register of Historic Places since 1962. This site contains religious shrines, rock shelters and petroglyphs and is thought to be the largest primitive quarry of its type, anywhere. Archeological evidence indicates that this area was used by prehistoric Hawaiians for obtaining basalt to make stone implements.

1.4.3.2 State and Local Level[10]

There are several state statutes, rules and departments that affect management decisions for Mauna Kea and UH Management Areas on Mauna Kea.

HRS 183C, Conservation District. Chapter 183C conserves, protects, and preserves important natural resources of the state through appropriate management and use to promote their long-term sustainability and the public health, safety and welfare.

HRS Chapter 205, State Land Use Law. The State Land Use Law establishes an overall framework for land use management whereby all lands in the State of Hawai'i are classified into one of four major land use districts: urban, rural, agricultural and conservation. Conservation lands are comprised primarily of lands existing forest and water reserve zones and include areas necessary for protecting watersheds and water sources, scenic and historic areas, park, wilderness, open space, recreational areas, and habitats of endemic plants, fish and wildlife. Conservation districts are administered by the BLNR and uses are governed by rules promulgated by the DLNR.

HRS Chapter 205-A, Hawai'i's Coastal Zone Management Program. The objective of the state coastal zone management (CMZ) program is to use an integrated approach to determine the policies and procedures that regulate state and county actions dealing with land and water uses and activities. Because in Hawai'i there is no point of land more than 30 miles from the ocean, the coastal zone management program is designed as an overall resource management policy and encompasses the entire state. The areas managed under this program have economic, historical, cultural, and biological considerations. Chapter 205-A requires all agencies to assure that their statutes, ordinances, rules and actions comply with the CMZ objectives and policies.

HRS Section 226, Hawai'i State Planning Act. The purpose of the Hawai'i State Planning Act is to define the topics and priorities that should be considered in planning for the future development of the state. It is intended to improve coordination among different agencies, to provide for the wise use of resources and to guide development. The act sets forth the state goals and objectives with regard to the

[10] Hawai'i Administrative Rules (HAR) are developed to implement the provisions of Hawai'i Revised Statutes (HRS).

development of policies and plans for economic development, population growth, education, crime, housing, and resource management.

HAR Title 13, Administrative Rules of the Department of Land and Natural Resources. HAR Title 13 defines the rules of practice and procedure for the lands that fall under the jurisdiction of DLNR. Each division within the DLNR has its own mission statement and set of rules. Several of these divisions have rules that are applicable to the management of Mauna Kea (see Section 1.4.2.2).

HAR Title 13, Chapter 5, Conservation District. HAR Title 13, Chapter 5 regulates land use in the Conservation District for the purpose of conserving, protecting, and preserving the important natural resources of the state through appropriate management and use, to promote their long-term sustainability and the public health, safety and welfare. The chapter establishes five subzones within the conservation district: protective, limited, resource, general, or special. For each subzone, the chapter describes the objective of the level of protection and identifies permitted uses along with the procedures necessary to obtain permission to engage in that use. Each use is assigned to one of four categories. The first category does not require a permit from the DLNR or BLNR. The second category requires a site plan, to be approved by the DLNR. The third category requires a DLNR permit. The fourth category requires a BLNR permit, and, where specified, an accompanying management plan.

The UH Management Areas on Mauna Kea are in the resource subzone. The objective of this subzone is to develop areas using management that ensures that the natural resources of those areas are sustained. To that end, many of the identified uses in this subzone fall under the third or fourth categories of land use and require, at minimum, a permit from the DLNR or BLNR. Some examples of activities that require a permit are data collection that involves incidental ground disturbance (e.g., rain gauges), erosion control, noxious weed removal that results in ground disturbance, the demolition of existing structures and removal of more than five trees larger than 6" in diameter. Astronomy facilities require both a permit and an approved management plan.

HRS Chapter 343, and HAR Section 11-200, Environmental Review. HRS Chapter 343 and Section HAR 11-200 establish a system of environmental review at the state and county level. The statute and rules provide that environmental concerns are considered for all proposed actions on State and county lands or for projects using state or county funds. HRS 343 requires an environmental assessment (EA) for actions that propose the use of any state or county land, including lands classified as within the conservation district, shoreline areas and historic sites. An environmental impact statement (EIS) is required if it is determined that the proposed action may have a significant impact. HRS 343 also requires a cultural impact assessment study to determine what effects the proposed project would have on Native Hawaiian cultural practices, features, and beliefs. In addition, Section 11-200 HAR provides for public participation through a public review process, as well as listing what classes of action are exempt from submission of an EA.[11]

HRS Chapter 6E, Historic Preservation. HRS Chapter 6E establishes that it is a policy of the state to preserve, restore, and maintain historically and culturally significant property. This chapter provides that all proposed projects that may affect any historic property, aviation artifact, burial site, or sites listed on the Hawai'i register of historic places, must be reviewed by the SHPD, which operates under DLNR. The summit region of Mauna Kea is designated as a historic district by the State of Hawai'i.

[11] Any future project within the UH Management Areas that has the potential to have an adverse impact will require the preparation of an EA or EIS under Chapter 343, HRS, Environmental Impact Statements and Section 11-200, Environmental Impact Statement Rules

HAR Title 13, Subtitle 13, Chapter 300, Inadvertent Discovery of Human Remains. The DLNR State Historic Preservation Division (SHPD) shall have jurisdiction over any inadvertently discovered human skeletal remains and any burial goods over fifty years old, regardless of ethnicity. Any discovery shall be immediately reported to the appropriate authorities including the SHPD. Upon discovery all activity in the immediate area of the remains must cease and appropriate action must be taken to protect the integrity of the burial site.

HRS Chapter 195D, Conservation of Aquatic Life, Wildlife and Land Plants. HRS Chapter 195D establishes the rules and regulations related to the conservation of indigenous aquatic life, wildlife, land plants, and their habitats. This chapter covers the state rules and regulations regarding endangered and threatened species, most of which are the same as the federal rules established by the Endangered Species Act. The chapter provides that the DLNR, after consultation with all appropriate agencies and interested parties, and on the basis of all available scientific, commercial, and other data, may determine that a species that is federally listed as threatened can be listed as endangered within the state and that a species that is not listed federally can be listed as endangered or threatened for the state.

HAR Title 4, Administrative Rules of the Department of Agriculture. HAR Title 4 covers the rules and regulations concerning issues that fall under the jurisdiction of the Department of Agriculture. Title 4 establishes the guidelines, limitations, and parameters for specific types of actions within the context of the Hawai'i Revised Statutes for the Department of Agriculture. Regulations set forth by HAR Title 4 govern pesticides, noxious weeds, importation and exportation of plants, prohibited animals, quarantines of plants and animals, restrictions on the importation of microorganisms, intrastate movement of bees, pests for control or eradication, management of agricultural resources, and aquaculture development.

HRS Chapter 152, Noxious Weed Control. According to HRS Chapter 152, "noxious weed" means any plant species that is, or that may be likely to become, injurious, harmful, or deleterious to the agricultural, horticultural, aquacultural, or livestock industries of the state and to its forest and recreational areas and conservation districts, as determined and designated by the department from time to time. This chapter establishes the criteria for the designation of noxious weeds and outlines the duties of the Department of Agriculture in terms of control and eradication of noxious weeds. Among other provisions, this chapter includes the prohibition of transportation of specific noxious weeds and the responsibility of the department to take measures to restrict the introduction and establishment of specific noxious weed species in areas that have been declared free of those noxious weeds.

HRS Chapter 342B, Air Pollution Control. The Department of Health, Clean Air Branch is responsible for air pollution control in the state pursuant to the federal Clean Air Act; HRS Chapter 342B; HAR Title 11, Chapter 59, Ambient Air Quality Standards; and HAR Title 11, Chapter 60.1, Air Pollution Control. The engineering, monitoring, and enforcement sections conduct engineering analysis, issue permits, perform monitoring and investigations, and enforce the federal and state air pollution control laws and regulations.

HRS Chapter 342D, Water Pollution Law. The Water Pollution law provides a comprehensive regulatory program for discharges of pollutants to the waters of Hawai'i. Administrative rules pertaining to wastewater systems are included in HAR Title 11, Chapter 62.

HRS Chapter 342J, Hawai'i Hazardous Waste Law. Hawai'i's Hazardous Waste law governs the management of hazardous waste and prohibits hazardous waste pollution.

HAR Title 11, Administrative Rules of the Department of Health. HAR Title 11 covers the administrative rules of items or concerns that fall under the jurisdiction of the Department of Health. Rules governing water quality, water pollution, wastewater management, solid and hazardous waste management, litter control, emergency medical services system, and sanitation all must be considered relevant to activities and management actions on Mauna Kea.

2 Natural Resources of Mauna Kea

Section 2 of the Mauna Kea Natural Resources Management Plan (NRMP) provides details on the current state of knowledge of the physical and biotic resources, including historical observations, current status, existing surveys and data, information gaps, and threats.

Section	Component Plan
2.1	Physical Environment
2.2	Biotic Environment

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2.1 Physical Environment

Rising 30,000 feet (9,144 m) above the ocean floor Mauna Kea is the highest insular volcano in the world (NPS 1994). It is home to numerous unique geologic features and a truly awe inspiring natural environment. Located on the Island of Hawai'i, Mauna Kea is the third oldest of five volcanoes composing the largest island within the Hawaiian Archipelago. Revered by both indigenous and modern Hawaiians, Mauna Kea still evokes feelings of spirituality from its visitors through majestic views and a landscape that reflect the volcanic history of our planet. Seemingly barren, desolate, and unchanging, the natural environment of the upper slopes and summit area are actually very much alive, revealing through its topography, geology, and climate an impressive history of geomorphic process and ecosystem development.

This management plan has been developed specifically for the UH Management Areas on Mauna Kea; however, it is impossible to constrain attributes of the natural environment within these boundaries. Therefore, while information within this section attempts to describe attributes specific to the Mauna Kea Science Reserve (MKSR) and Hale Pōhaku, often the scope of the discussion will necessarily incorporate features within the general landscape boundaries of approximately 9,000 ft (2,700 m) elevation to the summit, including adjacent lands such as the Mauna Kea Ice Age Natural Area Reserve (NAR) and the Mauna Kea Forest Reserve, both properties managed by the Department of Land and Natural Resources (DLNR). For clarity, the discussion in this section covers the area under management as three geographic zones: Hale Pōhaku; the upper slope zone, the area extending from roughly 9,000 to 12,900 ft (2,700 to 3,931 m); and the summit area, lands located above 12,900 ft (3,931 m).

The following description of the physical environment provides a basis for managing the physical resources. Section 2.1.1.1 describes regional volcanism, including an overview of the life cycle of Hawaiian volcanoes and the lava types associated with the various eruptions. Descriptions of the range of physiographic variables affecting the upper slopes of Mauna Kea are presented including: Mauna Kea's geology (Section 2.1.1), topography (Section 2.1.1.3) geomorphic processes (Section 2.1.1.4), surface features and soils (Section 2.1.2), hydrology (Section 2.1.3), climate (Section 2.1.4), air quality and sonic environment (Section 2.1.5), and visual resources (Section 2.1.6).

2.1.1 Geology

Geology is the science of identifying processes related to the formation of the earth, as recorded in rocks. This review of geologic resources focuses on the volcanic processes involved in the formation and geologic evolution of Mauna Kea, the chemical and physical properties of the lava, descriptions of the topography and unique geomorphologic features. This review attempts to present the most current information available on the geology of Mauna Kea and to identify information gaps.

2.1.1.1 Volcanism in Hawai'i

Throughout the world, volcanoes have continually been at work, altering the landscape. The infamous stratovolcanoes, such as Mt. Etna, in Italy; Mt. St. Helens, in the northwestern United States; and Mt. Pinatubo in the Philippines, are known for their pointed, conical shapes and histories of far-reaching destructive impacts caused by characteristic explosive eruptions. In contrast, Hawaiian volcanoes typically produce relatively more fluid lavas that build up locally, forming a rounded, rather than a pointed or conical mountain. They are said to resemble in profile a warrior's shield lying horizontally, and are called shield volcanoes. However, Hawaiian volcanoes are occasionally explosive and at times can be quite dangerous. Earth scientists continue to research the reasons for these differences in volcanic display, as well as volcanism in general.

Canadian geophysicist J. Tuzo Wilson proposed in 1963 the mechanism that is now generally accepted to be behind the ongoing propagation of the Hawaiian Archipelago, the west-northwest movement of the Pacific Plate, which underlies the Hawaiian Islands and moves at approximately 3.5 inches (9 cm) per year (Clague and Dalrymple 1989; Walker 1990). Wilson also proposed that a "hotspot" (now referred to as a mantle plume) was the source of magma responsible for the creation of the Hawaiian Island chain. Mantle plumes are convective columns of material that rise from near the core/mantle boundary. As the material approaches the base of the crust, a small fraction of the plume material undergoes a process called decompression melting that generates the magma that rises through the crust and is erupted on the ocean floor (or the surface of the continental land masses). In the case of Hawai'i, once a magma conduit forms through the crust, it remains active as the Pacific Plate carries it across the top of the plume. Using these theories as a basis, geologists have since refined the sequence of events and processes leading to the formation of the islands. The significant production of magma generated by the mantle plume beneath the Island of Hawai'i is due to its steady supply and consistency in magma volume, and its relatively fixed location (Clague and Dalrymple 1989). As the Pacific Plate rides slowly over the hotspot, volcanoes spring up, formed by the repeated discharge of magma. The slow advance of the plate eventually moves the volcano off the plume, cutting off the source of magma to the volcano above it. This movement has been likened to a conveyor belt; the plate is always moving slowly enough that the magma coming out of the ground deposits within a relatively localized area creating the mountain we identify as a volcano. Through this process about 129 different Hawaiian volcanoes, comprising more than 25 volcanic islands have been formed, stretching 3,800 miles (6,000 km) across the Pacific Plate (Walker 1990; Juvik and Juvik 1998). Hawaiian atolls (a ring of coral reef built on top of a subsiding volcanic island core) such as Kure, Midway and Pearl and Hermes are still visible and provide clear evidence of the path taken by the Pacific Plate and the ultimate fate of the islands formed over the mantle plume.

2.1.1.1.1 Life Cycle of a Hawaiian Volcano

Volcanoes world-wide form under many different circumstances and vary in their type of eruption, the type of material they erupt, and the length of time required for their formation. Starting from the ocean floor, Hawaiian volcanoes take hundreds of thousands of years to reach the ocean's surface, if they do at all. The following briefly describes the growth of what we know to be a Hawaiian volcano.

It is generally accepted that the life cycle of a Hawaiian volcano is comprised of four stages: pre-shield, shield, post-shield and rejuvenation (Sherrod et al. 2007). The stages often overlap, making definitive statements about exactly when one stage ends and another starts difficult. Not all volcanoes within the Hawaiian Archipelago have passed through all of the four stages and some have bypassed a stage completely. These four stages are also considered integral markers for the growth of Hawaiian volcanic islands. Four additional stages are recognized as part of the island growth sequence to accommodate pre-subaerial building and erosion stages: the submarine,[1] erosion, atoll and guyot.

The submarine stage is the initial phase of activity when the conduit from the mantle forms, and occurs within the pre-shield stage of volcano growth. Located approximately 18.6 miles (30 km) southeast of the Island of Hawai'i, Lō'ihi, the youngest of the Hawaiian volcanoes, is currently in this stage (Macdonald et al. 1983; Juvik and Juvik 1998). Lō'ihi is estimated to be a few hundred thousand years old and is still approximately 3,200 ft (1,000 m) below the ocean's surface.

[1] The submarine and erosion stages of volcanic island formation fall within the pre-shield stage of volcano growth.

The submarine stage transitions into an emergent stage when the volcano begins to rise above the ocean surface. The shield stage begins when the magma becomes more basaltic; this can occur when the volcanic edifice is below or above the ocean surface. This vent will form the subaerial lavas (predominantly pāhoehoe and ʻaʻā lavas) that will gradually extend the perimeter of the volcano while depositing progressively thicker blankets of volcanic material on the submerged flanks of the volcano. The lavas generated in the shield stage are primarily tholeiitic basalts, which is a descriptive term used to define its fundamental chemistry (see Section 2.1.1.1.2).

With time, the tholeiitic shield lavas may evolve chemically to more alkalic compositions and the volcano enters a post-shield stage; a stage not all volcanoes have gone through. An erosion phase is considered to be the next stage due to an extended period of eruptive quiescence. Should the volcano undergo a rejuvenation stage, eruptions start up again and new volcanic material covers older flanks of the volcano. The atoll stage is when most of the volcano has been eroded and subsided beneath the ocean, with only the reefs and parts of its original rock intact below the ocean surface. The final stage is the guyot, when the volcano and its fringing reefs are submerged to depths that no longer support the coral reefs. The development of coral is somewhat a function of an island's latitude. As latitude increases coral growth slows and often cannot keep up with island subsidence.

The youngest volcanoes in the Hawaiian chain are Kīlauea and Lōʻihi. Kīlauea forms a part of the southeast portion of the Island of Hawaiʻi. Kīlauea has been erupting continually since 1983 and is in a shield-building stage. The oldest volcanoes located along the northwest end of the Hawaiian Archipelago are believed to be more than 70 million years old (Clague and Dalrymple 1989) and are in the final, or guyot, stage of a Hawaiian volcano's life cycle (Juvik and Juvik 1998).

2.1.1.1.2 Lava Types

Lava is defined as "molten rock material at the surface." At many of the Hawaiian volcanoes and at Mauna Kea specifically, material discharged from a volcano can be broadly broken into sub-classes called lava and tephra. Lavas are erupted from vents in a relatively non-explosive manner and flow over the landscape under the force of gravity. Tephra is created through those explosive (pyroclastic) events associated with the presence of higher volumes of gas within the magma or when magma interacts with shallow groundwater.

Lava Chemistry: Although the lavas of individual Hawaiian volcanoes differ in many ways, including texture, density, and color, overall they comprise a relatively small array of chemically similar igneous rocks, varying only slightly in major-element chemistry, the significant components being silica, titanium, aluminum, iron, magnesium, calcium, sodium, potassium, phosphorus and manganese (Washington 1923; Macdonald et al. 1983; West et al. 1988). New drilling and analytical technologies are providing insight into the chemical make-up and, thus, the evolution of the lavas that mark the life stages of Hawaiian volcanoes. Researchers can now directly link differences in physical properties and chemical signatures to the environmental attributes of the magma source. Research has found that as conditions change within the magma chamber (a shallow 1–3 mi (2–5 km) accumulation of magma that typically underlies the summit calderas of Hawaiʻi's volcanoes), elements of the magma may come together, forming crystals that often become embedded in ejected lavas (Baker et al. 1996). As crystals form, the chemistry of the magma changes (West et al. 1988; Juvik and Juvik 1998). Initial changes of magma chemistry are associated with the formation of olivine crystals and consequent removal of magnesium and iron (Macdonald et al. 1983). Secondary changes involve the continued preferential removal of magnesium, calcium, and iron minerals to form pyroxene and feldspar crystals (Macdonald et al. 1983). In the case of

Mauna Kea, lava flows dominated by either tholeiitic (lower sodium and potassium) or alkalic (higher sodium and potassium) minerals have been used to delineate two of Mauna Kea's growth stages; tholeiitic minerals are indicative of the mountain's shield-building stage, whereas alkalic minerals are indicative of the post-shield stage (Sherrod et al. 2007).

Lava Flows: Morphologically there are two types of lava flows that comprise approximately 90 percent of all Hawaiian basaltic lavas: 'a'ā and pāhoehoe (Rowland and Walker 1990). The difference in the morphologies depends almost entirely upon the details of the amount of material extruded and the lava flow's cooling history. Through investigations of Kīlauea lava flows, Rowland and Walker (1990) determined that for Kīlauea, volumetric rates of discharge greater than 177–353 ft^3/s (5–10 m^3/s) will form 'a'ā whereas lower volumetric discharge rates will form pāhoehoe. Whether or not similar volumetric rates of discharge defined the formation of 'a'ā and pāhoehoe lavas present at Mauna Kea is unknown.

'A'ā: Roland and Walker (1990) have suggested that lavas that eventually become 'a'ā are erupted quickly, often at high rates, exposing a great deal of surface area in the process. Because of this, these lavas cool quickly, permitting phenocrysts or large conspicuous crystals to form within the lava flow (Macdonald et al. 1983). These crystals increase flow viscosity and material yield strength, leading to in-situ shearing as the lava moves. This shearing action breaks up the lava material, creating the clinkery pieces 'a'ā is so well known for. The typical 'a'ā flow moves in a rotating fashion, the top continually falling over in front of the advancing flow, which covers it (Macdonald et al. 1983). In this way the uppermost lavas are captured underneath, ultimately becoming the floor of the flow leaving the middle section unexposed and unaltered. Once solidified, a typical 'a'ā flow has three layers; a jagged surface, a dense core, and a rough floor as depicted in Figure 2.1-1.

Figure 2.1-1. A'a Lava

Typically known to flow more quickly than pāhoehoe, rates of ʻaʻā flow advance at Kīlauea have averaged more than 164 ft/h (50 m/h) (Rowland and Walker 1990). Moving and cooling relatively quickly, gas bubbles trapped within ʻaʻā are stretched and deformed, leaving elongated vesicles once the lava solidifies (Macdonald et al. 1983). While lavas of the shield stage and early post-shield stage are chemically similar, late post-shield lavas have more time to evolve. At time of eruption, these lavas were cooler and had a larger ratio of phenocrysts to melt, preferentially forming flows of ʻaʻā. Flows with this type of composition are the most recent expression of volcanic activity at Mauna Kea and were often ejected from summit cinder cones (Macdonald et al. 1983). The chemical composition and physical attributes of these "young" eruptions indicate movement of the magma conduit away from the mantle plume and the subsequent reduction in available magma.

<u>Pāhoehoe</u>: Lavas which eventually become pāhoehoe flows are erupted at relatively low rates (Rowland and Walker 1990) enabling a thin crust to form at the flow's surface (Macdonald et al. 1983). Insulated by this cooler crust, the protected internal lava maintains higher temperatures for longer periods than it does in flows that become ʻaʻā. As a result, phenocrysts typically do not form within flows of this type, permitting the thin, broad frontal lobes, or "toes," typically associated with pāhoehoe. Investigations at Kīlauea found pāhoehoe flows to average less than about 3 ft (1 m) thick and to advance at rates between 13 and 26 ft/h (4 and 8 m/h) (Rowland and Walker 1990). The slow cooling process also allows entrained gases time to vent out, forming spherical vesicles upon hardening (Macdonald et al. 1983). Early to mid-post-shield stage pāhoehoe flows capped much of Mauna Kea and are responsible for its smooth, shield-shaped appearance (Macdonald et al. 1983).

Tephra: Composed of the same material as lava but expressed in various shapes, sizes and masses, tephra is defined by volcanologists as any volcanic material ejected through the air by any mechanism. However much of the cinder tephra at Mauna Kea was created through pyroclastic (explosive) events; events through which magma is ejected more explosively than otherwise. As the magma is ejected from the vent, it is thrown into the air and quickly cooled; usually quickly enough to form glass. Any magma that is ejected like this is termed tephra, and in its various sizes and material properties is called ash, Pele's hair, Pele's tears, lapilli, and cinder. Any ejected product less than 0.1 in (2.0 mm) is called ash and cemented ash is termed tuff; products between 0.1 - 2.5 in (2.0-64 mm) are termed lapilli (little stone); blocks are larger than 2.5 in (64 mm). Pele's tears and Pele's hair are smaller bits of lava thrown up into the air and shaped by prevailing winds. They are glassy tephra products named after the volcano goddess Pele and shaped, as their names imply, in the form of teardrops and long, thin filaments. Cinder is also considered tephra. The main component of cinder cones, cinder usually is found no larger than a few inches in diameter; the less dense pieces generally referred to as 'pumice' (Macdonald et al. 1983). Spatter has a splashed-like appearance and is formed when blobs of lava are ejected into the air and hit the ground while still molten. Upon striking the ground spatter often welds various products together forming a mass sometimes termed an agglutinate.

2.1.1.2 Mauna Kea Geology

Mauna Kea is currently estimated to be between 600,000 and 1.5 million years old (Moore and Clague 1992; DePaolo and Stolper 1996; Wolfe et al. 1997; Sharp and Renne 2005) and is considered by the U.S. Geological Survey (USGS) to be an active post-shield volcano (Macdonald et al. 1983; Juvik and Juvik 1998). It is the tallest of the Hawaiian volcanoes visible today and has produced more than 7,000 mi^3 (30,000 km^3) of predominantly tholeiitic basalt within its shield-building stage alone (Wolfe et al. 1997). The shield growth and position of neighboring Kohala, Mahukona, and Hualālai volcanoes helped to shape Mauna Kea, buttressing its longer lava flows and preventing the formation of a west-lying rift zone (Wolfe et al. 1997). The presence of at least three glaciers that covered the summit region of Mauna Kea during the later part of its post-shield stage impacted the shape, size, and alignment of layers on and beneath the surface. These impacts were the result of the interaction of ice and eruptions that produced lava flows with unique boundaries, hyaloclastite, and probably ponded melt water (Porter 1987). In some cases melting ice provided water that initiated more-explosive eruptions, producing fine materials, such as ash and tuff. The formation of cinder cones, the movement of ice sheets, and the interaction of lava and ice shaped much of the summit area, and provides the evidence that is used to map the geologic past and lithology of Mauna Kea's formation (see Figure 2.1-2 and Figure 2.1-3).

2.1.1.2.1 Volcanic Stages and Surface Geology

Mauna Kea is currently in the post-shield stage (Wolfe et al. 1997). Close to 95 percent of Mauna Kea's mass was generated during the shield stage, and is composed primarily of tholeiitic basalts, none of which are visible at Mauna Kea's summit today (Sherrod et al. 2007). Material erupted during the shield stage is believed by some to have come from one primary rift zone extending eastward from the summit (Wolfe et al. 1997) and a now buried caldera (Porter 1972a, 1979c; Carlquist 1980) however other more recent publications suggest that Mauna Kea had no well developed rift zones (Holcomb et al. 2000; Kauahikaua et al. 2000). Lavas and other ejecta discharged during the current post-shield phase are primarily alkalic in composition and have been divided into two sub-stages: the older Hāmākua and the younger Laupāhoehoe Volcanics (Macdonald et al. 1983; Wolfe et al. 1997; Sherrod et al. 2007). The Laupāhoehoe, and to a lesser extent the Hāmākua lava and tephra deposits, are the most visible on the surface of the summit area and cover the older shield stage basalts (Porter 1979c; Sherrod et al. 2007). The significant mass of all volcanoes on the Island of Hawai'i induces subsidence. The rate of subsidence for Mauna Kea is approximately 0.12 in/yr (3 mm/yr), or 1,312 ft (400 m) in 130,000 years (Wolfe et al. 1997; Sharp and Renne 2005).

2.1.1.2.2 Post-Shield Volcanics

The two sub-stages of the post-shield Hāmākua and Laupāhoehoe Volcanics produced lava flows that vary in their chemical constituents and thickness; Hāmākua flows were a few meters thick while Laupāhoehoe flows were tens of meters thick (Porter 1997a). The post-shield stage is also known for its less frequent but more explosive eruptions producing ash, lapilli, and cinder (often termed scoria). Once ejected, finer particles such as ash were transported downwind, falling on the landscape in thick deposits (Porter 1997b). Heavier and denser products such as lapilli and cinder, falling close to the source, formed the massive cinder cones that dot Mauna Kea. Sticky, stubby 'a'ā lavas were also occasionally produced (Macdonald et al. 1983), typically pushed out at along the lower and downslope edges of existing cinder cones, often times partially burying the cone (Porter 1972b; Wood 1980). Significantly, during the post-shield stage, volcanic eruptions were taking place before, during, and after glaciers covered the upper slopes of Mauna Kea (Porter 1979c); Porter (2005) notes evidence to the interbedding of Mauna Kea lava and glacial deposits over the past 150,000 years,

Because of their visibility, summit post-shield Hāmākua and Laupāhoehoe Volcanics and the process of delineating their stratigraphy has been the subject of debate for many years. While all contributors to the various paradigms use combinations of lava chemistry and geology to support their conclusions, advances in chemical analysis have facilitated new perspectives on the geologic record at the summit. Hāmākua and Laupāhoehoe Volcanics have generally been separated following a chemical chart that places the results of rock chemistry into an igneous range between basalt and mugearite depending upon the evolution of the magma. Early lavas of the Laupāhoehoe series were considered transition hawaiites. Recently Wolfe and others (1997) suggested that these transition hawaiites be included within the Hāmākua Volcanics. Several interesting conclusions come from this: there is a great deal more Hāmākua visible at the summit than before and lavas associated with the hawaiite adze quarries are now considered part of the basalt family. Geologic evidence supports this determination, because the inter-layering of the basaltic and hawaiite lavas of this new paradigm has not been observed anywhere on the summit (Wolfe et al. 1997).

Hāmākua Volcanics: The Hāmākua Volcanics, named for basalt exposures within seacliffs between Hilo and Honoka'a, is sub-divided into two members, the Hopukani Springs Volcanic Member and the Liloe Spring Volcanic Member. Events associated with the Hopukani Springs Volcanic Member began approximately 200,000 years ago (Wolfe et al. 1997) and mark the beginning of a significant change in lava chemistry from predominantly tholeiitic composition to predominantly alkalic. Because the oldest samples of rock have been associated with proximity of the volcano to the center of the mantle plume (Bryce et al. 2005), the chemical changes indicated by these post-shield Hāmākua transition basalts may have been due to movement of Mauna Kea, riding atop the Pacific Plate, away from the plume. Exposed outcrops of the Hopukani Springs Volcanic Member are up to 98 ft (30 m) thick in some areas and lie beneath sediment outcroppings of the Pōhakuloa Glacier Member intrusion (Wolfe et al. 1997). Later Hāmākua events associated with the Liloe Spring Volcanics Member began 70,000–65,000 years ago (Moore and Clague 1992; Wolfe et al. 1997; Sherrod et al. 2007) and consist primarily of 'a'ā flows, the chemistry of which clearly indicate the completion of the transition to primarily alkalic composition (Wolfe et al. 1997). The exposed outcrops of this event are up to 164 ft (50 m) thick (Wolfe et al. 1997) and can be identified by a lithology corresponding to remnants of both the Pōhakuloa and Waihu Glacier Members. See Section 2.1.1.4.2 for additional information on glacier members.

Cinder cones of the Hāmākua Series are still visible, located along the lower north and northwest slopes of Mauna Kea. Most of the older summit cones of this period were destroyed and buried by the more recent Laupāhoehoe events (Wolfe et al. 1997). More information on Mauna Kea cinder cones can be found in Section 2.1.1.4.1. Xenoliths, an inclusion often found attached to another igneous rock that is not genetically related to the host rock, believed to be Hāmākua have also been found at Mauna Kea's summit cone (Fodor 2001).

Laupāhoehoe Volcanics: Materials from the younger, post-shield Laupāhoehoe Volcanics were erupted between 65,000 and 4,000 years ago, ejected through summit fissures and multiple cinder cones, including Pu'u Poli'ahu and Pu'u Waiau (Wolfe et al. 1997; Sherrod et al. 2007). This series is known for 'a'ā and pāhoehoe flows that buried, or capped, surface features of earlier events (Clague and Dalrymple 1989). This resulted in the gentle slope and shield appearance of Mauna Kea. The later flows of this series were mostly blocky 'a'ā, approximately 16–33 ft thick (5–10 m), although flows up to 82 ft thick (25 m) are still visible (Wolfe et al. 1997) (see Figure 2.1-5 and Figure 2.1-4).

The pu'u (cinder cones) distributed across Mauna Kea are formations of the post-shield eruptions and include Pu'u Ko'oko'olau, Pu'u Keonehehe'e, Pu'u Kanakaleonui and "a broad unnamed cinder cone that crests at 12,800 ft (3,900 m), 2 mi (3.4 km) northwest of the higher summit area of Mauna Kea" (Wolfe et al. 1997).

Lava tubes and caves within the MKSR are rare, and those that have been found have only small chambers (McCoy 2009). The small number of these features in the MKSR may be due to the lack of geologic process necessary for their formation or from past geologic conditions such as glaciers that caused caves and tubes to collapse. Lava tubes and caves are more common below 9,000 ft on Mauna Kea where they serve as important sites for avian subfossil deposits. The preserved bones of extant and extinct bird species have been collected from caves (up to 9,000 ft) on Mauna Kea. Species identified to date include nene (*Branta sandvicensis*), Dark-Rumped Petrel (*Pterodroma phaeopygia sandwichensis*), extinct flightlyess rails (*Porzana* sp.), and extinct finches (*Telespiza* sp.) (Giffin 2009).

Figure 2.1-2. Mauna Kea Geology

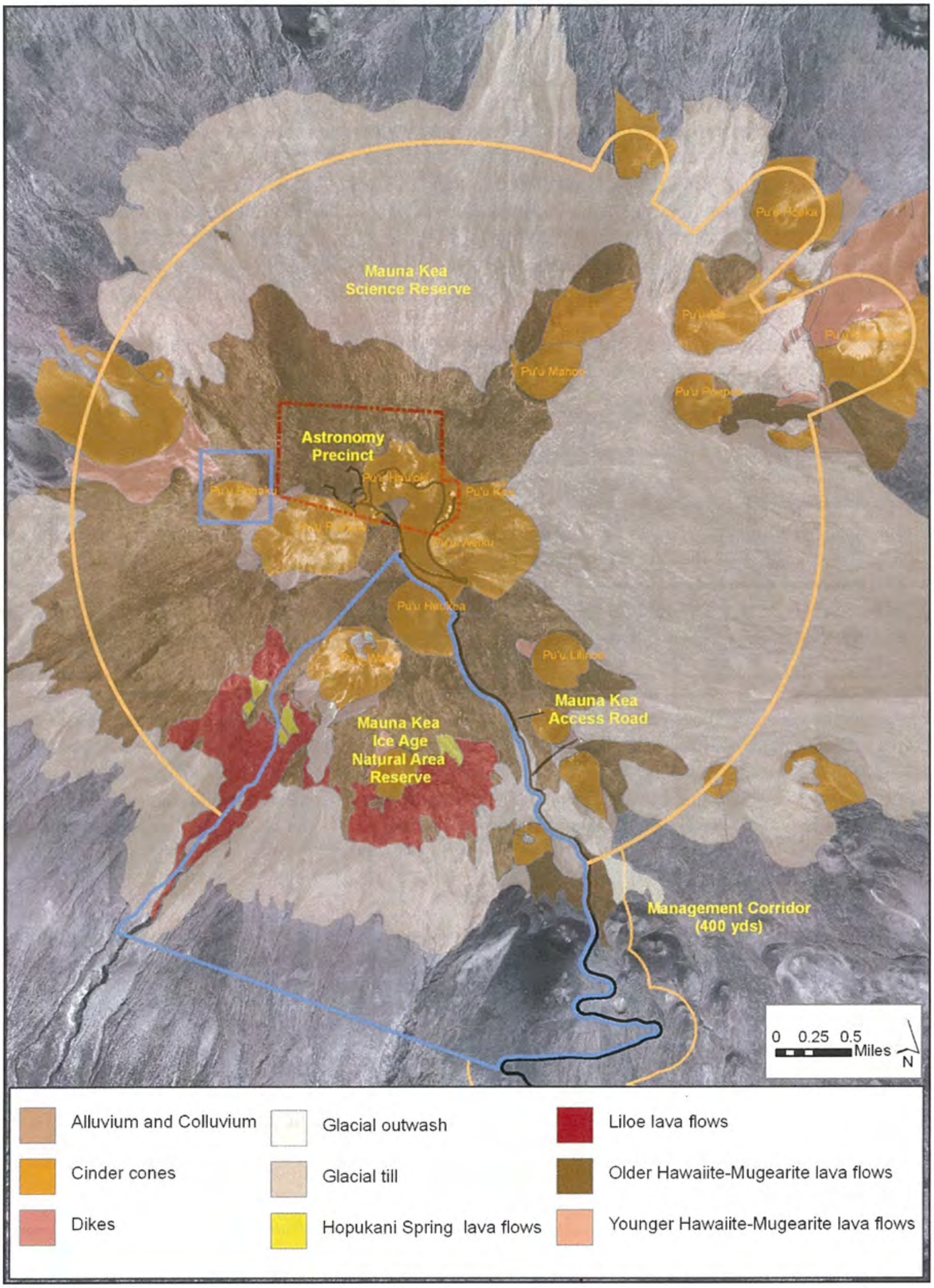
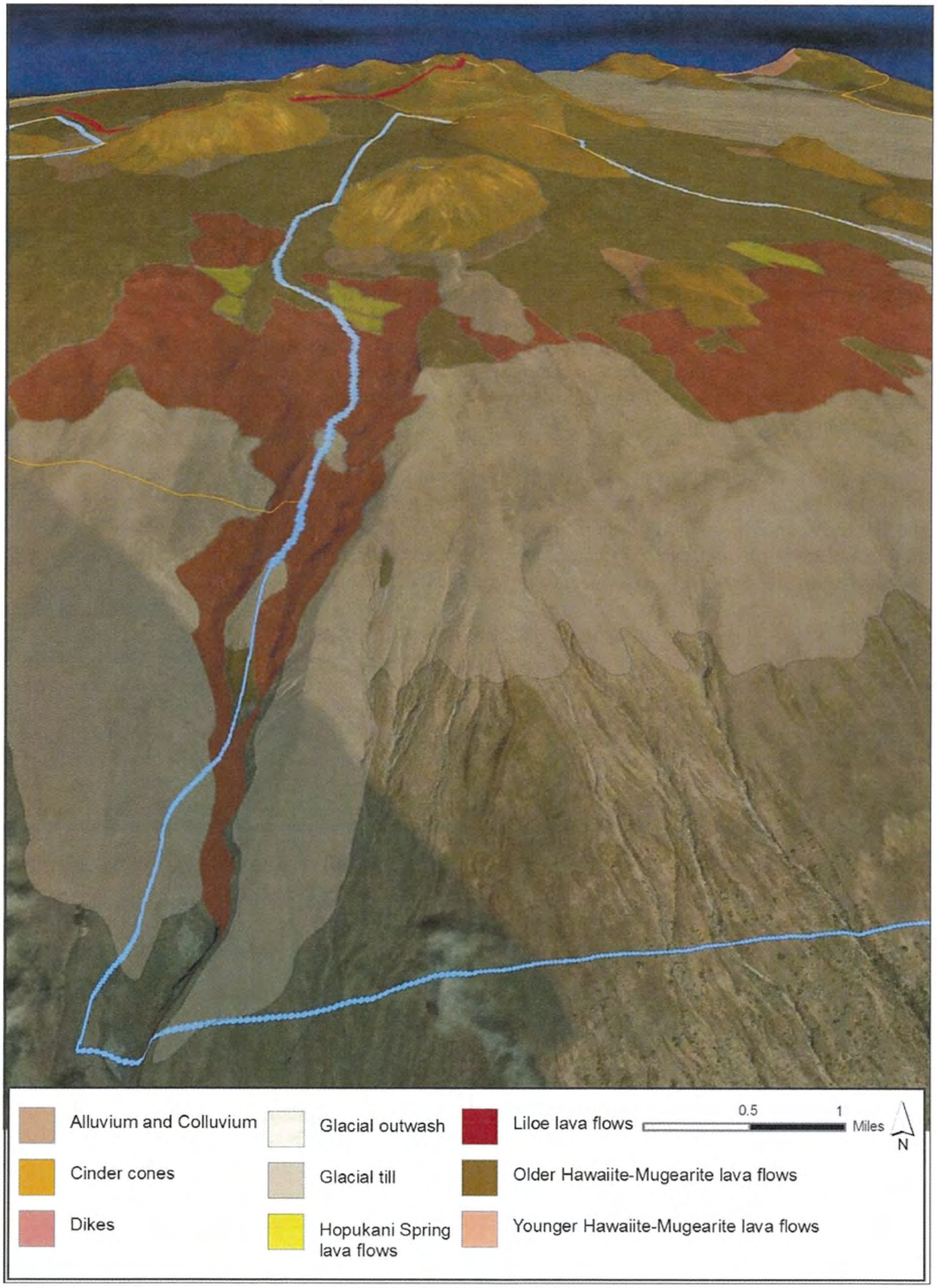


Figure 2.1-3 Mauna Kea Geology (3D)

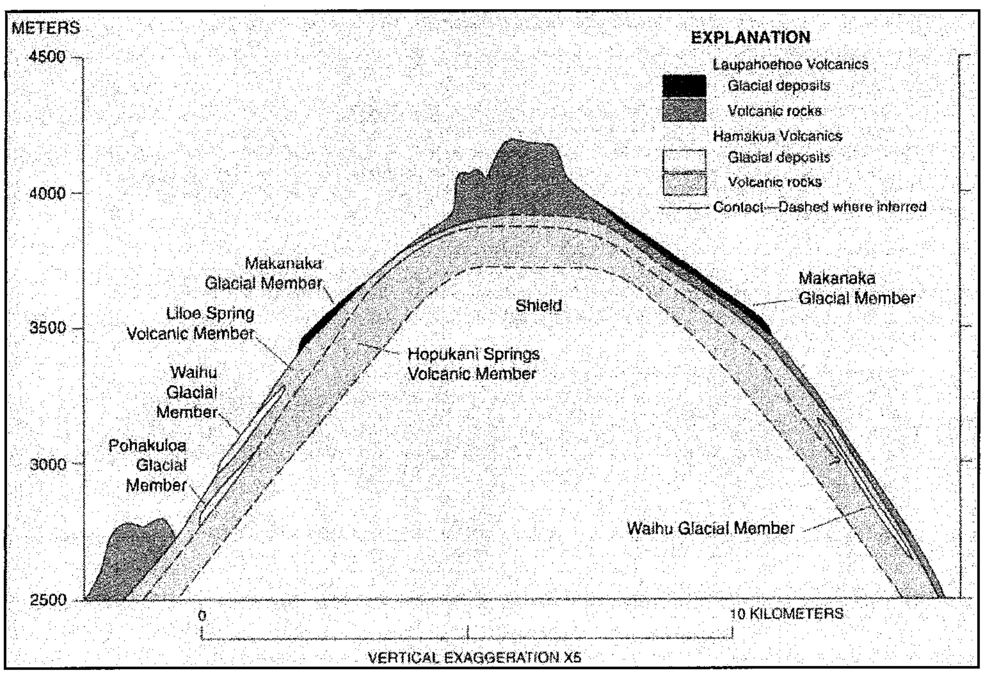


Surface Environment: The MKSR encompasses 11,288 acres (4,568 hectares) extending from the summit of Pu'u Wēkiu, at 13,772 ft (4,205 m), to the MKSR boundary, which encircles the mountain at approximately 11,500 ft (3,505 m) (see Figure 1-3). The actual summit of Mauna Kea is the apex of Pu'u Wēkiu, also referred to as the summit cone; however, the three cones Pu'u Hau'oki, Pu'u Hau Kea, and Pu'u Wēkiu are generally considered together to be the summit area, or Pu'u Kūkahau'ula.[2] Along its southern arc, the boundary is cut off for about 60 degrees where it turns upslope, forming a narrow wedge with its apex at 13,200 ft (4,032 m). This 3,750 acre (1,518 ha) wedge-shaped parcel is part of the Mauna Kea Ice Age NAR and is managed by the Department of Land and Natural Resources (DLNR). A second, smaller, square NAR parcel of 143.5 acres (58 ha) is cut out of the west side of the MKSR at an elevation of approximately 13,000 ft (3,972 m). The NAR units were created to preserve rare and unique geomorphologic features formed by the interaction of volcanic ejecta and glacial ice. Three lobe-shaped projections extend from the mostly circular boundary along the northeast alignment of the MKSR. The MKSR boundary was extended outward to include three pu'u on this part of the mountain. Classified as semi-arid, barren alpine-desert tundra (Mueller-Dombois and Krajina 1968; McCoy 1977; McCoy and Gould 1977; Ziegler 2002) and often dotted with lonely lava outcrops and boulders, the upper slopes and summit area are sparse, rough landscapes dominated by exposed rock with little soil cover or vegetation. The approximately 19 acre (7.7 ha) Hale Pōhaku parcel, located at 9,200 ft (2,804 m) is situated at the base of Mauna Kea's upper slopes.

The topography of Mauna Kea is primarily the product of numerous eruptions that created its shield shape and defined its maximum elevation, and of ancient glaciers that once covered much of the summit region. The combination of these two factors resulted in a landscape whose surface textures range from relatively smooth and free of large particles, to areas of broken lavas composed of 'a'ā chunks and other large rock material, to cinder cones with uniform surface particle size and relief.

Figure 2.1-4. Mountain Cross Section

From (Wolfe et al. 1997)



[2] For this discussion Mauna Kea's summit area includes lands above 12,900 ft (3,931 m).

Figure 2.1-5. Geological Layering of Mountain

From (Wolfe et al. 1997)

2.1.1.2.3 Future Volcanic Stages of Mauna Kea

Mauna Kea is currently classified as an active volcano in the post-shield stage of development, and while there has been no recent volcanic activity at Mauna Kea, volcanologists believe that it will probably erupt again (Walker 1990; U.S. Geological Survey 2002). Mauna Kea has erupted 12 times within the last 10,000 years; however, it has been at least 4,600 years since its last eruption (Lockwood 2000; Sherrod et al. 2007).

It is uncertain when the next eruptive stage will occur. Lockwood (2000) suggests that even given a recurrence interval of less than 1,000 years, an eruption is unlikely within the "humanly near future". Kohala volcano, which produced a similar alkalic cap, remained within its post-shield stage for approximately 250,000 years (Clague and Dalrymple 1989). It is expected, however, that any future volcanic activity at Mauna Kea will be prefaced by seismic activity and that erupted materials will resemble the thick and sticky lava flows of its more recent past (Lockwood 2000).

2.1.1.3 Topography

Topography is the analysis and description of ground surface features of a geographic area, including the relief and contours of the landscape and any unique attributes found across it. The following review provides a brief description of the topography of the upper slopes and summit area of Mauna Kea and, to a lesser extent, of Hale Pōhaku.

Fluvial processes driving surface erosion of the mountain are relatively minor across the landscape, due in part to minimal precipitation and the porous nature of much of its surface (see Section 2.1.1.4.3). The gulches that have eroded into the mountain slopes are the result of a process initiated by melting glaciers (see Section 2.1.1.4.2). Wind as an agent of erosion and as the carrier of smaller-sized volcanic ejecta has also played a small role in creating the topography (see Section 2.1.1.4.4).

Relief: The mountain slopes from 9,000 – 12,900 ft (2,743 – 3,931 m) around Mauna Kea range from 5 degrees to 20 degrees, and average approximately 15 degrees, as derived through 10-meter digital elevation modeling. The summit area, which includes elevations from 12,900 ft (3,931 m) to the tops of the highest cinder cone, encompasses a large, nearly flat plateau of remnant lava flows that were subsequently sculpted by glaciers. Numerous cinder cones dot this upper section of the mountain.

Approximately 23 cinder cones of various sizes jut up above the upper reaches of the mountain and dominate the summit landscape (Wolfe et al. 1997) (see Figure 2.1-6). Pu'u Hau'oki, Pu'u Kea, Pu'u Wēkiu, Pu'u Hau Kea, Pu'u Poli'ahu, Pu'u Waiau, Pu'u Pōhaku, and Pu'u Lilinoe all lie within the summit area of MKSR; while others including Pu'u Keonehehe'e, Pu'u Makanaka, Pu'u Poepoe, and Pu'u Māhoe are at slightly lower elevations. The largest cone, Pu'u Makanaka has a basal diameter greater than 4,000 ft (1,219 m) and is more than 600 ft (183 m) high (Macdonald et al. 1983). Most of the cones are between 656 – 1,969 ft (200 – 600 m) wide and 98 – 328 ft high (30 –100 m) (Porter 1972b). Cinder cones typically have steep slopes, averaging approximately 25–27 degrees along both their outer and inner faces (Porter 1972b). Between the cinder cones are relatively gently sloped plateaus of primarily Laupāhoehoe 'a'ā lavas. While it is clear that in some instances the lavas flowed from either the cone's base or around the cone, many of the cones appear to 'sit' on top of these plateau flow units, having been deposited during later, explosive events. Glacial till, as well as both terminal and lateral moraines from the three glaciers that were present across the summit area are visible along Mauna Kea's flanks, delimiting the furthest extent of the glacial advances (see Section 2.1.1.4.2).[3]

Mauna Kea's topography can be further understood by considering the summit landscape as four wedges or pie-shaped pieces that share a common apex located roughly at the center of the MKSR, on Pu'u Wēkiu (see Figure 2.1-7).

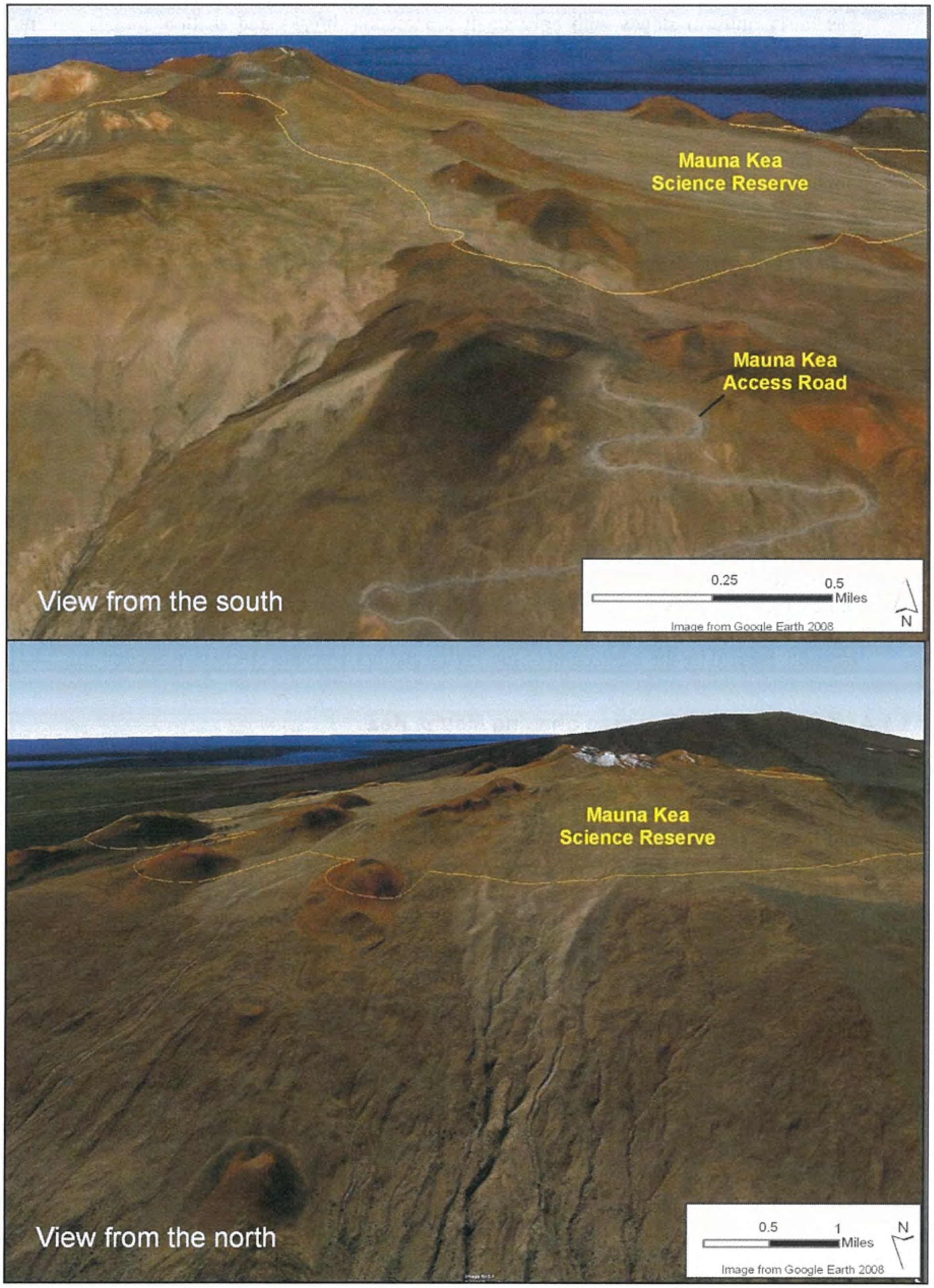
[3] *Moraine* is any deposit consolidated or unconsolidated, that is made up of various materials displaced by a glacier and deposited together within a fairly discrete area usually parallel (lateral) to the direction of or at the end (terminal) of the glaciers movement. *Till* is any deposit, transported via the glacier and placed along broad areas either adjacent to or at the toe of the glacier, but predominantly the latter. Till is usually a component of moraines.

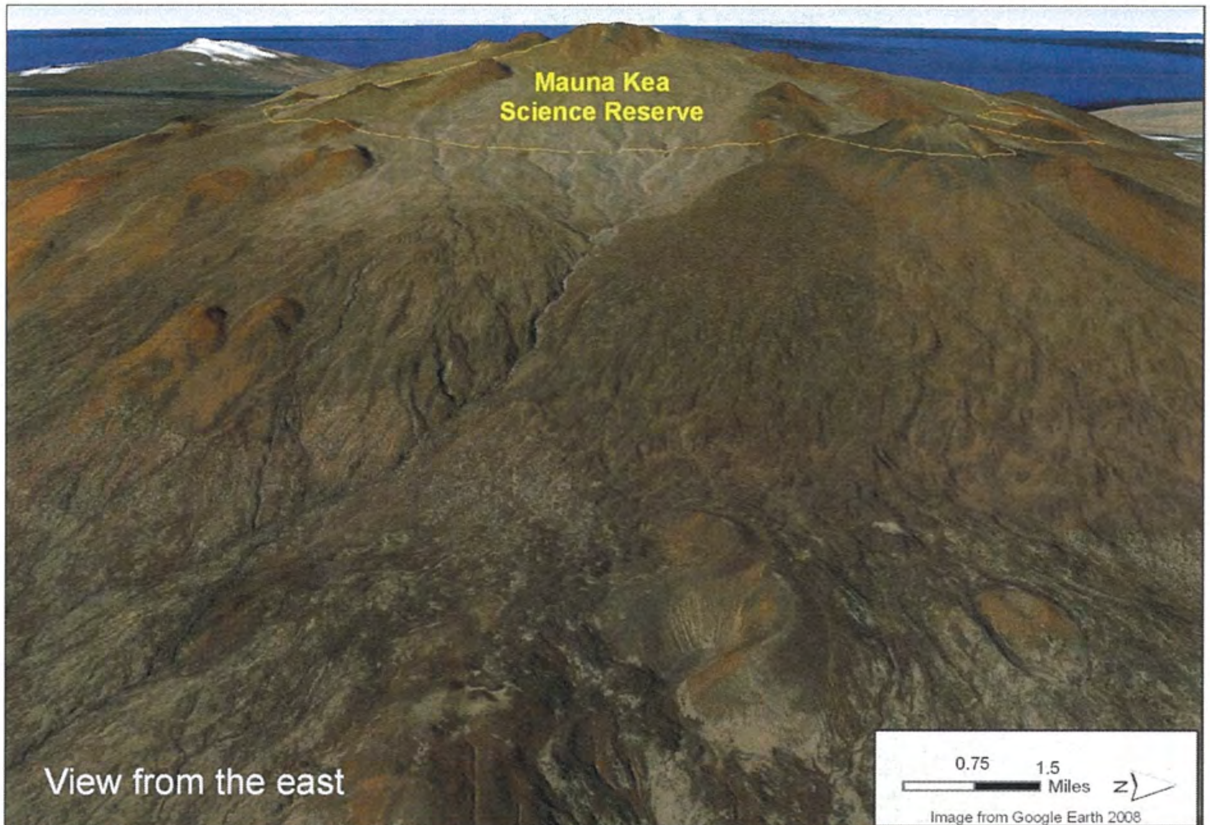
- The first piece encompasses the area between 290 degrees and 20 degrees along the arc of the MKSR boundary. It contains the area commonly referred to as the northern plateau. The plateau has fairly uniform slopes with only small topographic breaks and shallow gullies cut into its surface. Within this area, the elevation line of approximately 12,900 ft (3,931 m) marks a division in surface materials, with primarily till below the line and lava flows and cinders above. The entire surface is rocky and rough, with the primary difference in the surface materials being the size and shape of the rocks.
- The second piece includes the area from 20 degrees to 70 degrees along the arc of the MKSR boundary. This area is dominated by cinder cones aligned from the northeast to southwest. Slopes are steep on the cones and moderately sloped between them. Between the cones, the surface is predominately till, with some larger lava pieces around the bases of the cones. As on the northern plateau area, there is only minor incision of gullies into the land surface.
- The third piece encompasses the area from 70 degrees to 150 degrees along the arc of the MKSR boundary. The slopes and ground cover in this area are relatively uniform, with the latter being dominated by till. There are only moderate gullies cut into the surface, and gulches that become well defined are further downslope, below the MKSR boundary. Several of these downslope gulches fall within the large Wailuku watershed, which extends to the coast near Hilo.
- The fourth piece falls along the arc between 150 degrees and 290 degrees, and includes both NAR parcels. Cinder cones fall along margins of this area, and as a result, slopes are steep on the cones with surfaces dominated by cinder and lava flows around the bases. The western portions of this arc are dominated by lava flows, with rough ʻaʻā covering most of the surface. Surfaces range from rough, broken areas with large debris to smooth areas with small particles, due in part to glaciers scraping over the lava. The area is unique, in part because of the presence of glacial moraines that were deposited along the sides and at the terminal positions of the glaciers. This piece contains the most defined drainage network in the summit area, Pōhakuloa Gulch. The wedge-shaped Mauna Kea Ice Age NAR parcel contains hundreds of scattered outcrops of hawaiite formed by the interaction of glacial ice and hot volcanic ejecta (see Section 2.1.1.4.1).

2.1.1.4 Geomorphic Processes Shaping Mauna Kea

A component of geology, geomorphology is the study of landscape shapes and the processes that form them. Five geomorphic processes created Mauna Kea's surface features: volcanism, glaciation, water, wind, and weather. The most important of these are volcanism, glaciation, and the interaction of the two some 10,000 years ago. This interaction resulted in the deposition of buried ice sheets and fine ash layers that may affect ground water transmission and perhaps, to a lesser extent, supply. The lavas associated with the older shield stage, which compose the bulk of Mauna Kea, are the foundation on top of which the younger, post-shield eruptions and other geomorphic processes acted. This section describes the processes and the resulting geologic features. Their locations across the summit are depicted in Figure 2.1-8.

Figure 2.1-6. Summit Cinder Cones (four views)




Mauna Kea
Science Reserve
View from the east
0.75
1.5
Miles
Image from Google Earth 2008

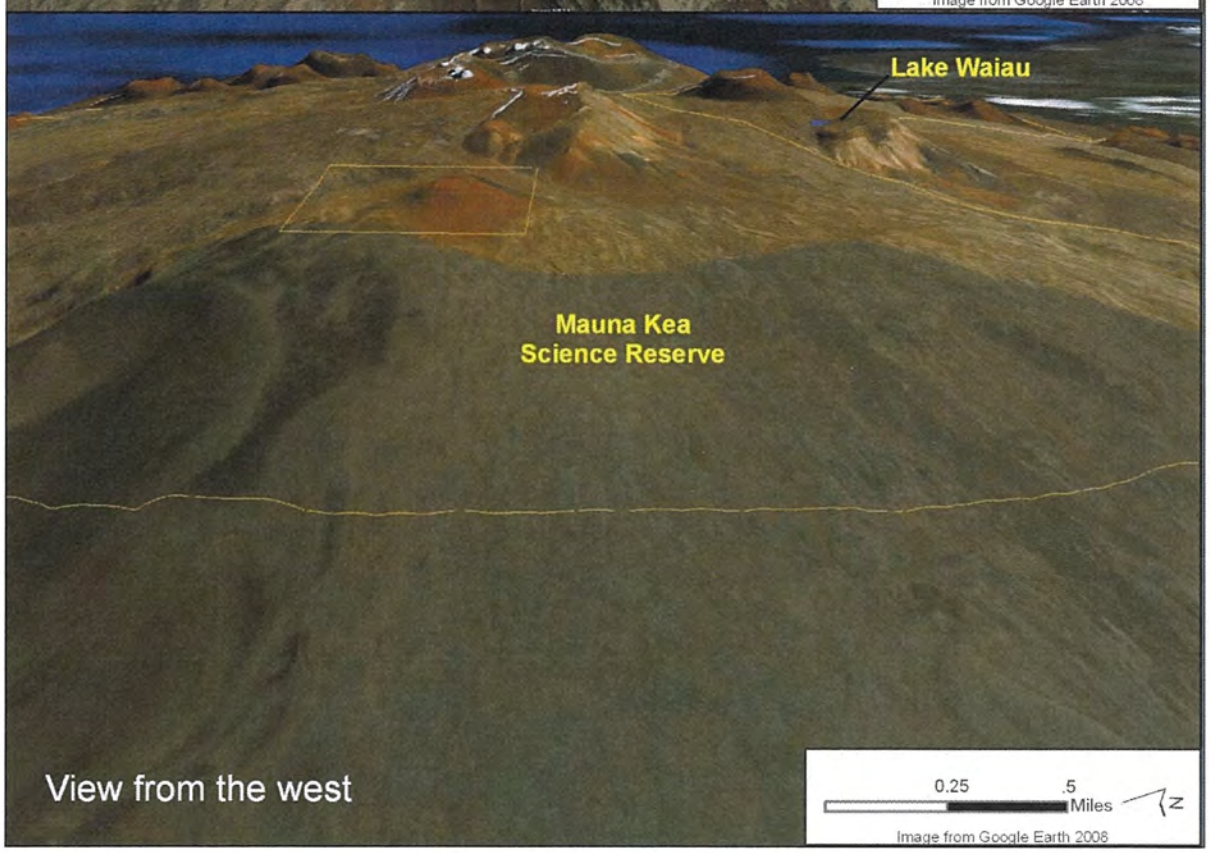
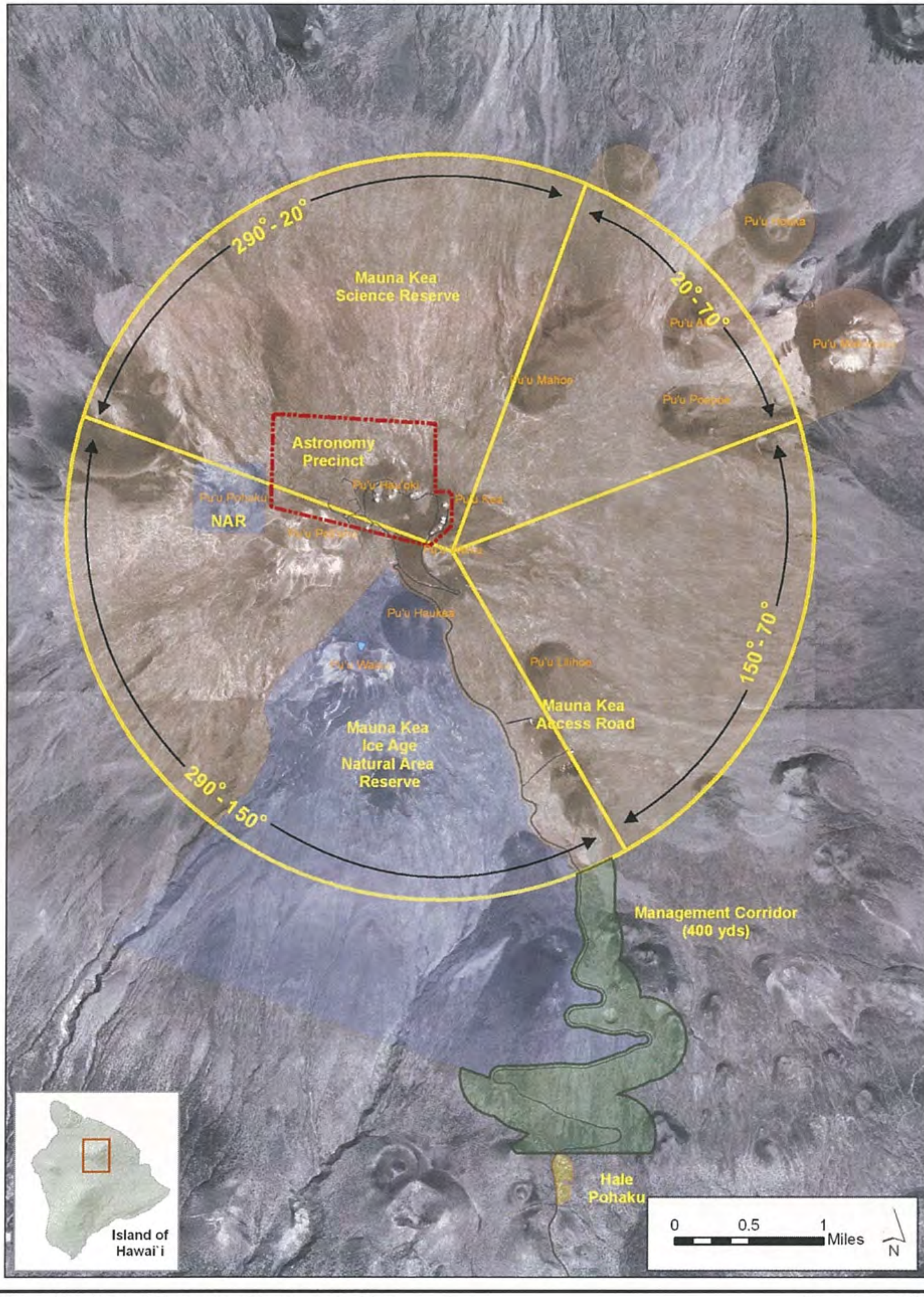

Lake Waiau
Mauna Kea
Science Reserve
View from the west
0.25
.5
Miles
Image from Google Earth 2008

Figure 2.1-7. Mauna Kea Topography



2.1.1.4.1 Volcanism

Significant geomorphic processes of volcanism include mountain swelling, eruptive events, and the eruption of lavas and ejection of explosive debris from the volcano, which in turn re-shape the landscape. The overall shape and mass of Mauna Kea is the result of the emplacement of significant volumes of lava from a series of volcanic eruptions. As new flows covered older flows, the mountain grew higher and broader. The morphology of the upper flanks and summit area of Mauna Kea was subsequently altered by the post-shield eruptions of the Laupāhoehoe Volcanics. The pu'u that dot the landscape resulted from the explosive eruptions that deposited tephra more or less symmetrically around the vents. This period of volcanism coincided with the presence of glaciers on the upper mountain. When the erupted lavas and ejected tephra met the glacial ice, they cooled quickly. The surfaces on which the ejecta were deposited were also affected, as were the rates of glacial melting and the amount of runoff. The combination of these factors resulted in the unique and varied geomorphic features of Mauna Kea, none of which would have been formed had the glaciers not been present (see Section 2.1.1.4.2).

Cinder Cones: Mauna Kea's late stage, post-shield eruptive activity, during both the Hāmākua Stage eruptions and the younger, Laupāhoehoe eruptions, resulted in the formation of hundreds of large cinder cones all across the volcano's summit and flanks (see Figure 2.1-6 and Figure 2.1-9). More than 300 large cinder cones dot the mountain (Porter 1972b). Wolfe and others (1997) mapped 23 cinder cones within the area of the MKSR, including three within the pie-shaped parcel and one in the square-shaped parcel of the Mauna Kea Ice Age NAR; Porter (1979b) shows 25.

Formation of cinder features is considered more common to a relatively brief explosive stage within the late post-shield than to other stages of Hawaiian volcanism (Macdonald et al. 1983; Juvik and Juvik 1998). It is suggested that the summit cones are composed of various combinations of 'a'ā lava flows and other types of pyroclastic debris, primarily cinder, much of which was dense enough to fall back near its source following eruption (Settle 1979). Denser products such as volcanic "bombs" and small boulders tumbled down the cones to litter lower slopes and the nearby plateau. Larger ejected pieces may have remained molten long enough to melt whatever they landed on, forming spots of localized welding (Macdonald et al. 1983; Wolfe and Morris 1996b). With the exception of the Hale Pōhaku lava flow, which lacks an associated cinder cone (pu'u), each eruptive event involved construction of such a cone and deposition of a blanket of coarse tephra followed by eruption of one or more lava flows. Cinder cones were built during the initial pyroclastic phase and were subsequently modified by lava issuing from their flanks or bases (Porter 1972a). In cases where lavas did not reach the surface localized dikes may have been produced, as is suggested by Macdonald et al. (1983). Should this be the case, these dikes, most likely not greater than 10 ft (3 m) thick, would still be present as part of the cone's inner structure (Macdonald et al. 1983).

Although the makeup and integrity of the outer layers of cinder cones are well understood, few investigations have been conducted to better understand the core lithology of individual cinder cones summit wide. Tephra, considered the primary constituent of cinder cones, usually ranges in size between "coarse cinder to fine ash" (Porter 1973b), with occasional larger pieces such as lava bombs and spatter (Porter 1972b; Macdonald et al. 1983). Investigations by Porter found hyaloclastites (quenched glass fragments formed through eruption in water or under ice) to be a principle component of both Pu'u Waiau and Pu'u Poli'ahu (Porter 1979b, 2005). In addition, subsurface investigations during construction on Pu'u Hau'oki revealed deposits of cinder at least 130 ft (40 m) below the surface (University of Hawaii Institute for Astronomy 2002). This gives the impression that for at least some cones, a large portion of the volume may be composed of only light-weight pyroclastic material and not lava flows.

Figure 2.1-8. Unique Geologic Features

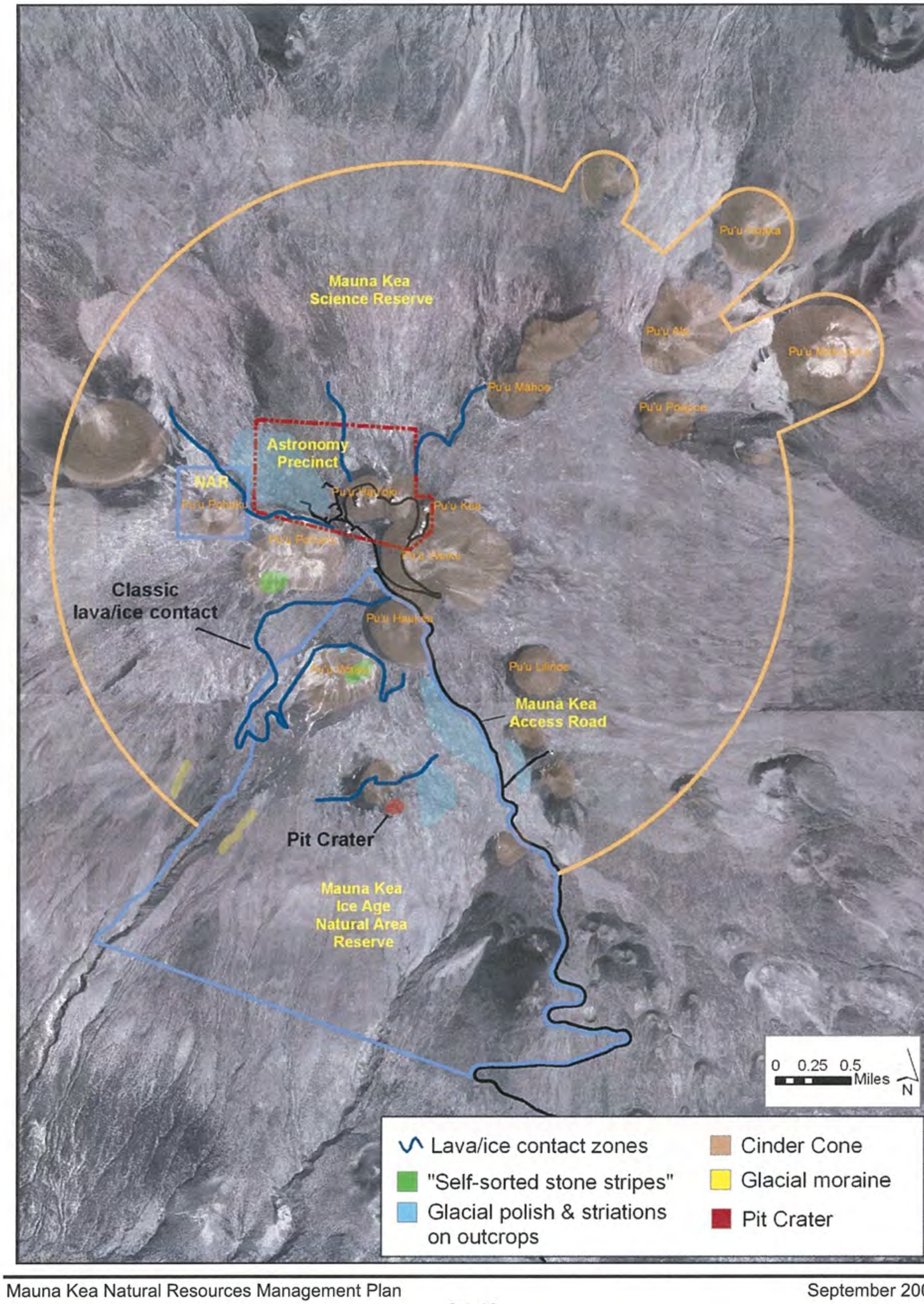


Figure 2.1-9. Mauna Kea Cinder Cones

Raw Adze (Hawaiite) Outcrops: Outcrops of hawaiite, the dense and highly prized tool-making material of the Mauna Kea adze quarries, were formed when the volcano erupted while covered with one of three glaciers known to have occupied the summit during the Pleistocene, approximately 70,000 to 150,000 years ago (Porter 1979a; Sherrod et al. 2007). These outcrops were formed when lava was quickly cooled by surrounding glacial ice, forming a dense, fine-grained material ideally suited for stone work. This cooling process also influenced the formation of the "widely spaced intersecting joint planes" (Cleghorn 1985) that made the rock well suited to mining and the subsequent production of tools. McCoy attributes the large mass of rejected rock fragments to what has been defined as 'rock shock,' which "occurs when a blow directed at one side of the piece dislodges a chunk from the opposite side" due to imperfections in the rock (McCoy 1977).

Stretching between elevations of 8,600 – 11,130 ft (2,622 – 3,393 m) (McCoy 1977; Bayman and Nakamura 2001), there are hundreds of outcrops, not continuous, and not all outcroppings are of similar adze-making quality. However, these hawaiite outcrops and, specifically the outcrop making up the Mauna Kea adze quarry (Keanakako'i) within the Mauna Kea Ice Age NAR, are believed to be the largest in the Pacific region to produce material of such high-quality (Bayman and Nakamura 2001).[4] It has been suggested that because of this quality, Mauna Kea adze material was highly sought after locally, and may even have reached other areas of Polynesia as an item of trade (Lane 1956; Cleghorn 1985).

[4] Based on new chemical analysis of these rock outcroppings, it has been proposed that instead of belonging to the later Laupāhoehoe Volcanics, and thus being hawaiite rock, the rocks composing the quarries are actually of early post-shield origin and belong within the Hāmākua basalts (Wolfe et al. 1997).

Pit Craters: Pit craters are uncommon on Mauna Kea; one of the few is located south of Pu'u Ko'oko'olau, within the Mauna Kea Ice Age NAR (Lockwood 2000). Macdonald et al. (1983) suggest that pit craters typically result from a sudden decrease in magma supply, which permits subsidence within a localized area. In this case, the unnamed pit crater may have been created when material pushing up that region was diverted and erupted from another location (Macdonald et al. 1983). There is also evidence to suggest that the pit crater was not eroded or pushed away by glaciers, but because the Mākanaka glacier filled it with ice, protecting it so that it was not filled by glacially transported material, the pit crater was only gently scoured upon the glacier's final dieback (Lockwood 2000).

2.1.1.4.2 Glacial Processes

Probably the most recent and significant naturally occurring geomorphic contributor to alteration of the summit landscape has been the series of glacial events that occurred between approximately 180,000 and 13,000 years ago (Porter 1979a, 2005; Sherrod et al. 2007). Originally thought to be the only incidence of Hawaiian glaciation (Porter 1975; Wolfe et al. 1997), it has more recently been suggested that starting approximately 800,000 years ago, ice also capped Maui's Haleakalā volcano (10,000 ft [3,055 m] elevation) (Moore et al. 1993; Porter 2005).

The summit of Mauna Kea was covered with glacial ice during three periods; the sedimentary deposits left behind are termed "glacial members" (Sherrod et al. 2007). The Pōhakuloa Glacial Member is the oldest of the three, believed to have begun forming approximately 100,000–200,000 years ago (Porter 2005). Porter (2005) notes that dates for the older members are potentially much less accurate, due to a low potassium content within the material used for analysis. The Waihu Glacial drift, also difficult to date accurately, is believed to have developed around 70,000–150,000 years ago (Porter 2005) and is the second oldest member.

The Mākanaka Glacial Member, which occurred between 31,000 and 18,000 years ago, is the youngest (Porter 1979a, 2005; Sherrod et al. 2007). The Mākanaka glacier is thought to have covered 27 mi^2 (70 km^2) of the Mauna Kea summit, with the exception of a few high cinder cones that projected above the ice as 'nunataks' (glacial kīpuka).[5] With ice sheets up to 400 ft (122 m) thick in some areas, the volume was estimated to be 1.2 mi^3 (5 km^3) (Porter 1979a; Porter 1987). The location and extent of remnant glacial sediment suggests that at some point, ice extended as low as 9,842 ft (3,000 m) (Porter 1979a; Walker 1990; Porter 2005). Evidence of these glacial events can be seen in various forms and at different scales throughout the MKSR and within the neighboring Mauna Kea Ice Age NAR. The following features and rock deposits provide evidence for the glacial period.

Till and moraines: During their expansion and retreat, glaciers slowly eroded large amounts of lava and tephra from their upper reaches and transported this material down slope. Most of this eroded debris was deposited at the bases of the glaciers as broad expanses of till stretching over acres of land around the summit and marking the extent of the glacier's advance (Wentworth 1935; Porter 2005). Till blankets much of Mauna Kea's summit above 11,000 ft (3,353 m), while some of the till deposits are found as low as 9,842 ft (3,000 m) (Porter 1979a) and are as thick as 130 ft (40 m) (Wolfe et al. 1997). Till forms the entire eastern flank of Mauna Kea from 11,000 ft (3,353 m) to the base of Pu'u Wēkiu and is well-preserved along Pōhakuloa Gulch, at the western boundary of the Mauna Kea Ice Age NAR. Additional

[5] In this context, a nunutak is an exposed area of a cinder cone not covered with ice or snow within a glacier.

evidence of this process can be seen in the terminal and lateral moraines visible in the NAR parcels (see Figure 2.1-10).[6]

Glacially polished rock surfaces: Glacially polished lava outcrops are found throughout the MKSR and Mauna Kea Ice Age NAR. Marks on rock outcrops, such as ground-in striations and "chatter marks" (fine-scaled curved cracks), as well as smooth-polished rock, tell of the immense weight and force of the ice sheets as they moved across the summit plateau (Macdonald et al. 1983; Lockwood 2000). Additional evidence of glacial movement includes the presence of "erratics," stones transported by moving glaciers and deposited far from their point of origin. Especially well-preserved examples of glacial polish and related features are found along both sides of the summit access road, between 12,000 and 12,800 ft (3,658 and 3,901 m) and on the lava flow underlying the Astronomy Precinct, north of Pu'u Poli'ahu (Lockwood 2000).

Figure 2.1-10. Glacial Till and Moraines

From (Wolfe et al. 1997)

Lava and ice contact zones: Evidence to support volcanic activity and subsequent interaction of lava and glacial ice has been documented at several summit locations within the MKSR and in the Mauna Kea Ice Age NAR (Porter et al. 1977; Wolfe et al. 1997). As thick glaciers covered the mountaintop, eruptions from below the ice forced some of the lava to travel inside "melt caves at the bases of glacial ice" (Lockwood 2000). The result of at least some of these events was fine-grained flow margins where lava was in direct contact with glacier ice. The margins of one of these sub-glacial lava flows bounds the western side of the Astronomy Precinct, north of Pu'u Poli'ahu (Lockwood 2000), while another is

[6] It is interesting to note that features such as U-shape valleys, or cirques, features characteristic of montane landscapes formed under the influence of glaciers are not present on Mauna Kea. It is likely that the moderate slopes of the shield were not conducive to creating these features.

responsible for the fine-grained adze material found within the Mauna Kea Adze Quarry (Bayman and Nakamura 2001; Bayman 2004). Many of the deposits and structures created by these sub-glacial eruptive events are found only in the submarine environment, where lava is in direct contact with water; they include large pillow lavas, gas spiracles, and hyaloclastic (quenched glass) deposits (Lockwood 2000). Similar lava-ice hydrothermal events have also been associated with the alteration of much of the rock at Pu'u Waiau and Pu'u Poli'ahu (Wolfe et al. 1997).

Hydrologic features: Waikahalulu Gulch and Pōhakuloa Gulch, along the south-southwestern flank, are thought to have been incised into the mountain flanks by glacial melt-water laden with moraine debris draining off the summit (Macdonald et al. 1983; Lockwood 2000; Porter 2005). These melt waters are also thought to be responsible for first filling Lake Waiau (Sherrod et al. 2007).

Periglacial processes: Although Mauna Kea is situated within the tropics, the trade wind inversion caps the orographic and convective rise of clouds, at approximately 7,000 ft (2,133 m), resulting in a dry and cool climate nearly year round on the upper slopes and summit area (see Section 2.1.4). This climatic pattern places significant controls on the rate of biogeochemical process across the upper reaches of the mountain. The climate slows the rate of soil development, including the weathering of rocks, and functions to preserve abiotic features as opposed to causing their breakdown. Some of the features that are directly or indirectly linked to the weather patterns of Mauna Kea are presented below.

Sorted Stones: Found on the inner rim of Pu'u Waiau and on the southwestern slopes of Pu'u Poli'ahu are stones neatly sorted into parallel lines that follow the in-situ slope (Lockwood 2000) (see Figure 2.1-8). During specific temperature regimes, particulates of ash and pebble-sized materials in the groundcover are systematically separated as freeze and thaw events capture and release the particles (Noguchi et al. 1987). Freezing events form small pedestals underneath the grains at night; as temperatures increase with the onset of morning, the ice pedestals melt and the larger pieces are slowly moved down-hill by gravity (Werner and Hallet 1993). A similar process is seen at Haleakalā, on Maui (Noguchi et al. 1987).

Permafrost: Evidence for the presence of permafrost within two summit crater cones (including Pu'u Wēkiu) was first identified by Woodcock and Furumoto in 1969 (Woodcock et al. 1970). The largest patch is approximately 98 ft (30 m) wide and 33 ft (10 m) thick and has inundated a matrix of boulders, cinder, and ash found at the base of the south slope of the Pu'u Wēkiu crater (Woodcock et al. 1970). The patch was found to persist year-round, with only minimal melting in the initial 9.8 ft (3 m) subsurface layers and almost no melting in the deeper layers over a four year period (Woodcock et al. 1970). The second patch was found on the southeast rim of Pu'u Hau Kea (Woodcock et al. 1970). Despite the fact that the ambient air temperature is often far above freezing, it is believed that the permafrost formed due to a combination of very high evaporation rates, low angle of sunlight and presence of cool air trapped at the bottom of the cinder cone, directly above the ground cover at these locations (Woodcock 1974). Woodcock further suggests that while no melting or sublimation is visible on the surface, melting is most likely occurring at the lower boundary (Woodcock 1974). This melting is possibly due to a thermal disequilibrium between the cone surface and its core (Woodcock and Friedman 1980; Woodcock 1987). Isotope analysis of the permafrost has disproved previous suppositions that melt water from permafrost could be a contributor to seep water surfacing at lower elevation springs (Arvidson 2002; Ehlmann et al. 2005).

Nieve Penitentes: Not a common occurrence, nieve penitentes (also called sunspikes or suncups) have been spotted for brief periods of time at Mauna Kea (Wentworth 1940; Cooper 2008) (see Figure 2.1-11). Individually oriented towards the noon-day sun and often several feet high (Wentworth 1939), these jagged pinnacles of snow are formed by a combination of differential melting and evaporation.

Figure 2.1-11. Nieve Penitentes
Photo courtesy of Andrew Cooper

2.1.1.4.3 Fluvial Processes

Fluvial processes occur as water moves across the landscape, removing and then redepositing materials it encounters. On Mauna Kea, water comes from rainfall, snow, and ice-melt. The size and volume of material that runoff can move are functions of the volume of water concentrated along the flow path and slope of the ground surface on which it is flowing. There have been few geomorphic studies of summit fluvial processes specifically at Mauna Kea. Much of the available information has been obtained indirectly, through the study of influencing factors such as springs and past glacial activity. Fluvial processes and erosion associated with fluvial weathering are infrequent and occur very slowly on Mauna Kea. This is believed to be due to an "excessively drained" surface according to the Natural Resources Conservation Service (NRCS) Soil Survey (Sato et al. 1973).

Rills and gullies: As described in Section 2.1.1.3, the summit area and upper flanks of the mountain are dissected by very small ephemeral rills and gullies, which are only moderately incised and do not have hydraulic geometries able to convey much water. Most of the channel incision begins at the base of the upper flanks, around 11,400 ft (3,500 m), coinciding with the point where the mountain's steeper side-slopes begin. Most rivulets and gullies that originate within the MKSR are in areas covered primarily by fine till, not in areas of lava and cinders, because the latter two materials are highly porous and more resistant to movement.

Gulches: Pōhakuloa and Waikahalulu Gulches are the most developed drainage channels along the upper slopes of the mountain. Unlike rills and gullies, they originate in higher elevation areas covered in lava and cinders. These channels likely formed following large-scale scouring of and movement of materials down the present-day gulch alignment by glaciers (see Section 2.1.1.4.2). Pōhakuloa Gulch stretches from the overflow mouth of Lake Waiau at 13,020 ft (3,970 m) to approximately 7,000 ft elevation (2,134 m). This gulch is the area within the upper slopes and summit region most affected by fluvial processes. On a very fine scale, Arvidson (2002) calculated that a layer of material about 0.04 in (1 mm) thick is being removed from the Pōhakuloa Gulch basin each year by fluvial erosion. An intermittent source of overland flow in Pōhakuloa Gulch is overflow water from Lake Waiau. The discharge occurs irregularly, only when the lake reaches its maximum depth of approximately 7.5 ft (2.3 m). Other large gulches on the mountain are most prominent at mid to lower elevations, with small channels extending up to approximately 10,000 ft (3,048 m). They include the Wailuku River and Ka'ula Gulch on the windward side and Kalōpā Gulch to the north.

Other surface evidence of fluvial processes in the MKSR and at Hale Pōhaku is found at locations where the surface material has been disturbed, such as near buildings, along roads and trails, and adjacent to parking areas. Compaction lowers porosities at these sites, where water collects and becomes runoff, instead of percolating into the ground. This can result in the formation of rills and gullies at points of high water momentum, such as at the mouths of culverts.

Lake Waiau: Immediately adjacent to the MKSR and located within the NAR property boundary is Lake Waiau (see Figure 2.1-12). Unique in its formation, evolution, and persistence, Lake Waiau is revered by many Hawaiians as the swimming pool created for the snow goddess Poli'ahu by her father, Kane (Melvin 1988). Lake Waiau is one of Hawai'i's few confined surface water bodies (Massey 1979), and at approximately 13,020 feet (3,968 m) in elevation, it is one of the highest alpine lakes in the United States (Laws and Woodcock 1981). The small, heart-shaped lake is only 300 ft (91 m) in diameter and approximately 7.5 ft (2.3 m) deep at capacity (Woodcock et al. 1966; Laws and Woodcock 1981). Using depth and surface area estimates made in 2000, the storage values in the lake have been computed to be 4.4 million gallons (16.7 million liters) at its maximum depth and 0.96 million gallons (3.6 million liters) at its minimum depth (Ebel 2000). Lake Waiau is believed to have been formed approximately 15,000 years ago, following the last glacial retreat (Woodcock 1974). The source of the lake's water now is thought to be precipitation, both as rainfall and snow melt, collected within the cone's approximately 35 ac (14.2 ha) watershed—and not from groundwater contained in relic layers of ice or permafrost within the ground as previously thought (Woodcock 1980; Ehlmann et al. 2005; Lippiatt 2005).

Subsurface water movement within the interior watershed of Pu'u Waiau is believed to maintain a persistent level of water at Lake Waiau (Woodcock and Groves 1969). The subsurface water flow is also thought to be the mechanism that transports and delivers at least some of the sediments found in the lake (Woodcock et al. 1966). Water percolating through the surface cinders most likely encounters an impermeable layer that routes the subsurface runoff into the lake basin.

The lake water is perched above an impermeable floor consisting of fine sediments of local[7] and possibly foreign[8] origin, and clays formed through hydrothermal alteration,[9] or all of these (Ugolini 1974; Fan

[7] Local refers to deposits of volcanic materials that were either discharged across the ground or dropped from the air.

[8] Foreign refers to deposits from sources outside the immediate area, likely transported to Mauna Kea by upper atmospheric winds.

[9] Hydrothermal alteration is geochemical process whereby material under goes morphologic and chemical changes due to the presence of water under super heated conditions. In the case of Lake Waiau it is hypothesized that this process resulted in an impervious layer that lines the crater and bed of the lake. See Section 2.1.2.3 for additional information.

1978; Woodcock 1980; Wolfe et al. 1997). It was surmised that seepage water originating from outside of Pu'u Waiau basin flows into and out of the lake primarily during periods of drought (Woodcock 1980; Laws and Woodcock 1981). Hypotheses of potential seepage from the lake were supported by a correlation between water surface level of Lake Waiau and discharge rates at lower-elevation seeps throughout the year; the correlation being stronger during periods of drought (Woodcock 1980). However, later studies, which used data and information of the earlier studies including those that presented the seepage hypotheses, all concluded that seepage into and out of the lake, if it is occurring at all, is at volumes that are insignificant with respect to the hydrology of the lake or springs located along Pōhakalua Gulch (Ebel 2000; Johnson 2001; Ehlmann et al. 2005).

Sediments found in Lake Waiau have been of interest across a spectrum of scientific inquiry. Formed at the bottom of the cone, most probably during the final retreat of Pleistocene glaciers (Woodcock et al. 1966), the lake is a natural collection site for sediment of various origins (Fan 1978). The lake has been cored several times (Woodcock et al. 1966; Laws and Woodcock 1981; Peng and King 1992). From cored samples a 3,600 year-old ash layer, at the time believed to record the most recent eruption, was identified (Woodcock et al. 1966). Core data indicate that the lake sediments are more than 25 ft (7.5 m) thick; the profile at 5 ft (1.5 m) below the surface contains coarse ash particles as large as one millimeter in diameter (Woodcock et al. 1966). There is also evidence of varving (discrete layers of sediment within the profile), which is thought to be caused by annual blue-green algal blooms (Woodcock et al. 1966; Arvidson 2002). Initial investigation of the sediments revealed that 5 percent of the total sediments found within the initial two meters were composed of coarse black ash layers, 10 percent was from finer ash layers, and that the remaining "85 percent of the sediments were found to be about 75 percent water, five percent combustible organic materials, and 20 percent clastic particles" (Woodcock et al. 1966). More detailed analysis of the particulates revealed the presence of plagioclase, montmorillonite clays, and quartz (the quartz is probably aeolian and foreign (from outside Hawai'i) in origin) (Fan 1978). Gas releases from deeper probes of the lake were identified as methane, believed to be the product of the decomposition of organic matter (Woodcock et al. 1966).

Seeps and streams: Ground water is the source of seeps and streams found between 8,500 and 11,000 ft (2,591 and 3,353 m), near Pōhakuloa and Waikahalulu gulches (Woodcock 1980; Arvidson 2002) (see Section 2.1.3.3). While the precise hydrologic connection of water from the summit to these seeps and streams is unknown, isotopic analysis of the water has shown it to be made up of "current summit rainfall and snow melt" (Arvidson 2002; Ehlmann et al. 2005), and it is not derived from remnant buried permafrost or ice, as previously suggested (Woodcock 1980). The similarity between isotopic analyses of the current summit rainfall and snowmelt and that of the seeps and streams feeding the two gulches means only that waters at both areas contain the same isotopes. It does not necessarily mean they are connected along subsurface flow-paths.

2.1.1.4.4 Aeolian Processes

Although there have been no investigations specific to quantifying the geomorphic effects of wind at Mauna Kea, wind is generally regarded as a dominant force for both erosion, and movement of regional particulates within the summit region.[10] It is also commonly accepted that wind increases the rate of evaporation of water from the mountain. During explosive volcanic eruptions at Mauna Kea winds carried significant volumes of silt-sized particles as far as several kilometers from the source vent (Porter 1973b), where they accumulated in some locations as deposits up to 10.5 ft thick (3.2 m) (Porter 1997a). At locations where material is available for dating, these deposits provide a good record of wind direction

[10] Aeolian, or eolian, is the process of erosion and deposition of particles by the wind.

patterns at the mountain, suggesting "that Mauna Kea has remained within the trade-wind belt since at least before the last glaciation" (Porter 1997a). It is clear that throughout this time the prevailing winds have altered the landscape, incising the ridges of cinder cones and reshaping surface features created by past events (Porter 1997a).

Figure 2.1-12: Lake Waiau, looking west

Analysis of core samples from Lake Waiau found an ash layer believed to be approximately 3,600 years old (Woodcock et al. 1966; Porter 1997a). Sedimentary quartz, a metaphoric mineral not found in Hawaiian basalts was identified in Lake Waiau core samples (Fan 1978), suggesting that some of the material was foreign, blown in probably by jet stream currents in the upper atmosphere (Woodcock et al. 1966; Sridhar et al. 1978; Woodcock 1980). Finer sediments from lower elevations may also make their way to the summit region, riding the same currents bringing up the food that sustains summit inhabitants such as the wēkiu bug (Howarth and Montgomery 1980). Aeolian deposition may also be responsible for the fine particles that have accumulated within holes on the surface; however, while these and similar aeolian transport and deposition mechanisms are common to many environments, no literature investigating these processes in the summit region of Mauna Kea was found. At elevations below 10,000 ft (3,048 m) other deposits of ash, sand, and loess (silt of aeolian derivation) are exposed along the flanks, some of which are overlain by younger flows of the Laupāhoehoe Volcanics (Wolfe et al. 1997).

2.1.1.5 Geological Studies and Surveys of Mauna Kea

Since the late 1800s, when J.D. Dana conducted seminal geomorphic analyses of the islands (Macdonald et al. 1983; Wolfe et al. 1997), the complex and anomalous backdrop of Mauna Kea's summit region has provided, and continues to provide, endless fascination for modern scientists. Since the time of Dana's work, numerous geological surveys have taken place around the islands. On the Island of Hawai'i, including Mauna Kea, these have ranged from studies assessing the slope stability of the cinder cones, to identifying the presence of a persistent layer of permafrost underground, to detailed analysis of lava chemistry.

Geologic History and Processes: The formation of Mauna Kea and its subsequent evolution have been the topic of studies and papers for many years. The first to consider the geology of Mauna Kea was R.A. Daly, in the early 1900s (Wolfe et al. 1997). The first complete geologic survey of the mountain was published by Stearns and Macdonald (1946). Besides a general mapping of the geology, their text describes local eruptive processes, volcanic events, differentiation of the various volcanic materials, and the physical properties of lava flows, cinder cones, ash deposits and other volcanic debris (Stearns and Macdonald 1946). Later work, to the extent that the existing technology allowed, has built upon this knowledge, further refining evidence of flow paths, eruptive sequencing, and chemical signatures (Furumoto et al. 1973; Clague 1974; Macdonald et al. 1983; Exley et al. 1986; Clague 1987; Winterer et al. 1989; Wright and Clague 1989; Moore et al. 1990; Moore and Clague 1992; Carson and Clague 1995; Clague 1996; Yang et al. 1999; Xu et al. 2005). The evolution of Mauna Kea and the development of the lavas characteristic of the growth stages of Hawaiian volcanoes have been described through the chemical signatures of surface rock; in particular, Frey (1990) concludes that lavas of the post-shield stage reflect movement away from the mantle plume. More recent isotope analysis also supports this conclusion (Eisele et al. 2003).

Rowland and Walker (1990) investigated discharge volumes and flow rates of magmas erupted from Hawaiian volcanoes, as well as the initial morphology of the volcanoes and how the magma preferentially turns into one or more of the various types of erupted materials. Clague and Dalrymple (1989) present a comprehensive and thorough summary that discusses, among other topics, Hawaiian-Emperor Chain mantle plume mechanics, associated mantle-plate dynamics, volcano formation, subsidence, and volcano propagation. One of the seminal Hawaiian volcanologists, Walker, offers additional support to the arguments offered in Rowland and Walker (1990) and Clague and Dalrymple (1989), summarizing subsidence and the formation of dikes and describing the formation processes and growth stages of Hawaiian volcanoes (Walker 1990).

Published by the USGS, the *Geologic Map of the Island of Hawai'i* provides a detailed description and map of the mountain's geology (Wolfe and Morris 1996a). It details and dates the specific volcanic and environmental processes that created the summit region of Mauna Kea. Similarly, the *Geologic Map of the State of Hawai'i,* also published by USGS, summarizes the geology of the entire state, using the results of the most recent chemical analyses (Sherrod et al. 2007). Contributions to the body of knowledge of Mauna Kea lavas continue through the on-going analysis and research of drill cores obtained through the Hawai'i Scientific Drilling Project.[11] Analyses of the extracted cores have permitted identification of discrete sequences of buried lava-flow boundaries, lava chemical signatures, and associated environmental conditions at time of eruption (Alt 1993; Baker et al. 1994; Beeson et al. 1996; Hofmann and Jochum 1996; Abouchami and Hofmann 2000; Moore 2001; Feigenson et al. 2003). Moore and Clague (1992), under constraints similar to those of other investigations, present volcano ages derived from comparisons of depth and chemical signatures of subaqueous lavas and submerged coral reefs. Their investigations suggest that Mauna Kea completed its shield building stage approximately 250,000 – 300,000 years before present (Wolfe et al. 1997; Sherrod et al. 2007). Wolfe et al. (1997) present other

[11] The purpose of the Hawaii Scientific Drilling Project is to better understand the geochemical and geophysical processes that produced the Hawaiian Islands; to explore the deep structure of a Hawaiian volcano; and to characterize ground water flow and geochemistry inside an ocean-island volcano. The project has drilled a continuously cored borehole to a total depth of 11,540 ft (3,500 m) adjacent to Hilo Bay that has recovered a nearly continuous stratigraphic record of Mauna Kea lava flows dating back to ~600,000 years before present. http://www.icdp-online.org/contenido/icdp/front_content.php?idcat=714

age data, and suggest a re-defining of the post-shield Hāmākua and Laupāhoehoe Volcanics. Specifically, this new paradigm affords several geological considerations, including the conclusion that much more Hāmākua series lava is visible at the summit than previously believed and that the lava used as quarry material was formed late in the Hāmākua series. The most detailed map of the geology on Mauna Kea to date was prepared by Wolfe et al. (1997).

Cinder Cones: Surveys of Mauna Kea's cinder cones (Porter 1972b, 1975; Settle 1979; Wood 1980) include both the summit and flank regions of the mountain and continue where predecessors Macdonald et al. (1983) left off, defining in even greater detail the numerous influences on the processes that created these structures. Of particular interest Porter (1972b), identified an association between cone height and width, defining a ratio between the two that was later found valid for cinder cones world-wide. Although Porter (1972b) suggests that in locations adjacent to cinder cones, low-density, porous tephra can account for 20–50% of the total material, observations by Wood (1980) of more recent cinder cone development elsewhere (but under conditions similar to those understood to have occurred at Mauna Kea), suggest that while eruptive attributes create a cone feature dominated by cinder, it is actually lava that accounts for most of the material extruded at the cone site. Both Porter (1972b) and Wood (1980) have also presented arguments suggesting a relationship between the distance to the magma source and the distance between cones.

Chemical: Observations of the nature of volcanic materials and investigations into their chemical make-up have been the subject of scientific inquiry since the late 1800s. In his seminal Hawaiian Islands petrology series, Washington (1923) summarized the current scientific knowledge on the chemical attributes and signatures of the igneous material of the Hawaiian Islands. Since then, the chemical analyses undertaken to describe the elemental constituents and chemical signatures of Hawaiian lavas are too numerous to detail; however, they have provided significant insight into the relationship between chemical signatures, magma evolution and material availability from the underlying mantle plume. The most recent contribution has been through the Hawai'i Scientific Drilling Project and associated research (Stopler et al. 1996; Sharp and Renne 2005).

Adze Quarries: Adze quarries at Mauna Kea are generally characterized by "mounds and surface scatters of stone debitage" (Cleghorn 1985) (see Section 2.1.1.4.1). The largest and best preserved of these lie within the Mauna Kea Adze Quarry (Keanakāko'i), which stretches between 8,600 and 11,130 ft in elevation (2,622 and 3,393 m) (McCoy 1977; Bayman and Nakamura 2001). Field surveys, most notably by Porter (1979b), identified the material mined for adze production as remnants of a subglacial eruption that occurred approximately 170,000 years ago. McCoy summarizes early surveys of the adze quarries (from the 1880's and later) (McCoy 1977; McCoy 1984) and has been involved in on-going field surveys (McCoy et al. 2008).

Permafrost: A patch of permafrost at least 33 ft thick (10 m) was discovered in 1969 at the bottom of the southern slope of Pu'u Wēkiu (Woodcock et al. 1970; Woodcock 1974) (see Section 2.1.1.4.2). Subsequent surveys attempt to explain the circumstances surrounding the presence of the permafrost and the mechanisms that sustain buried ice and permafrost layers within the volcanic substrate (Woodcock et al. 1970; Woodcock 1974, 1987).

Glacial Activity: Evidence of glacial activity on the summit of Mauna Kea was first recognized by Daly in 1909 (Porter 1975) and first documented by Gregory and Wentworth (1937). Since then, surveys have been conducted by Powers and Wentworth (1941), Stearns (1945), and most notably by Porter (1973a, 1975; Porter et al. 1977; 1979b, 1986; 1987; 2005). Through periods of waxing and waning, the glaciers are thought to have capped the summit for approximately 145,000 years, ending about 13,000 years ago (Dorn et al. 1991; Wolfe et al. 1997).

2.1.1.6 Threats to the Geology

For purposes of this discussion, the geology of Mauna Kea refers to the mountain flanks, shield silhouette, cinder cones, pit craters, and glacial evidence. Within the MKSR, most of the changes associated with the local geology are from one of the following types of physical disturbance: wind; the movement of ice, snow, and water; rare geologic occurrences like earthquakes and volcanic eruptions; and human activity. Natural processes that can alter geologic and morphologic features are not considered threats to geologic resources. For discussion purposes, the only threats to natural geologic features are those caused by human activities. Specific activities representing such threats include use of hiking trails to the point that they become incised into the ground; any activity that displaces or removes a significant amount of material (e.g., cinder ground cover); altering the existing structure or lithology of the subsurface; and vandalism of surface features such as rock outcroppings and cinder cones. These and other anthropogenic threats to the mountain's geology are discussed in Section 3.2.

Volcanic and Earthquake Hazards: While not all seismic events along the Hawaiian Archipelago have been associated with volcanic activity, most volcanic activity is associated with the occurrence of some degree of earth movement. Earthquakes related to volcanic activity are generally caused by magma movement and can be pre-cursors to eruptions; other earthquakes are due to structural weakness "at the base of volcanoes or within deep locations beneath the islands" (U. S. Geological Survey 1997a). Earthquakes in Hawaiʻi are considered to be difficult to predict. It is generally recognized however, that the Island of Hawaiʻi is one of the most seismically active areas in the United States and experiences magnitude 6 or higher events at approximately decadal intervals (Klein 1995; Klein and Wright 2000; Klein et al. 2001). Probabilistic seismic hazard maps for the Island of Hawaiʻi have been developed and indicate that the highest hazard is for the southeast coast with the second highest hazard location being the Kona coast (Klein et al. 2000). Potential hazards related to earthquakes at MKSR include puʻu slope-failure and landsliding, fracturing of the confining layers of Lake Waiau, and potential damage to manmade structures within the UH Management Areas.

Hale Pōhaku and Mauna Kea's summit region lie within Zone 7 of the USGS lava flow hazard map (U. S. Geological Survey 1997b). This zone is considered to have a low probability of coverage by lava flows outside of localized upwelling events, and there has been no recent evidence to support an eruption at Mauna Kea within the near future.

2.1.1.7 Geologic Resources Information Gaps

The following information gaps regarding the geology and physical landscape of the MKSR have been identified through review of the literature and consultation with local experts:

1. Subsurface Geology and Structure of Summit Cinder Cones
   Previous construction excavations and analysis of a few exploratory substrate borings have been analyzed and provided information that has led to some basic assumptions about the composition of the inner structure of the summit's cinder cones. The information has also shown that there can be gross dissimilarities between cones. More specific investigation into the subsurface stratigraphy within and underlying summit cinder features to learn about their individual physical composition and structural limitations will contribute to more effective management of infrastructure at the summit, for existing structures, potential structures, and for decommissioning activities. For example, with such increased understanding, buildings and other facilities can be

engineered to be placed underground, so they would be less visually intrusive. Data from subsurface cores also have the potential to provide information on the hydrology of the mountain's upper watershed, the nature of hydro-geologic systems, and how inputs from summit precipitation and snowmelt affect the hydrologic cycle.

2.1.2 Surface Features and Soils

From 9,000 ft (2,743 m) upward Mauna Kea is a dry environment with much of its surface covered with rock that has been moderately altered by biogeochemical reactions. Geological changes occur here at rates at either end of the spectrum: explosively fast and glacially slow. Due primarily to low rates of precipitation and a cool temperature regime, biogeochemical weathering of rocks is very slow and predominately mechanical in nature. This environmental setting is the primary reason why so much of the area does not contain soils, and why disturbances to surface features remain visible for long periods.

2.1.2.1 Ground Surface

Mauna Kea Science Reserve: The higher elevations of the MKSR have been classified as Very Stony Land or Cinder Land and are composed entirely of post-shield volcanic material.[12] A combination of coarse gravel to cobble-sized pieces of cinder and lava covers the ground surface of most of the summit area. Cinder is the dominant component of the cinder cones forming the summit and it is this debris that makes up the cones outer slopes (Porter 1972b; Wood 1980; Wolfe et al. 1997). Areas that were capped by lava flows at the summit plateau are relatively flat and dark grey to black in color, with a low albedo (surface reflectivity); ʻaʻā flows deposited before glaciers covered the summit area later lost their original craggy surfaces when glaciers that slid over them. Exposed outcrops of moraine and till from these glacial icecaps are composed of poorly sorted cobbles, rocks, and boulders (Wolfe et al. 1997). Rills and small gullies incising the flanks of Puʻu Poliʻahu, Puʻu Waiau, and other cones are indicative of a naturally altered layer that is less porous and more prone to erosion than cones that do not contain less porous layers of ash or other material (Wolfe et al. 1997).

Lava flow outcrops are scattered throughout the MKSR, poking out from layers of cinder, till, and a slowly increasing coating of finer particles as one descends the mountain. Many of these outcrop formations are the result of lava erupting under the icecaps of the glacial periods (see Section 2.1.1.4.2).

Hale Pōhaku and Mauna Kea Summit Access Road: The ground surface of the lower-elevation Hale Pōhaku facilities is covered with small particles that are several centimeters deep in some locations. The slopes of cinder cones in the vicinity of Hale Pōhaku are comprised of larger fragments than those of the summit and have been dusted with fine grained particles. The lowest lying areas are littered with cinder and small lava rocks.

Several trails at Hale Pōhaku and within the MKSR have been used frequently enough that they have been etched into the ground surface. Only four trails are monitored by rangers: the Lake Waiau trail, the Mountain trail, the trail up Puʻu Poliʻahu, and the Summit Trail (see Section 3.1.3.3). Any new trails created by visitors are covered up by Ranger staff as soon as they are observed. Very little original surface material remains on the more frequented trails, most having been crushed or kicked to the sides by hikers. During a site visit it was observed that trails are covered with a slippery layer of fine sediment, likely generated from the crushed cinder. In addition, hikers were seen walking in adjacent areas where footing is more stable, increasing the impact area of the trail.

[12] See information on soils from the Natural Resources Conservation Service at: http://www.hi.nrcs.usda.gov/soils.html.

Other areas of disturbed surface features include areas adjacent to the Summit Access Road and the drainage networks around Hale Pōhaku. Along the road, culvert inlets are often filled with coarse and fine sediment, while at culvert outlets it appears that over time water and sediment have slowly cut into the mountain, forming larger and larger gullies. Similar impacts are evident along the edges of the parking areas, on adjacent land.

2.1.2.2 Soils

The process of soil formation, or pedogenesis, involves the interaction of five variables: parent rock material, time, climatic conditions, presence of vegetation, and topography (Brady and Weil 2000). While any of these five can be a limiting factor in soil formation, in the summit region of Mauna Kea, three of the five are limiting factors: the dry climate, a general lack of vegetation, and the topography. Constituents of pedogenically (naturally) derived soils such as ash can be valuable stratigraphic markers of volcanic activity (Porter 1973b). Because they form over long periods, soils may also be valuable environmental indicators and chemical databases of the mountain's past. The following review focuses on the classification, locations and characteristics of the soils of Mauna Kea.

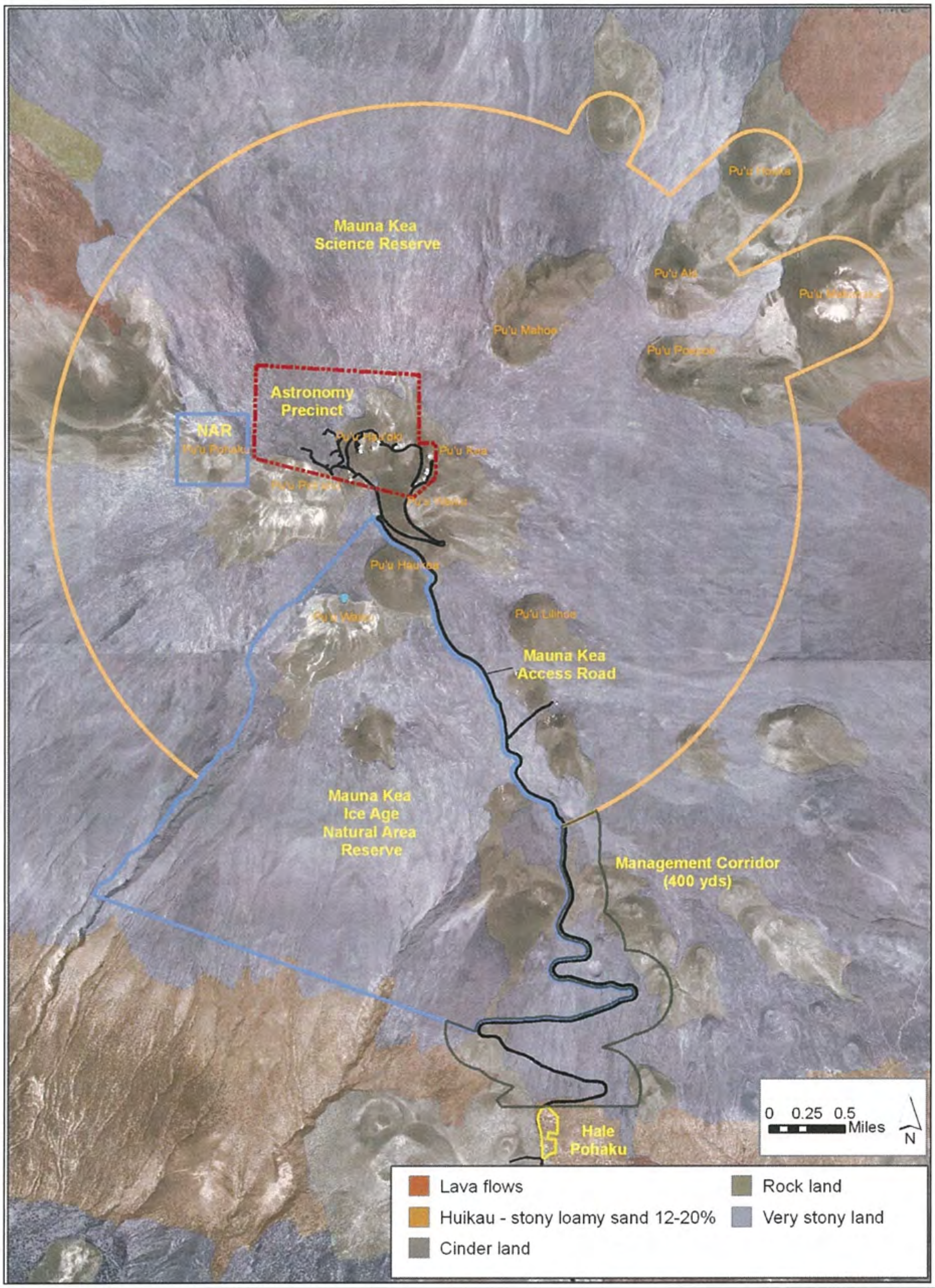
2.1.2.3 Soil Classification

The *Soil Survey of the Island of Hawaii, State of Hawaii*, published by the Department of Agriculture Natural Resources Conservation Service (NRCS), which houses the national soil survey, does not list any soils at the summit of Mauna Kea (Sato et al. 1973).[13] However, formations that may be considered soils, that have soil-like properties, or both, have been found within the summit region (see Figure 2.1-13). These pockets of soil-like material have been classified as very young Andisols-Aridisols (lava) and Andisols-Entisols due primarily to the volcanic ash, cinders, and lava constituents available to create a soil (Juvik and Juvik 1998; Hotchkiss et al. 2000).

Deposits of volcanic lavas, ash, glacial till, and other materials have been weathered in-situ, making them soil-like. A few of these formations found at the summit include the potentially hydrothermally altered subsurface layers within Pu'u Wēkiu and other cones (Ugolini 1974; Fan 1978), the lake sediments found at the bottom of Lake Waiau (Woodcock et al. 1966), and lower-elevation ash paleosols (soils formed on a past landscape) formed long ago, during long periods of volcanic rest (Porter 1997a; Sheldon 2006). Many of these have since been buried by more recent eruptions (Porter 1997a; Sheldon 2006). Contributions from aeolian sources are also likely, as are contributions from glaciers in the form of till (Ugolini 1974).

[13] See also: http://www.hi.nrcs.usda.gov/soils.html

Figure 2.1-13. Soils of Mauna Kea



Due perhaps to events associated with lava-ice interaction and subsequent hydrothermal alteration, as well as glacial conditions, Ugolini (1974) suggests that pedogenesis has occurred within the upper 6 in (15 cm) of a soil profile found within Pu'u Wēkiu. Below this depth, a clay-rich soil with secondary minerals is believed to have been altered in-situ, indicating that at some locations in the region processes related to soil formation are occurring within the subsurface (Ugolini 1974). Differences in texture and mineralogy observed at Pu'u Waiau and other sites on the north side of the summit may indicate a more advanced stage of alteration due to the presence of clays and "X-ray amorphous colloids over crystalline material," both of which represent alteration by hydrothermal processes (Ugolini 1974). The material of these and other cones is much more susceptible to weathering, its reduced permeability being responsible for the retention of water within Pu'u Waiau and the persistence of Lake Waiau (Woodcock 1980; Wolfe et al. 1997). It has been suggested that the less porous substrate was formed by explosions caused by lava-ice interaction in an at least partially submerged glacial environment (Ugolini 1974; Porter 1979a; Woodcock 1980). A differing theory suggests that alteration of the substrate occurred not from lava-ice interaction, but through the effect of hot, sulfur-bearing gasses and hot water or steam percolating through the cones (Wolfe et al. 1997). Hydrothermal alteration of the substrate at these and other neighboring sites was also noted by Ugolini (1974) and Fan (1978). Paleosols are mentioned within the literature, and Porter (1997a) has conducted an extensive analysis of the late Pleistocene aeolian sediments. However, because soils that may have developed within the summit region have since been covered by flows, most exposed paleosols are not within the MKSR but at lower elevation construction sites and stream outcroppings.

Two buried soils (Humuula and Hookomo) separated by three distinct tephra layers were identified by Porter (1973b) just below Hale Pōhaku, around 9,186 ft (2,800 m). Other paleosols found by Porter, also at lower elevations, were considered "developed," formed within dark-yellowish-brown loess and having soil horizons 8–12 in thick (20–30 cm) (Porter 1997a).

Below an elevation of 9,000 ft (2,743 m), three soil series have been identified by the NRCS: the Huikau Series (6,000 – 9,000 ft (1,829 – 2,743 m)), the Apakuie Series (5,500 – 8,000 ft (1,676 – 2,438 m)), and the Hanipoe Series (5,000 – 6,500 ft (1,524 – 1,981 m)) elevation (Sato et al. 1973; Wolfe and Morris 1996a). Two soils have been identified within these soil series; Andisols-Aridisols and Andisols-Entisols (Juvik and Juvik 1998). All three soil series are moderately to excessively well drained and consist of very fine to loamy sands on slopes that vary between gentle, at the lower elevations, to steeper slopes, at 9,000 ft (2,743 m) (Sato et al. 1973). As described within the NRCS soil survey, the lower Hanipoe soils have moderately rapid permeability with minimum erosion hazard and support a wide diversity of vegetation. Further upslope the Apakuie soils are more permeable and thus have a smaller erosion hazard. Huikau soils of the higher elevations are very permeable and due to stronger winds associated with these elevations have a high capacity for aeolian erosion.

2.1.2.4 Soil Surveys

The NRCS soil survey of the Island of Hawai'i is undergoing a complete update, which is expected to be completed by 2011 (Jasper 2008). This survey is public, and information is available through the NRCS website.[14] Other relevant work includes soil nutrient studies and site investigations that helped to identify ten habitat types based upon soil profiles found during work on Mauna Kea (Balakrishinan and Mueller-Dombois 1983). Additionally, the known limitations for soil development within the summit region were used to help create models that may lead to a better understanding of past ecosystem development and in modeling potential environmental conditions under a changing climate regime (Hotchkiss et al. 2000).

[14] http://www.hi.nrcs.usda.gov/technical/bi_index_map.html

2.1.2.5 Threats to Surface Features and Soils

Threats to the existing soils and soil-like features of the UH Management Areas include the consistent displacement of particulates due to use of off-road areas by hikers and vehicles and any changes to the existing hydrogeology. While processes of erosion are natural occurrences, with increased human presence and associated increased use of the off-road areas comes a greater potential for the movement of materials through both natural and anthropogenic mechanisms. For example, as water is most likely one of the primary forces moving finer sediments downhill, any activity that alters existing hydrology will affect how much sediment is moved, how far it is moved, and the amount of impact the movement will have.

2.1.2.6 Soil Information Gaps

The following information gaps regarding the soils of the UH Management Areas have been identified through review of the literature:

1. Soil Components and Movement
   The NOAA Mauna Loa Observatory monitors air quality for a number of variables, one of which is the concentration of airborne particulates. Some of the aeolian debris found at the observatory, is dust originating in Asia and is seen every year (Barnes 2008). It is possible that some of this dust has been deposited in Lake Waiau and may change its chemistry and the composition of the sediment layer of its bottom. Other aeolian debris that gets suspended in the airshed and deposited across the region is likely fine materials generated from the exposed surfaces of Mauna Kea.

2.1.3 Hydrology

The following review focuses on the hydrology of Mauna Kea, including the various types of water inputs and their sources, surface and subsurface hydrologic pathways, water resources, and water quality.

2.1.3.1 Water Budget Analysis

A hydrologic cycle describes the movement of water on, above and below the earth's surface. To understand Mauna Kea's hydrologic cycle and effectively manage its components, it is necessary to know the spatial distribution of precipitation inputs. Spatial distribution is also needed to calculate a water budget analysis, which is a hydrologic assessment conducted to account for the inputs and losses and to identify flow paths and the fate of water in a given area. In general, a water budget considers inputs and losses. For Mauna Kea, inputs come in the form of precipitation and losses occur through infiltration, evapotranspiration, and sublimation.[15]

Primary water inputs to the hydrologic cycle of Mauna Kea are rainfall and snow, and to a lesser extent fog condensation (see Section 2.1.3).[16] Anecdotal evidence and published literature agree that water input from rain and snow varies from year to year and that the range can be considerable. Snow's contribution to the total precipitation of the upper slopes and summit area was found to be significant (Ehlmann et al. 2005).

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[15] Infiltration is the process by which water penetrates into the ground surface. A portion of the water is tied up in the soil and may be extracted by plant roots, and a portion flows deeper until it encounters the groundwater. Evapotranspiration is the process by which water enters the atmosphere by evaporation and plant transpiration. The process by which water in its solid phase is transformed directly to vapor phase without first passing through the liquid phase.

[16] On Mauna Kea, fog drip is associated with vegetated areas below 9,000 ft (2,743 m) and is not a contributing source of water for upper elevation watersheds(Arvidson 2002).

On Mauna Kea, above 9,000 ft (2,743 m), mean annual precipitation is low (see Section 2.1.4) and evaporation levels are high. Rates of pan evaporation[17] have been quantified by at least two researchers during the past 30 years, with estimates of 70 inches (178 cm) per year (Ekern and Chang 1985). Although the pan evaporation estimate is not the actual evaporation, its high value means that meteorological conditions of the summit area are conducive to evaporation and that water loss is significant. Since precipitation inputs are low and evaporation is high, the amount of water available for infiltration is likely small, both relative to input and in absolute terms. Although the amount of precipitation that infiltrates into the ground is unknown, it is generally accepted, and is reported by the NRCS, that infiltration rates in the summit region are high, and that during heavy precipitation events, water reaching the ground surface quickly infiltrates (see Section 2.1.2). The redistribution of snow across the mountain by wind is known to occur, which affects water distribution across the landscape, increasing it in areas favorable for snow deposition and decreasing it in wind-blown areas. The scarcity of vegetation means that very little rainfall is intercepted by vegetation or evaporated off leaves or other plant surfaces. However, many areas of the landscape have broken rocky surfaces that protrude above the ground, increasing overall surface area. These surfaces may trap and hold water, exposing it to evaporation.

2.1.3.2 Watersheds

A watershed is defined as an area where runoff generated across the landscape discharges at a common outlet. Eight State of Hawai'i delineated watersheds fall within the boundaries of the MKSR (see Figure 2.1-14). Three of the watersheds have only a few acres of their area in the MKSR. Most of the land within the MKSR falls within three watersheds: Pōhakuloa, along the southern flank; Wailuku, on the east side; and Kalopa, along the north. For all three of these watersheds, the water generated from the portion of their areas that falls within MKSR most probably constitutes only a small portion of their total water inputs, due largely to the low precipitation amounts on the upper slopes and summit area.

2.1.3.3 Surface Water

Rivers and Streams: According to the DLNR Commission on Water Resource Management (CWRM), the State agency that defines stream flow status, none of the streams in MKSR watersheds are perennial (having continuous flow all year). The Wailuku River is the only river whose numerous gulches extend along the upper flanks of Mauna Kea, and where these coalesce, down slope near the 10,000 ft elevation (3,048 m), stream flow is considered to be perennial.[18]

Lake Waiau: The only persistent surface water body at the summit is Lake Waiau, a small, heart-shaped feature having an average surface area of approximately 1.5 ac (0.6 ha) (Arvidson 2002; Menviel n.d.). Located at the bottom of Pu'u Waiau, the lake freezes almost entirely during colder times of the year and has never been known to dry up. Its depth varies between 1.6 ft (0.5 m) and 7.5 ft (2.3 m), at which point the water overflows and drains into Pōhakuloa Gulch from a low point along the lake's west side (Woodcock 1980; Menviel n.d.). An extensive discussion of the hydrology and geology of Lake Waiau is presented in Section 2.1.1.4.3. There are no other perennial surface water bodies within the MKSR.

Seeps and Springs: Three low-volume spring-seeps Hopukani, Waihu, and Liloe Springs are known to emanate from Mauna Kea's southwestern flank along Pōhakuloa Gulch within the Mauna Kea Forest Reserve, with other, smaller volume seeps found neighboring Waikahalulu Gulch (Arvidson 2002). While

[17] Pan evaporation (potential evaporation rate) is a measure of evaporation from a pan of water that is continually supplied with water. It is representative for open water bodies. Actual evaporation varies and is some fraction of the total precipitation value.

[18] Perennial/Significant Streams as defined by the CWRM, Hawaii Stream Assessment Project, 1993

the specific water sources of these springs are unknown, studies conducted by Woodcock (1980) using radioactive-isotope tritium indicated that the source water for Waihu Spring originated in relatively recent events and was probably not from relic permafrost or subsurface ice. Therefore precipitation and, possibly, Lake Waiau are believed to be the primary contributors to Waihu Spring, specifically, and perhaps other springs (Woodcock 1980). The hypothesis of Lake Waiau being the source for Waihu Spring is not supported by the conclusions of Ebel (2000) and Ehlmann et al. (2005) following their respective studies on the hydrology of the lake and the springs. Ehlmann concludes, on the basis of isotope ratios, that permafrost is not the source of water for Lake Waiau, while Ebel estimates that seepage from Lake Waiau contributes at most only 3 percent of the total flow volume of the springs. It may be that water is being transported along unknown, dense, subsurface lava flows, ash layers, or buried till, where it flows along the path of least resistance leading to a particular spring outlet. It is likely that the springs are fed by water infiltrating into the substrate from across the upslope watershed areas, percolating downward until it encounters a confining layer that directs flows towards the seeps and springs (see Section 2.1.1.4.3).

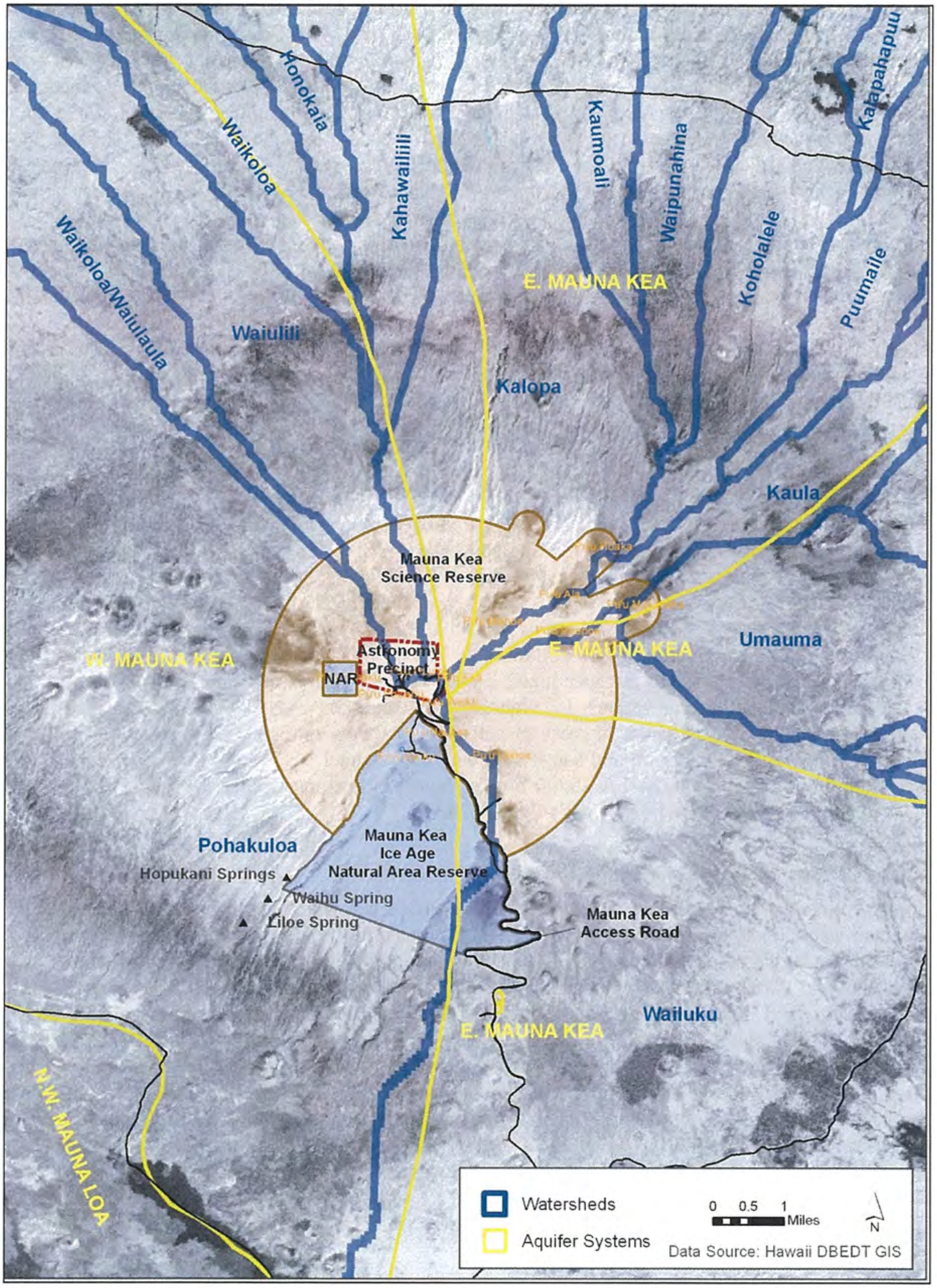
2.1.3.4 Groundwater

During the assembly of background information for this management plan, no studies were located that investigated and mapped groundwater flow paths or groundwater head levels specifically within the MKSR or Hale Pōhaku. Information regarding the substrate composition and their alignments was obtained from geologic studies that have identified and delineated most of the surface formations and some of the stratigraphy on the mountain, and from limited information gathered from soil borings drilled in support of construction for observatories and other infrastructure. Groundwater transportation rates in the summit region of Mauna Kea are unknown, and no flow paths have been identified. It is generally believed that groundwater flows along the direction of the ground surface slope, although the presence of variable subsurface features, such as dikes and sills, with low hydraulic conductivity, likely alter groundwater flow rates and flow paths. Groundwater flow paths are important, in part, to understanding the potential movement of leachate from underground waste water systems (see Section 3.1.1.2.6). Very limited information was found discussing the fate and transport of leachate from the summit region,[19] and it is unknown how much of the total volume of leachate from these systems, if any, makes it to the mountain's aquifers.

There have been studies using surrogates such as isotope signatures or surface-water mass balance estimates to infer flow paths and hydrologic connectivity of groundwater generated from: 1) the Astronomy Precinct to Lake Waiau and the springs along Pōhakalua Gulch, and 2) between the springs along Pōhakalua Gulch and Lake Waiau (Woodcock 1980; Ebel 2000; Johnson 2001; Ehlmann et al. 2005). In general, the studies found that rain and snowfall are the sources of water across and within the MKSR and for springs along Pōhakalua Gulch, and that Lake Waiau is not hydrologically connected to the water generated on lands outside its watershed basin, the basin delineated as the inner slopes of Pu'u Waiau (see Section 2.1.3.3).

[19] Nance conducted a limited investigation of groundwater transmission between Lake Waiau and existing and proposed septic systems located in the Astronomy Precinct (NASA 2005). He concluded that leachate from septic systems would not flow into or toward Lake Waiau.

Figure 2.1-14. Hydrology of Mauna Kea



Aquifers: The MKSR is located above five State of Hawai'i delineated aquifer systems, while Hale Pōhaku is over one, the Waimea Aquifer (see Figure 2.1-14). The Waimea Aquifer system also lies under the land encompassed by the west half of the MKSR, including both NAR parcels. The southeast portion of the MKSR, approximately one-quarter of its surface area, lies over the Onomea Aquifer, which also lies within and beneath the Wailuku Watershed. The three other aquifers, Hakalau, Pa'auilo and Honoka'a, lie beneath the lands comprising the east and northeast areas of the MKSR. The Astronomy Precinct is located entirely above the Waimea Aquifer. It is possible, but unconfirmed, that water infiltrating into the substrate from the Astronomy Precinct flows out of the Waimea Aquifer boundary along preferential flow paths that route water to the other aquifer systems. As part of the 2005 Keck Outrigger EIS proceedings, authors calculated hypothetical impacts of nitrogen and phosphorus on the two Waiki'i wells (Nos. 5239-01 and 02) located 13 mi (20 km) west of the summit. Using conservative assumptions, increases in nitrogen and phosphorus in the Waiki'i well water were calculated to be approximately 0.4 and 1.6 percent, respectively, for the two chemicals (NASA 2005). Several of the observatories, including CFHT, Gemini, UH 2.2 m and UH 0.6 m are located along the easternmost boundary of the Waimea Aquifer, and it is possible that water discharged from their septic systems flows toward the Hakalau or Onomea Aquifer systems. However, as stated previously, the fate of the effluent is unknown.

2.1.3.5 Water Quality

Water quality parameters of Lake Waiau investigated by Massey (1978) and others in 2003 indicated a slightly alkaline water, with conductivity ranging between 109 and 121 µS/cm (at 25°C), and very low levels of dissolved constituents (NASA 2005). A turbid look and greenish tint to the lake water has been noted by observers for many years (Bryan 1939; Neal 1939; Wentworth and Powers 1941; Maciolek 1969; Group 70 1982; Arvidson 2002) and is attributed to algae mats growing on the bottom of the lake (Woodcock et al. 1966; Massey 1978; Dillon 1979). There are, however, accounts from visitors to the lake in which a green tint was not mentioned (Raine 1939). In 1977, a severe reduction in lake water levels with concomitant elevations in phytoplankton biomass was identified and classified as hypereutrophication (a significant increase in nutrients, including nitrogen and phosphorus) (Laws and Woodcock 1981). Fecal coliform and bacteria parameters obtained from samples from Hopukani Spring were found to be negligible (NASA 2005). Similar investigations into well water found at much lower elevations were also found to be negligible (NASA 2005).

2.1.3.6 Threats to the Hydrology

Threats to the hydrology of Mauna Kea include those associated with human presence and activity on the mountain and climate change. Human activities that have the potential to impact water resources quality, and to a lesser degree quantity, include any actions that add to the current wastewater volume or that change in-situ patterns of water movement. Examples are: leaking facility pipes; accidental spills of contaminants; and improperly filtered wastewater. These contributions may affect the quality of water seeped to springs along Mauna Kea's flanks, as well as the fresh water aquifers beneath the mountain. Potential threats from changes in climate involve alteration of current weather patterns, such as changes in rainfall or wind. While the exact impacts of climate change to the MKSR are unknown, results of some general climate circulation model runs suggest that the trade wind inversion will be more persistent. This scenario is expected to result in a reduction of the number of storms that frequent the islands annually and subsequently lower precipitation levels at the upper slopes and summit area of Mauna Kea. Such a change may impact the volume of the annual snowpack and its persistence; the thickness of permafrost and its extent and persistence; and annual precipitation regimes. See Sections 2.2.1.3.6 and 3.2.11.

2.1.3.7 Hydrology Information Gaps

The following information gaps regarding the hydrology of the MKSR have been identified through review of the literature:

1. Watershed Calculation: Snow and snow-water equivalence distribution
   Some observatories in the MKSR record data on several atmospheric and meteorological variables, including rainfall, wind vector, relative humidity, pressure, and temperature. The precipitation measurements recorded by the Subaru Telescope, located at 13,658 ft (4,162 m), reflect inputs from rain, snow water, and fog drip as the latter condenses on the inner face of the collection funnel (Hayashi 2008).[20] During our review of data sets and literature we did not find information on annual snowpack depth for Mauna Kea or the snow-water equivalent of the snowpack, nor did we locate any published reports that quantify the loss of water in the solid phase, that is from snow and ice, due to sublimation. This information is critical to understanding and synthesizing the hydrologic cycle of the mountain, and without it descriptions of the hydrologic cycle must include caveats and assumptions. Further, based on our limited conversations with persons familiar with Mauna Kea, it is widely believed that most of the water contained within the snow is lost via sublimation; however, without data to support that belief, we must treat it as conjecture, because sublimation and its effect on the snow-water equivalence is a complicated physical process.

2. The fate of leachate or liquid waste containing dissolved or suspended contaminants from septic and cesspool systems.

3. Extent and thermal gradient of the permafrost
   The existence of permafrost on Mauna Kea was discovered in 1969 (Woodcock 1974). A patch of permafrost at least 33 ft (10 m) thick was identified at the summit. While the potential spatial distribution of permafrost across the MKSR was modeled (Ehses 2007), its actual distribution and its potential impacts to summit hydrology are not known.

4. Groundwater maps of water levels, flow paths and recharge rates

2.1.4 Climate

2.1.4.1 Overview of Mauna Kea's Climate

Climate refers to the average of recorded weather variables over some period of time, which is then used to represent meteorological condition. At the upper elevations of Mauna Kea, the prevailing conditions are dry, windy, and cool, with high visibility and low surface albedo; it has been designated as semi-arid, barren alpine desert tundra (Ugolini 1974).

Climatic Influences: The atmospheric feature that most strongly influences the climatic regime of Mauna Kea, as in other parts of the Hawaiian Islands, is the North Pacific Anticyclone. This semi-permanent high pressure ridge is located some 2,000 miles (3,219 km) north and east of the Hawaiian Islands, shifting its center from lat 30° N, long 130° W, in the winter, to lat 40° N, long 150 W, in the summer. The anticyclone is formed as warm air from the equatorial zones rises and moves north toward lat 30° N. where the air cools and sinks back toward the earth's surface. This system is commonly referred to as a Hadley Cell, named after the first western scientist who described it. A result of the sinking air is the trade winds that blow outward from the center of the cell, and in this case, toward the Hawaiian Islands. As the

[20] See Mauna Kea Weather Center: http://www.jach.hawaii.edu/weather/

warm air sinks and blows from the northeast, it encounters rising air from the ocean surface that cools as it rises, and at the point of contact between the two air parcels the layer of warm air overlies the cool air. This atmospheric feature is termed an inversion; in Hawai'i it is commonly called the trade wind inversion. In vertical profile, the air column around Hawai'i under this climatic regime can be described as comprising three layers: from sea level to 2,000 ft (610 m) is the marine layer, where evaporation from the ocean lifts water upwards; from 2,000 ft to 7,000 ft (610 m to 2,133 m) is the cloud layer, where water in the air parcel condenses, forming clouds; from 7,000 ft (2,133 m) to approximately 20,000 ft (6,096 m) is the dry inversion zone, where the atmosphere is dry and stable. Figure 2.1-15 depicts a typical inversion capping of the clouds at approximately 7,500 ft.

Figure 2.1-15. Trade Wind Inversion Cap

A second significant factor governing the weather patterns of the Hawaiian Islands is their position on the earth and the fact they are surrounded by a large thermal control—the ocean. Another factor in the climatic regime is the amount of incoming solar radiation, which, due to the island's position in the tropical belt, results in only small annual shifts.

Seasons: There are two meteorological seasons in Hawai'i, winter, (October–April) and summer (May–September), with the trade winds blowing approximately 80 percent of the time in the summer and 50 percent of the time in the winter (Giambelluca and Sanderson 1993). Pre-contact Hawaiians recognized these two seasons as the cool (winter) season (*ho'oilo*) and the warm (summer) season (*kau).* Rainfall associated with the trade winds results from winds encountering the side of the islands almost perpendicular to the incident angle, which forces the air parcels upwards, cooling it, whereupon the moisture in the air condenses and forms clouds which often generate rain. On the windward sides of the islands, trade wind showers are common; however, from sea level to 7,000 ft (2,133 m), the amount and frequency of the rainfall received in a given location is strongly correlated with elevation.

The highest trade wind rainfall rates occur on the windward sides of the islands, in an elevation band of 2,500 to 7,000 feet (762 to 2,133 m). At 7,000 ft, (2,133 m) the trade wind inversion caps upward migration of the clouds, and thereafter, rainfall decreases elevation. As a result, when the trade wind inversion is present, Mauna Kea remains dry from roughly 7,000 ft (2,133 m) upwards (da Silva 2006). Average annual rainfall totals, represented by isohyetal lines, show a significant decrease from 7,000 ft, (2,133 m) to the summit elevations at the top of Mauna Kea (see Figure 2.1-16).

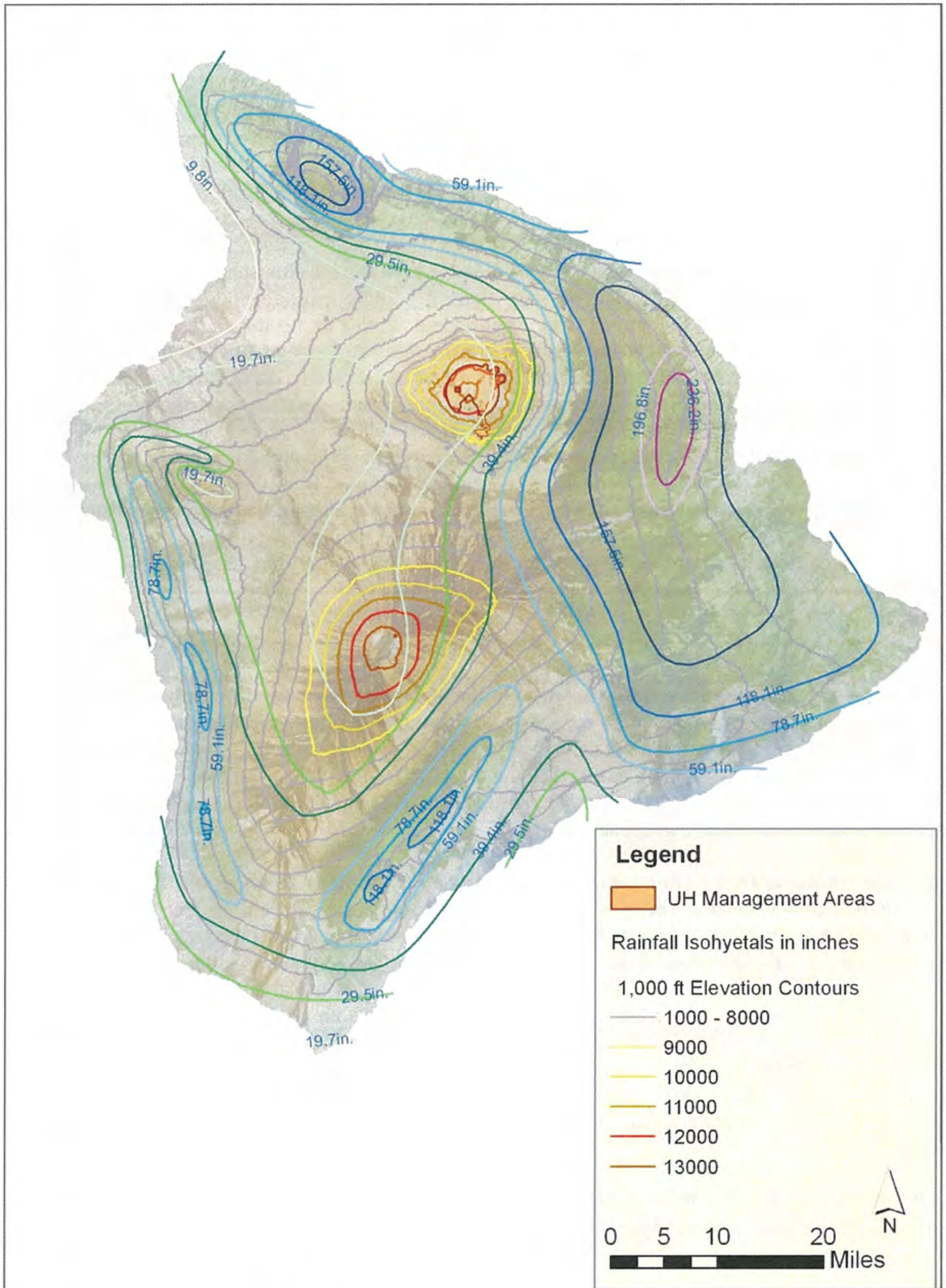
Storms: The Hawaiian Islands are subjected to other weather patterns when the trade winds break down due to a shift in the high pressure ridge caused by perturbations in the atmosphere. In some cases ridges of high pressure set up over the islands, causing winds to be light and allowing local land sea breezes to develop. Other shifts from the normal trade wind regime are due to the storms that frequent the islands, including cold front storms, upper-level and surface low-pressure systems (including kona lows) tropical depressions, and hurricanes. Storms caused by cold fronts generally occur in the winter months and deliver high precipitation levels. Cold fronts of varying intensities arrive from the northwest, causing varying amounts of rainfall and moderately strong winds. Following the passage of the leading edge of the front, skies clear and temperatures reach seasonal lows during the night time hours. Storms caused by kona lows also visit the islands during the winter months, arriving from the southwest. Kona storms are less variable in rainfall levels, are more frequent, and contribute the highest percentage to annual rainfall levels in the leeward and high-elevation areas of the islands. Storms created by upper-level low-pressure systems reach the island periodically, again mostly during the winter months. These storms often bring intense rainfall and strong damaging winds.

Hurricanes and tropical storms are rare occurrences in Hawai'i, but when they reach the islands, they can cause widespread damage. Hurricanes and tropical storms occur during the summer months and can cover entire islands. Such storm systems bring most of the annual precipitation to Hawaii's leeward areas and the mountainous zones above 7,000 ft (2,133 m), including Mauna Kea (Giambelluca and Sanderson 1993). The number of winter storms that reach the islands varies year to year, with the northwest islands of the archipelago receiving more events than the southeast islands. No records were located documenting the number of non-trade-wind storms that affect Mauna Kea annually, but it is presumed to be highly variable, with a range of two to ten storms a year.

El Niño Southern Oscillation: Generally occurring every four to seven years, El Niño events are associated with a general warming of the ocean's surface water near the eastern Pacific, off the coast of Peru. The associated moist, warm air rises, destabilizing the upper atmosphere. This encourages the development of thunderstorms over the equator, and significantly reduces wind flow and precipitation everywhere in Hawai'i (Juvik and Juvik 1998), while increasing winds at higher elevations, including the Mauna Kea summit region (da Silva 2006). El Niño conditions are generally associated with a greater number of tropical cyclones (Juvik and Juvik 1998). La Niña events are the opposite phase of the El Niño Southern Oscillation cycle and are associated with a cooling of the ocean's surface temperatures (Juvik and Juvik 1998). The associated cooler conditions create weather patterns opposite those of El Niño events, resulting in frequent storms to the Islands (Juvik and Juvik 1998), including the summit region (da Silva 2006).

Climate Change: A comprehensive discussion of various hypotheses concerning how climate change may affect the Mauna Kea climate regime is presented in Section 2.2.1.3.6.

Figure 2.1-16. Rainfall (Isohyetal Lines) on the Island of Hawai'i



2.1.4.2 Climatic Variables

Wind: Approximately 80 percent of the time, the wind blows from the west at the upper elevations of Mauna Kea. This typically changes during warmer months, and for the remaining 20 percent of the time, wind comes from the east (Juvik and Juvik 1998; da Silva 2006). On occasion, southerlies will form, due to unstable upper atmospheric conditions. Southerlies bring in storm fronts and large amounts of rain (Birchard 2008). Average wind speeds at 8,530 ft (2,600 m) at Pu'u La'au range between 2.7 to 3.6 miles per hour (1.2 to 1.6 meters per second) (Nullet et al. 1995). Average wind speeds at Mauna Kea's summit normally vary between a maximum of 23 miles per hour (10 meters per second) in January and a minimum of 11 miles per hour (5 meters per second) in September (da Silva 2006); however, higher speeds have been noted during storms (NASA 2005). The dry and breezy conditions facilitate high rates of evaporation at the summit and maintain the cool, dry atmosphere (da Silva 2006; Birchard 2008). The pan evaporation rate for the summit area is reported as 70 in (178 cm) per year (Ekern and Chang 1985), and Nullet et al. (1995) observed rates of evaporation ranging between 0.16 and 0.6 in/day (4.1–15.2 mm/day) at their Pu'u La'au station or 27–57 in/year (693–1,460 mm/yr).

Wind vectors (direction and speed) across the summit area play a large role in the aeolian environment, transporting small debris including bugs from lower elevations up to the summit area. Obstructions to wind flow such as at the crests of the pu'u can redirect the wind or slow it, creating eddies or small vortexes that reduce the energy, or holding capacity, of the wind, allowing debris in the air parcel to fall out. The aeolian environment of the summit area is unique, the persistent wind forcing resident fauna to adapt (see Section 2.2.2.2). A literature search did not find any studies investigating the effects of the observatories on the wind vectors; it is logical to assume, however, that there are some effects on a micro scale. The nature of these effects on deposition and transport of wind-borne debris is unknown. The observatories have been designed, however, to minimize turbulent drag on the air stream, which may reduce their effects on the summit aeolian regime. The observatory support buildings are, for the most part, conventional boxes both at the summit and Hale Pōhaku.

Research by Businger and others has begun to measure wind variability within one of the summit area pu'u (Businger 2008). Part of the study's goal is to measure wind vectors on the inside and outside of the pu'u to better understand how the physical structure of the area affects deposition of food supplies for the wēkiu bug.

Temperature: Due to its latitude, annual temperature flux in Hawai'i is small, with a mean daily temperature difference of only 7.5° F (4°C) at the summit of Mauna Kea between the coldest month and the warmest month (da Silva 2006). During winter, between October and April, the mean daily minimum temperature is 32.5°F (0.28°C); during the summer, between May and September, the mean daily maximum is 40°F (4.4°C) (da Silva 2006). Mean monthly temperatures above the inversion layer generally range between 24.8°F and 32.9°F (-4°C and 0.5° C) in January, one of the coldest months, and between 38.3°F and 42.8°F (3.5°C and 6.0°C) in September, considered a warm summer month (da Silva 2006). Even though variability between annual mean lows and highs is minimal, temperature ranges recorded at the summit area are quite large, ranging from 2°F to 61°F (-16.6°C to 16.1°C). Average temperatures at Hale Pōhaku, at 9,000 ft (2,743 m), range between 30°F and 70°F (-1°C and 21°C) throughout the year (Group 70 International 1999).

Precipitation: The longest period of record of statistical data representative of the summit area climate is from the National Weather Service (NWS) station Mauna Kea Observatory 1, at an elevation 13,780 ft

(4,200 m).[21] The data set represents years 1969–2000, a 31-year period of record. For this period, average precipitation is reported as 7.41 in (188 mm). It is unknown if this precipitation value includes the contribution of water from snowfall. The Subaru Telescope recorded precipitation data for a period of seven years from 1999 to 2005. Mean annual precipitation was estimated at 15.5 in (393 mm) by interpolating annual precipitation from a cumulative plot for 1999–2003 (Miyashita et al. 2004). This value includes the contribution from snowfall, although the efficiency of snow capture by the recording instrument is unknown. Ehlmann et al. (2005) reports annual precipitation as a range of 4.7 to 17.7 inches (12 to 45 cm) recorded at the VLBA, located below the summit area. It is obvious from these numbers that the mean precipitation is variable year to year.

Average relative humidity for Mauna Kea was found to stay relatively constant, at approximately 36 percent throughout the year, with the highest values occurring during November (41 percent) and the lowest during April (30 percent) (da Silva 2006), therefore its effect on local precipitation may be minimal. The dew point was also observed to stay relatively consistent, having an annual mean value of 4.1° F (-15.5° C), with the coldest month being December at -1.3° F (-18.5°C) (da Silva 2006).

The amount and duration of snow and ice covering the summit during the months of November–March is variable (Laws and Woodcock 1981). Snowpack volumes fluctuate from year to year (da Silva 2006) as does, most likely, the formation of ice. No data on average snowfall, snowpack volumes, or patterns of ice formation for the MKSR was found in the literature; however, based upon precipitation occurrence, associated relative humidity, and average temperatures, da Silva (2006) calculated that snowfall was more likely to occur at the MKSR in January than in any other month.

2.1.4.3 Climate Studies at the Summit of Mauna Kea

Nullet et al. (1995) performed a two-year study along a cross-section of the Island of Hawai'i to document differences in climate patterns between the leeward and windward sides of the island. In her dissertation, da Silva (2006) contributes to the understanding of prevailing weather conditions at the summit. She compiled meteorological datasets from the Canada-France-Hawai'i Telescope between September 1994 and March 2006 and from the United Kingdom Infra-Red Telescope between May 1991 and March 2005. She then analyzed numerous attributes, including pressure, temperature, relative humidity, and snowfall as model-derived proxies.

2.1.4.4 Threats to Climate

The impacts and threats associated with global warming on the climate regime of Mauna Kea are discussed in Section 2.2.1.3.6, Climate Change.

2.1.4.5 Climate Information Gaps

The following information gaps regarding the climate at high elevation areas of Mauna Kea have been identified through literature review and consultation with experts:

1. Data and Analysis
   While it is evident from the literature that the meteorological processes over the Island of Hawai'i are fairly well understood, climate data such as precipitation associated with snowfall and analysis of the spatial distribution of precipitation specific to the summit region and upper slopes

[21] It is unknown at which observatory this station is located, since its metadata data does not contain a name corresponding to an observatory. It is possible that it is the UH 0.6 m telescope, because its installation coincides with the initial date of the climate data collection.

of Mauna Kea is lacking. Specifically, snowpack depth and its snow-water equivalent is not measured or recorded. In addition to providing information important for understanding local conditions and dynamics, collection of these data over the long term will be valuable to any future studies investigating climate change.

2. Climate Modeling
   Future work suggested by da Silva (2006) includes using wind and other climate models to extend our understanding of relationships such as food availability for the wēkiu bug, wind trajectory and resulting range of food dispersal. With appropriate and accurate data sets, modeling for any number of atmospheric conditions could be investigated. These data and analyses would greatly assist identification of the typical and not-so-typical weather averages, while allowing investigation into the potential effects of climate change.

2.1.5 Air Quality and Sonic Environment

While it may be a truism that air quality is a significant factor affecting astronomers at Mauna Kea, religious practitioners, recreational users, the tourist industry, and local residents all value the clear views and clean air at the summit. Increased noise levels at MKSR affect all visitors to the summit, albeit in varying degrees. Because the summit area is used by many visitors as a place for worship and silent contemplation, the natural quiet associated with the higher elevations of Mauna Kea is considered a natural resource.

2.1.5.1 Air Quality

The quality of the air at the summit of Mauna Kea is well known throughout the astronomy community. Contributors to air pollution at the summit include vehicle exhaust and fugitive dust from road grading, construction, and other activities conducted on unpaved surfaces. Although there is no active monitoring for air quality at the Mauna Kea summit, the National Oceanic and Atmospheric Administration (NOAA) Mauna Loa Observatory has collected air quality data for the summit of Mauna Loa since its construction in 1956 (Juvik and Juvik 1998; Barnes 2008). These data indicate that for the air pollutants considered by the Hawai'i State Department of Health (DOH) to be of greatest concern (ozone, carbon monoxide, and sulfur dioxide), the air quality at Mauna Loa is excellent. Given the similarities between the two locations, it has been suggested that the overall air quality at Mauna Kea is excellent as well (NASA 2005; Barnes 2008). Five DOH monitoring stations do exist at other locations on the island, including at Hilo and Kona and at three locations in the Puna District; however, all of these monitor air quality below the trade-wind inversion layer.

Another potential source of air-borne particulates and sulfur dioxide is Kīlauea volcano. Early 2008 volcanic activity from Halema'uma'u Crater at Kīlauea Volcano released record amounts of the gas, as much as 4.4 million pounds/day (2,000 tonnes/day) and ambient air concentrations were found to exceed 40 ppm along the road neighboring the crater's rim (U. S. Geological Survey 2008b). This far exceeds the DOH and federal air quality standards for this pollutant, which limits sulfur dioxide concentrations to 0.14 ppm based on a 24-hour averaging period.[22] Sulfur dioxide releases from the Kīlauea summit prior to late December 2007 have typically been 330,693–440,925 pounds/day (150–200 tonnes/day) (U. S. Geological Survey 2008b). Kīlauea also generates ash emissions. One such emission created an ash plume 0.5 to 1.0 mile above ground level (0.8–1.6 km) (U. S. Geological Survey 2008a). The new Kīlauea vent sits at nearly 4,000 ft elevation (1,219 m), but gas and ash debris emitted from it are most likely kept below the inversion layer when it is present. However, even during periods of southerly winds this may

[22] http://hawaii.gov/health/environmental/air/chart.pdf

not be an issue, as the NOAA Mauna Loa Observatory has not noted recent increases in air-borne particulates that can be directly associated with the new vent (Barnes 2008).

2.1.5.2 Sonic Environment

It is generally assumed that the ambient noise levels at the summit and Hale Pōhaku areas are low, with vehicle traffic, wind, and short-term construction being the most pervasive contributors; regular observatory operations contribute only minimally (NASA 2005). However, because noise measurements are not taken routinely, it is difficult to document what "low" actually describes. Noise-sensitive receptors include the primary users of the mountain (e.g., scientists, cultural practitioners, recreational users). Consultation with contemporary religious practitioners has documented that the noise associated with the observatories and vehicular traffic at the summit is "...destructive to the silence and spiritual ambience that is necessary to their proper religious observances" (NASA 2005). The US Army Pōhakuloa Training Area (PTA) abuts the Mauna Kea Forest Reserve at approximately 7,400 ft elevation (2,255 m), along the mountain's south-southwest flank. Live fire is permitted at this installation and navigable airspace above neighboring Bradshaw Army Airfield extends vertically to 8,700 ft (2,652 m); however, nothing was found in the literature to suggest that military-related noise is an issue at the MKSR or Hale Pōhaku.

DOH Noise Division has designated Mauna Kea's summit region as conservation with residential zoning. Associated noise limits are 45 dbl for evening hours and no more than 55 dbl during the day (Toma 2008). Potential human-related noise impacts are addressed in Section 3.2.6.

2.1.5.3 Threats to Air Quality and Sonic Environment

Threats to Mauna Kea's air quality and sonic environment primarily revolve around the presence of humans and their levels of activity. Potential future increases in the number of people visiting, working, and recreating at the UH Management Areas may increase the levels of these impacts. See also Sections 3.2.5 and 3.2.6.

2.1.5.4 Air Quality and Sonic Environment Information Gaps

The following information gaps regarding the air quality and sonic environment of the MKSR have been identified through review of the literature:

1. Air quality baseline
   Due to the air quality requirements of the observatories, air quality, as it pertains to clarity of light, is well monitored. Air quality at Mauna Kea is not monitored by the DOH (Kihara 2008). Valuable contributions to the understanding of macro- and micro-scale processes of global climate change could be obtained through consistent but low-maintenance monitoring of summit air quality at the MKSR and at Hale Pōhaku.

2. Ambient noise levels baseline
   Very little information was found regarding the impact of noise generators on the summit regions. Potential contributors to elevated noise levels are the Army's PTA, Bradshaw Army Airfield, and local and tourist-related air travel. Monitoring at MKSR and Hale Pōhaku for an initial baseline for background and ambient noises and their levels would provide a data set for future comparison.

2.1.6 Visual Environment

The attributes ascribed to the appearance of Mauna Kea are also considered one of the mountain's natural resources, a resource that has been valued for generations.

2.1.6.1 Viewshed

There is an ancient Hawaiian saying: *Mauna Kea kuahiwi ku haʻo i ka mālie* (Mauna Kea is the astonishing mountain that stands in the calm). Many Hawaiians consider the summit region of Mauna Kea a "sacred landscape." Some draw a sense of inspiration, well-being, and security by looking at it from a distance; Maly (1999) writes, "Simply looking at Mauna Kea from afar, seeing it standing there reaching to the heavens, gave the Hawaiian spiritual strength." Others are drawn closer, and ascend the mountain to view its features.

Famous for its dominating presence and its smooth, shield-like silhouette, Mauna Kea has been a beacon for centuries to travelers coming to the islands. Similar in significance is the view from Mauna Kea. Descriptions of sweeping views were often recorded by early Western visitors; those looking up to the summit and those looking down from the top of Mauna Kea:

Friday, April 25. The appearance of Hawaii, this morning was exceedingly beautiful. We were within a few miles of the shore; and the whole of the eastern and northern parts of the island were distinctly in view, with an atmosphere perfectly clear, and a sky glowing with the freshness and splendor of sunrise. When I first went on deck, the gray of the morning still lingered on the lowlands, imparting to them a grave and somber shade; while the region behind, rising into a broader light, presented its precipices and forests in all their boldness and verdure. Over the still loftier heights, one broad mantle of purple was thrown; above which, the icy cliffs of MOUNA-KEA…blazed like fire, from the strong reflection of the sun-beams striking them long before they reached us on the waters below. As the morning advanced, plantations, villages, and scattered huts were distinctly seen along the shore…

In the evening Hawaii and Mouna-kea again, at a distance, afforded another of the sublimest of prospects;—while the setting sun and rising moon combined in producing the finest effects on sea and land. The mountains were once more unclouded, and with a glass we could clearly discern immense bodies of ice and snow on their summits… [Observations of C.S. Stewart sailing into Hilo Bay in April 1823 (Maly and Maly 2005).]

The view from the summit was sublime beyond description, embracing, as it did, the three other great mountains of Hawaii, and the grand old "House of the Sun [Haleakala]," 75 miles distant, looking up clear and distinct, above a belt of clouds. ['The Ascent of Mauna Kea, Hawaii', Report of W.D. Alexander on the Mauna Kea Trip of 1892, (Maly and Maly 2005).]

Today, visitors to the summit can more easily experience the vistas, including breathtaking sunrises and sunsets. Residents from around the island value the changing colors of Mauna Kea throughout the day, with people from the eastern side describing the mountain's beauty at sunrise, while those on the northwestern side experience the sunsets (Maly 1999).

On a cloud-free day, views from the summit region include Mauna Loa to the south, Hualālai to the west, the flanks of summit cinder cones to the east, and other islands in the Hawaiian chain to the north-northwest. Due to persistent cloud cover, Hilo usually cannot be seen during the day, and due to a lighting ordinance, Hilo's street lights use low-pressure sodium lamps to reduce night-time glow from populated areas (Wainscoat 2007). To reduce thermal impacts, the observatories are painted white and when skies are clear, the summit region and observatories can be seen from Hilo, Honoka'a, Waimea, Kilauea summit, sections of the Mauna Kea Summit Access Road and much of Puna. Views from Hilo are of the southern and eastern flanks, while views from Waimea are of the northern flanks of Mauna Kea. During warmer months, the formation of an inversion layer between 5,000 and 9,000 ft (1,524–2,740 m) may obstruct views of the summit from lower elevations, as well as views of the lower elevations from the summit. Due to topography, Hale Pōhaku is not visible from the summit, while views of the summit region and the observatories from other portions of the Mauna Kea Summit Access Road and Hale Pōhaku are blocked from view, in many places, by cinder cones.

As mountain topography is an integral part of the local viewscape, it must be considered during planning for any proposed development, redevelopment, or decommissioning of facilities in the summit region. Existing observatories have impacted the viewscape in some locations, both from the summit and of it, and they do obscure portions of the 360-degree view from the summit area. Section IX of the 2000 Mauna Kea Science Reserve Master Plan provides a physical planning guide that contains guidelines for future development of the summit and support facilities, including siting and design criteria to reduce visual impact of new facilities (Group 70 International 2000). This included designation of the Astronomy Precinct, to consolidate astronomical development (see Figure 1-3). The plan seeks to minimize the visual impact from significant cultural areas by respecting views from the pu'u and archaeological sites in the siting of any potential future facilities, along with avoiding interference with the visual connections between the major shrine complexes and pu'u. Trails that become etched into the cinder from repeated use are another consideration for local viewscapes. As described in Section 3.2.1, these footpaths can be visually distracting and disturb habitat.

2.1.6.2 Light Quality

In addition to striking views from and of Mauna Kea, the "seeing" ability from the summit region as it relates to astronomy is very high. It has been well documented that the MKSR is a premier location for astronomical activities (Walker 1983; Businger et al. 2002; Wainscoat 2007). This is in part because the atmosphere above the higher elevations of Mauna Kea is so stable (Walker 1983; Businger et al. 2002). Dark skies, generally favorable weather, and clean, clear air permit almost year-round un-obscured conditions for optimal night seeing. These attributes of seeing ability are affected directly and indirectly by four primary factors: the site's remote location, its elevation, its topography, and the climate (Businger et al. 2002). Managing these attributes for optimal influence on night sky viewing will be essential to the continued success of astronomy at the MKSR.

One of the main issues found within the literature is the impact of night glow from populated areas, which is affected by the types of lighting used in residential, business and industrial districts at night (Wainscoat 2007). The light emitted from these sources has increased sky brightness by as much as 30% above natural levels in some areas (Wainscoat 2007). A strong lighting ordinance enacted in 1989, on the island of Hawai'i, has helped maintain optimal darkness by requiring that existing street lights be retrofitted with fully enclosed, low-pressure sodium bulbs (Copman 2007). The yellowish hue of the sodium lights provides effective illumination and is expected to save money, because they use less energy than older bulb types (Copman 2006; Wainscoat 2007). In addition, the light fixtures prevent light scatter, reducing the glare that negatively affects seeing quality both on the street and at the MKSR. Light from as far away as Maui is also affecting viewing quality at the summit, as is light from neighboring PTA (Wainscoat 2007). Approximately 6.2 miles (10 km) away from the summit of Mauna Kea, PTA is "the single largest source of light pollution for the observatory[ies]" (Wainscoat 2007). Impacts from this source may be lessened however; older style lights also reduce the effectiveness of night-vision equipment used during night training events, and the Army is slowly retrofitting (Wainscoat 2007).

2.1.6.3 Threats to the Visual Environment

Threats to the visual environment of Mauna Kea include anything (existing and new) that impacts the viewshed. This includes buildings, signs, roadways, parking lots, trash receptacles, and portable toilets. Threats also include signs of erosion (e.g., trails, culvert gullies) and vandalism of natural features (rock paintings, and destruction, removal, and movement of material). And, finally, they may include symbolic features such as rock sculptures and offering platforms placed within the UH Management Areas.

2.1.6.4 Visual Information Gaps

No information gaps regarding the visual environment were noted.

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2.2 Biotic Environment

Mauna Kea, the tallest mountain in Polynesia, has the greatest diversity of biotic environments anywhere in the Hawaiian Archipelago (Juvik and Juvik 1984). Ecosystems on Mauna Kea range from the highly modified fertile lowlands to an alpine stone desert located at the summit at 13,796 ft (4,205 m). For the Mauna Kea Natural Resources Management Plan, the ecosystems under consideration are those found above approximately 9,000 ft (~2,700 m), beginning at Hale Pōhaku and rising to the summit. High elevation ecosystems on Mauna Kea can be divided into two basic types: the subalpine ecosystem, which occurs from approximately 5,600 ft to 9,800 ft (1,700 m to 3,000 m) elevation, and the alpine ecosystem, which occurs above 9,800 ft (3,000 m) (Gagné and Cuddihy 1990). The shift from subalpine to alpine ecosystems is determined by the elevation of the nocturnal ground frost line (Mueller-Dombois and Fosberg 1998). The subalpine and alpine ecosystems can be further subdivided by vegetation community, as described in Section 2.2.1. The following sections (Sections 2.2.1 through 2.2.4) discuss the plant, invertebrate, bird, and mammal species found in the subalpine and alpine ecosystems of Mauna Kea (with the focus being on Hale Pōhaku and the Mauna Kea Science Reserve (MKSR)). Each section also reviews previous research for each group (especially biological surveys) done at Hale Pōhaku and the MKSR, as well as information gaps, and threats to native populations of plants and animals.

In addition to the general descriptions of the flora and fauna, more-detailed discussions of federal and state Threatened and Endangered species, Candidate Species, and Species of Concern are presented in each section. Threatened and Endangered Species are species that are legally required to be protected (under either federal or state law) (see Section 1.4.3). Candidate species are those species not yet listed but for which there exists sufficient evidence on biological vulnerability and threats to support a proposal to list as Endangered or Threatened. There is no legal mandate to protect Candidate Species, but generally it is in the best interest of land mangers to protect them in order to prevent the need for listing. Species of Concern are those species that might be in need of conservation action, but that are not currently Listed or Candidate species. Species of Concern receive no legal protection and use of the term does not necessarily imply that a species will eventually be proposed for listing. The numbers of federal and state listed species that occur, or potentially occur, in the subalpine and alpine regions of Mauna Kea covered by this management plan are presented in Table 2.2-1. Many of the species in the State of Hawai'i lists are also included in the federal lists, so the two lists overlap. The total number of species that are protected by either federal or state laws found (or formerly found) in the areas covered by this plan are: 12 Endangered, one Threatened, two Candidate, and 16 Species of Concern (two of which are also listed as state Endangered on islands other than Hawai'i). These species are listed in Table 2.2-2. See the glossary for more detailed definitions of the terms Endangered, Threatened, Candidate, and Species of Concern.

Table 2.2-1. Number of Federal and State Listed Species, Candidate Species, and Species of Concern found or potentially found at Hale Pōhaku and MKSR

	Group			
Legal Status	Plants	Arthropods & Snails	Birds	Mammals
Federally Endangered	4	0	5	1
Federally Threatened	1	0	0	0
Federal Candidate for Listing	1	1	0	0
Federal Species of Concern	0	6	6	0
State Endangered	4	0	5	1
State Threatened	1	0	0	0
State Candidate for Listing	1	0	0	0
State Species of Concern	4	3	0	0

Table 2.2-2. List of Federal and State Threatened, Endangered, Candidate, and Species of Concern found, or potentially found, at Hale Pōhaku and MKSR

Group	Scientific Name	Common Name	Legal Status[2]
Endangered Species			
Plant	*Argyroxiphium sandwicense sandwicense*	'Ahinahina, Mauna kea silversword	FE, SE
Plant	*Asplenium fragile* var. *insulare*	Diamond spleenwort	FE, SE
Plant	*Phyllostegia racemosa* var. *racemosa*	Kiponapona	FE, SE
Plant	*Vicia menziesii*	Hawaiian vetch	FE, SE
Bird	*Branta sandvicensis*	Nene (Hawaiian goose)	FE, SE
Bird	*Buteo solitarius*	'Io	FE, SE
Bird	*Hemignathus munroi*	'Akiapola'au	FE, SE
Bird	*Loxioides bailleui*	Palila	FE, SE
Bird	*Pterodroma sandwichensis*	'Ua'u (Hawaiian petrel)	FE, SE
Mammal	*Lasiurus cinereus semotus*	'Ope'ape'a (Hawaiian hoary bat)	FE, SE
Threatened Species			
Plant	*Silene hawaiiensis*	Hawai'i catchfly	FT, ST
Candidate Species			
Plant	*Ranunculus hawaiiensis*	Makou	FC, SC
Arthropod	*Nysius wekiucola*	Wekiu bug	FC
Species of Concern			
Plant	*Chamaesyce olowaluana*	'Akoko	HSOC
Plant	*Cystopteris douglasii*	Douglas' bladderfern	HSOC
Plant	*Dubautia arborea*	Mauna Kea dubautia, na'ena'e	HSOC
Plant	*Sanicula sandwicensis*	Hawaii black snakeroot	HSOC
Arthropod	*Agrotis melanoneura*	Black-veined agrotis noctuid moth	FSOC, HSOC
Arthropod	*Coleotichus blackburniae*	Koa bug	FSOC
Arthropod	*Hylaeus difficilis*	Difficult yellow-faced bee	HSOC
Arthropod	*Hylaeus flavipes*	Yellow-footed yellow-faced bee	FSOC, HSOC
Arthropod	*Micromus usingeri*	Flightless brown lacewing	FSOC
Snail[3]	*Succinea konaensis*	Succineid snail	FSOC
Snail	*Vitrina tenella*	Zonitid snail	FSOC
Bird	*Asio flammeus sandwichensis*	Pueo	FSOC, SE[4]
Bird	*Chasiempis sandwichensis*	'Elepaio	FSOC
Bird	*Hemignathus virens virens*	'Amakihi	FSOC
Bird	*Himatione sanquinea*	'Apapane	FSOC
Bird	*Pluvialis fulva*	Kolea (Pacific golden plover)	FSOC
Bird	*Vestiaria coccinea*	'I'iwi	FSOC, SE[5]

2.2.1 Botanical Resources

The following review of botanical resources focuses on the conditions at Hale Pōhaku (and surrounding areas), the Summit Access Road (from Hale Pōhaku to the summit), and the Mauna Kea Science Reserve (MKSR). Information on the plants found in these areas was gathered primarily from a small number of botanical accounts of high elevation habitats on Mauna Kea (Hartt and Neal 1940; Smith et al. 1982; Char

[2] Legal Status: FE = Federally Endangered, FT= Federally Threatened, FC = Federal Candidate for listing, FSOC = Federal Species of Concern, SE = State Endangered, SC = State Candidate for Listing, HSOC = Hawaii State Species of Concern, ST = State Threatened.
[3] It is unknown whether snails are present at Hale Pōhaku – no surveys for snails have been completed at this elevation.
[4] State Endangered on Oahu only.
[5] State endangered on Oahu, Lanai, and Molokai only.

1985, 1990, 1999b, a; Group 70 International 2000; Pacific Analytics 2004), two review reports (Conant et al. 2004; Aldrich 2005), general accounts on high elevation flora in the Hawaiian Islands (Gagné and Cuddihy 1990; Wagner et al. 1990; Mueller-Dombois and Fosberg 1998), and a variety of other scientific publications that provided additional information on the area.

The makeup of the high elevation plant communities found on Mauna Kea differs depending on whether they are located in the subalpine or alpine ecosystems (Aldrich 2005). Some plant species are found in both ecosystem types, but most flowering plants are limited to the subalpine ecosystem, which is found below the nocturnal ground frost line[6], at approximately 9,800 ft (3,000 m). Hale Pōhaku and the lower portions of the Summit Access Road fall into the subalpine community, which can be further divided into māmane woodlands and subalpine shrublands. The MKSR and upper portions of the Summit Access Road fall within the alpine community, which can be further divided into alpine shrublands, alpine grasslands and alpine stone desert (see Figure 2.2-1). Detailed information regarding the subalpine and alpine communities on Mauna Kea is provided below. Although they are not plants, fungi and lichens are also addressed in this section, as they are often treated as plants by land mangers, and many have close associations with plant communities.

A list of vascular plants occurring at Hale Pōhaku and the MKSR is presented in Table 2.2-3. Lichen species are presented in Table 2.2-4, and mosses in Table 2.2-5. Threats to the subalpine and alpine plant communities of Mauna Kea are discussed in Section 2.2.1.3, and information gaps are discussed in 2.2.1.4. Photos of common native species found in the subalpine and alpine zones are presented in Figure 2.2-2. Photos of rare plants (Threatened, Endangered, Candidate, Species of Concern) are presented in Figure 2.2-3. Photos of common invasive species are presented in Figure 2.2-4.

2.2.1.1 Subalpine Plant Communities (Hale Pōhaku and Lower Summit Access Road)

The subalpine community on Mauna Kea can be divided into three major types: open dry forest (or woodlands) dominated by māmane (*Sophora chrysophylla*) trees, tussock grassland, and subalpine dry shrublands. Tussock grasslands were once an important vegetation community on Mauna Kea. These grasslands were made up of *Deschampsia nubigena, Panicum tenuifolium, Poa sandvicensis, Trisetum glomeratum, Agrostis sandwichensis,* and *Eragrostis atropioides* (Mueller-Dombois and Fosberg 1998). However, overgrazing by feral and domesticated sheep and goats, and establishment of invasive weed species, has virtually eliminated these grasslands (Mueller-Dombois and Fosberg 1998).

Subalpine dry shrublands are dominated by pūkiawe (*Leptecophylla tameiameiae*), ʻōhelo (*Vaccinium reticulatum*) and an occasional ʻōhiʻa tree (*Metrosideros polymorpha*) (Cuddihy and Stone 1990). The dry shrubland community may also be found above treeline up to 9,800 ft (3,000 m) and grades into the alpine dry shrubland community (Gagné and Cuddihy 1990). Because of the similarity between the subalpine and alpine dry shrublands, these communities are discussed in more detail in 2.2.1.2 (Alpine Communities).

Subalpine woodlands are dry most the year, with annual rainfall ranging from 15 to 39 inches (380 to 1,000 mm), most of which falls between December and March. Fog drip from clouds that form in the afternoons is an important source of moisture in this region (Gilbertson et al. 2001). Understory plants tend to be concentrated under māmane trees, where they receive fog drip (Gagné and Cuddihy 1990).

[6] The nocturnal ground frost line is the elevation above which frost form at night. Below this elevation frosts seldom form.

Māmane occurs in almost pure stands on the eastern, northern, and western slopes of Mauna Kea, and in a narrow band at tree line on the southern slope (Scott et al. 1984). Other tree species, such as pilo (*Coprosma montana*) are scarce, and naio (*Myoporum sandwicense*) is absent in these areas (Scowcroft and Conrad 1992). Naio trees are co-dominant with māmane on the southwestern slopes of Mauna Kea (Scott et al. 1984).

Māmane woodlands once stretched from sea level on the leeward side of Mauna Kea to the tree line, but have been greatly reduced due to habitat alteration at lower elevations (for grazing, agriculture, and development) and uncontrolled grazing at the higher elevations by feral sheep (*Ovis aries*), mouflon sheep (*O. musimon*), goats (*Capra hircus*), and historically, cattle (*Bos taurus*) and horses (*Equus caballus*) (Giffin 1982; Scowcroft and Giffin 1983; Hess et al. 1999). The lower elevation for the māmane-naio forest type is currently approximately 6,000 ft (1,800 m) (Aldrich 2005). Although feral grazer abundance was greatly reduced in the area in the 1980s, and is currently low[7], the forest has not fully recovered, due to continued browsing and the presence of invasive plant species that inhibit māmane regeneration (Williams 1994; Hess et al. 1996). The understories of most māmane forests are now dominated by invasive grasses such as orchardgrass (*Dactylis glomerata*), common velvetgrass (*Holcus lanatus*), sweet vernalgrass (*Anthoxanthum odoratum*), and Kentucky bluegrass (*Poa pratensis*) (Hess et al. 1996), although native grasses can still be found in some areas (see below). The heavy growth of the invasive grasses suppresses germination of māmane seeds and increases the likelihood of fires in the dry woodland (Hess et al. 1996). Māmane regeneration in these degraded woodlands is highest in the higher elevation areas (such as at Hale Pōhaku), where grass densities are low (Hess et al. 1996).

Prior to human disturbance, dry forests and shrublands were some of the most diverse plant communities in Hawai'i (Cuddihy and Stone 1990; Aldrich 2005). Māmane forests are thought to have always been fairly open, and historically had an understory community with many herbaceous species and abundant shrubs such as pūkiawe, 'ōhelo, and 'āheahea (*Chenopodium oahuense*) (Mueller-Dombois and Fosberg 1998). Although the understories of the māmane woodlands on Mauna Kea are currently dominated by invasive grasses and shrubs, native understory species can still be found in the region. Native plant species commonly found in māmane forests (historically and/or currently) are listed below (Skottsberg 1931; Hartt and Neal 1940; Gagné and Cuddihy 1990; Mueller-Dombois and Fosberg 1998; Char 1999a; Aldrich 2005; Bishop Museum 2007b, a). A list of plant species found in the subalpine region (at and near Hale Pōhaku) on Mauna Kea is presented in Table 2.2-3.

Native grasses and sedges found in māmane woodlands include Hawai'i bentgrass (*Agrostis sandwicensis*), alpine hairgrass (*Deschampsia nubigena*), lovegrass (*Eragrostis* sp.), mau'u lā'ili or Hawaii blue-eyed grass (*Sisyrinchium acre*), pili uka (*Trisetum glomeratum*), two sedge species (*Carex macloviana and C. wahuensis*), and Hawai'i wood rush (*Luzula hawaiiensis*). Alpine hairgrass and pili uka are the two most common grasses in this community (Cuddihy and Stone 1990; Char 1999a). Native herbs found in the māmane woodlands include Hawai'i stinging nettle (*Hesperocnide sandwicensis*), 'ena'ena (*Pseudognaphalium sandwicensium*), makou (*Ranunculus hawaiensis*), and Hawaii black snakeroot (*Sanicula sandwicensis*). In addition, botanical surveys of Mauna Kea done in the 1820s and 1830s indicated that the native strawberry, or 'ōhelo papa (*Fragraria chiloensis*) was abundant in the subalpine and alpine regions (Hartt and Neal 1940). It has declined in abundance on the island of Hawai'i, possibly due to a pathogen introduced with the naturalized woodland strawberry (*Fragraria vesca*) (Wagner et al. 1990).

[7] Sheep, and evidence of browsing, continues to be observed in the subalpine and alpine zones of Mauna Kea. A flock of approximately 60 sheep was observed in February 2008 in Pohakuloa Gulch within the Ice Age Natural Area Reserve (Hadway 2008).

Native shrubs and trees found in māmane woodlands include (Cuddihy and Stone 1990; Gagné and Cuddihy 1990):

- ʻakoko (*Chamaesyce olowaluana*)
- ʻāheahea (*Chenopodium oahuense*)
- ʻaiakenēnē (*Coprosma ernodeoides*)
- alpine mirror plant (*Coprosma montana)*
- ʻaʻaliʻi (*Dodonaea viscosa*)
- three species of naʻenaʻe (*Dubautia arborea, D. ciliolata ciliolate,* and *D. scabra*)
- nohoanu *(Geranium cuneatum hololeucum)*
- pūkiawe (*Leptecophylla tameiameiae*)
- ʻūlei (*Osteomeles anthyllidifolia*)
- ʻākala (*Rubus hawaiensis*)
- alpine catchfly (*Silene struthioloides*)
- alpine tetramolopium (*Tetramolopium humile humile*)
- ʻōhelo (*Vaccinium reticulatum*)

Of these, pūkiawe is the most common in the higher elevation reaches of the subalpine community (Gagné and Cuddihy 1990; Mueller-Dombois and Fosberg 1998). Native vines and lianas commonly found in māmane woodlands include two species from the mint family (Lamiaceae): littleleaf Stenogyne (*Stenogyne microphylla*) and māʻohiʻohi (*Stenogyne rogosa*), and a large climbing liana or sprawling shrub, pāwale (*Rumex giganteus*) (Cuddihy and Stone 1990; Gagné and Cuddihy 1990).

Non-native species commonly found in the māmane woodlands include the invasive grass species discussed above and several herbs and shrubs including telegraph plant (*Heterotheca grandiflora*), hairy cat's ear (*Hypochoeris radicata*), Virginia pepperweed (*Lepidium virginicum*), and common mullein (*Verbascum thapsus*) (Gagné and Cuddihy 1990). Common mullein is an invasive species and is listed as a Hawaiʻi State Noxious Weed (Division of Plant Industry 1992; DOFAW n.d.). Other state and federal noxious weeds found in the subalpine community include the federally listed Kikuyu grass (*Pennisetum clandestinum*), and the state listed fountain grass (*Pennisetum setaceum*) and fireweed (*Senecio madagascariensis*). Common mullein and telegraph plants were very abundant in the vicinity of Hale Pōhaku in October 2007 (personal observation). Invasive species are discussed further in Section 2.2.1.3.3.

Plant Communities at Hale Pōhaku

Char (1999a) describes māmane woodlands at Hale Pōhaku as clumps of māmane trees, 16 to 18 ft tall, interspersed with open areas of bare soil or rocky outcroppings. She describes understory plants at Hale Pōhaku as tending to be denser under and around the clumps of māmane, with groundcover plants being primarily mixed bunch grasses forming upright tussocks. The most abundant grasses are two native grasses, alpine hairgrass (*Deschampsia nubigena)* and pili uka (*Trisetum glomeratum)*, and an introduced needlegrass, *Nassella cernua* (called *Stipa cernua* in Char's 1999 report and all older references). Common non-native grasses and herbaceous species found at Hale Pōhaku include ripgut brome (*Bromus diandrus*), orchardgrass (*Dactylis glomerata*), hairy cats-ear (*Hypochoeris radicata*), alfilaria or pin clover (*Erodium cicutarium*), sheep sorrel (*Rumex acetosella*), common groundsel (*Senecio vulgaris*), and common mullein (*Verbascum thapsus*). Patches of non-native California poppy (*Eschscholzia californica*) are locally common near the cabins. Char (1999a) does not mention the high density of common mullein or fireweed (*Senecio madagascariensis*) currently found at Hale Pōhaku. In fact, fireweed is not mentioned at all in Gerrish (1979) or Char (1985, 1999a), suggesting this population increase is a recent development.

Shrub species recorded at Hale Pōhaku include ʻāheahea (*Chenopodium oahuense*), pūkiawe (*Leptecophylla tameiameiae*) and nohoanu (*Geranium cuneatum*). The latter two are associated with rocky areas. Two native vines, littleleaf stenogyne (*Stenogyne microphylla*) and māʻohiʻohi (*Stenogyne rogosa*) are found climbing into the canopy of some māmane trees (Char 1999a). Although she did not mention it in her 1999a report, Char stated in 1985 that the indigenous ferns kalamoho (*Pellaea ternifolia),* ʻiwaʻiwa *(Asplenium adiantum-nigrum),* and olaliʻi *(Asplenium trichomanes)* were frequently found among the rocks in the area immediately adjacent to and above the Mid-Level Facilities maintenance area, along with Hawaiʻi catchfly (*Silene hawaiiensis)*, a federally listed Threatened Species.

In addition to the māmane woodland found at Hale Pōhaku, there is a small grove of Eucalyptus trees above the information station parking lot. A few shrubs of non-native tagasaste, or broom (*Cytisus palmensis*), also occur here.

Subalpine Fungal Communities

There have been relatively few studies of the higher elevation fungal communities on Mauna Kea, and no fungal surveys have been conducted at Hale Pōhaku itself. Despite the dry conditions on Mauna Kea's upper elevations, there are a wide variety of fungal species that inhabit the subalpine and alpine habitats found there. A survey of higher fungi[8] conducted in the māmane-naio forests on Mauna Kea between elevations of 6,000 and 9,000 ft (1,828 and 2,743 m) found 71 species of Ascomycetes (cup fungi such as yeast, mildew, morels and truffles) and Basidiomycetes (club fungi such as mushrooms, toadstools, earthstars, stinkhorns, brackens, rusts, and smuts) (Gilbertson et al. 2001). Desert stalked puffballs and earthstars are characteristic fungi found in higher elevation areas on Mauna Kea and commonly appear after rains (Hemmes and Desjardin 2002). Some of the more common ground-dwelling species that occur in māmane-naio woodlands include the salt-and-pepper shaker earthstar (*Myriostoma coliforme*), partially-buried puffballs such as *Disciseda anomala* and *Disciseda verrucosa*, fornicate earthstars (*Geastrum fornicatum*), hygroscopic earthstars (*Geastrum corollinum and G. campestre*), desert stalked puffballs (*Battarraea phalloides*), and stalked puffball (*Tulostoma fimbriata* var. *campestre*) (Hemmes and Desjardin 2002). Hemmes and Desjardin (2002) report *Tulostoma fimbriata* var. *campestre* growing above the treeline, at 9,842 ft (3,000 m), often in association with plants such as the silversword (*Argyroxiphium sandwicense* ssp. *sandwicense*). Some of the more common fungi that appear on trees and downed tree-branches include *Heliocybe sulcata* and *Hypoxylon submonticulosum*, conks such as *Phellinus robustus*, and bracket fungi such as *Gloeophyllum trabeum* (Gilbertson et al. 2001; Hemmes and Desjardin 2002). A new species of witch-broom-forming fungus (*Botryosphaeria mamane*) has been discovered growing on māmane trees, generally causing death of the branches it infects (Gardner 1997). Other newly discovered species include four white-rot associated fungi, *Hyphodermella maunakeaensis, Phanerochaete crescentispora,* and *Radulomyces kamaʻaina*, and *Radulomyces poni* (Gilbertson et al. 2001).

An important group of fungi for the functioning of native ecosystems are the mycorrhizal fungi, which form symbiotic associations with the roots of plants (Habte 2000). The plants provide the fungi with carbohydrates (from photosynthesis) and in return, the fungi greatly increase the surface area of the roots for better absorption of water and mineral nutrients such as phosphates (Gemma and Koske 2001). The presence of the fungi may also improve plant resistance to disease (Habte 2000). Plants grown in areas where the mycorrhizal fungi have been eliminated (such as disturbed, eroded, or denuded areas) often do

[8] Higher fungi are those that produce complex fruiting bodies and release spores (for example, mushrooms). Lower fungi include the Zygomycotina and the Chytridiomycotina. Chytrid fungi are important saprophytes and parasites in both aquatic and terrestrial habitats and are biodegraders of materials such as chitin, keratin and cellulose. They also play a role in nutrient recycling. Chytrid fungi have been implicated in the global reduction of frog populations. Zygomycetes are mostly terrestrial fungi and live in decaying plant or animal matter. Bread mold (*Rhizopus stolonifer)* is an example of zygomycotinid fungi.

very poorly (Habte 2000; Gemma and Koske 2001). The most common mycorrhiza are the arbuscular mycorrhiza (AM). The fungi found in arbuscular mycrorrhizae are generally not plant-specific, and are difficult to study because they cannot be grown without the host plant (Gemma and Koske 2001). Mycorrhizae are especially important to plant growth in nutrient-poor soils, such as in Hawai'i where soils tend to have low amounts of available phosphorous (Gemma et al. 2002). Over 90% of endemic Hawaiian plants regularly form arbuscular mycrorrhizae in the field, and most of these species require AM to grow in low-fertility soils (Gemma and Koske 2001; Gemma et al. 2002). AM fungi are found in most Hawaiian soils, even in high altitude areas and on young lava flows (Gemma et al. 2002; Koske and Gemma 2002). Many native plants in the subalpine māmane woodlands and shrublands that have been tested were found to form associations with AM fungi. Native species found to form AM include māmane (*Sophora chrysophylla*), pūkiawe (*Leptecophylla tameiameiae*), ʻōhelo (*Vaccinium reticulatum*), ʻaiakenēnē (*Coprosma ernodeoides*), ʻaʻaliʻi (*Dodonaea viscosa*), naʻenaʻe (*Dubautia ciliolata ciliolata, and D. scabra*), ʻōhiʻa (*Metrosideros polymorpha*), and ʻūlei (*Osteomeles anthyllidifolia*) (Koske et al. 1990; Gemma and Koske 2001). As research into AM fungi continues, there is no doubt that additional native species will be found to form associations with AM fungi. Many non-native invasive species also form associations with AM fungi (Koske et al. 1992). The relationships between invasive plants and mycorrhizal communities are discussed further in Section 2.2.1.3.3 (Invasive Plants). Because mycorrhizal fungi are easily eliminated in disturbed and barren areas, any restoration or transplanting attempts made in the subalpine and alpine zones on Mauna Kea should be done with seedlings that have been inoculated with AM fungi in the greenhouse, in order to increase the chance of establishment of the plants in the field (Habte 2000; Gemma and Koske 2001).

2.2.1.1.1 Threatened and Endangered Species

Endangered plant species (federal and state) found (historically and/or currently) in the subalpine community include the Mauna Kea silversword (*Argyroxiphium sandwicense* subspecies *sandwicense*), diamond spleenwort (*Asplenium fragile* var. *insulare*), kiponapona (*Phyllostegia racemosa* var. *racemosa*), and Hawaiian vetch (*Vicia menziesii*). The only Threatened plant species found in the subalpine community is Hawaiian catchfly (*Silene hawaiiensis*).

Historical records indicate that the endangered Mauna Kea silversword grew abundantly as low as 6,000 ft (1,800 m) above sea level (Hartt and Neal 1940). The Mauna Kea silversword is found in a Department of Land and Natural Resources (DLNR)-maintained enclosure near Hale Pōhaku and in the MKSR. This spectacular but extremely rare species is discussed in more detail in Section 2.2.1.2.4.

Diamond spleenwort, a fern, is currently found in scattered populations on Hawaii Island between 5,250 and 7,800 ft (1,600 and 2,380 meters) elevation, including Hawaii Volcanoes National Park, Hilo, Puʻu Hualalai, Puʻu Waʻawaʻa, 1823 lava flow, Hualālai summit, Keauhou Ranch, Puʻu Huluhulu, Kapāpala Forest Reserve, and Puʻu Moana and Pōhakuloa Training Area (Shaw 1997; USFWS 1998a). It was previously found on Mauna Kea as high as 9,600 ft (2,926 m) (Hartt and Neal 1940). This species has not been observed at Hale Pōhaku (Char 1999a).

Kiponapona is a vine normally found in mesic to wet forests on the windward slopes of Mauna Kea and Mauna Loa. It was recorded by Cuddihy in 1979 (Bishop Museum 2007a) as occurring in a subalpine community at Shipman Ranch, above Maulua and below Keanakolu Road, on the northeast slope of Mauna Kea. This species has not been observed at Hale Pōhaku (Char 1999a).

Hawaiian vetch is a climbing herb that was previously found in the subalpine communities on Mauna Kea and Mauna Loa (Skottsberg 1931) but is currently found only at lower elevations (Wagner et al. 1990). This species has not been observed at Hale Pōhaku (Char 1999a).

Hawaiian catchfly is a sprawling shrub found in open, dry areas up to approximately 9,880 ft (3,011 m) in elevation (USFWS 2002). It is closely related to *Silene struthioloides* (Wagner et al. 1990). *S. hawaiiensis* was recorded at Hale Pōhaku by Char, in 1985. However, in her 1999a summary report, she observed only *S. struthioloides* (no species of *Silene* were recorded in her 1990 survey of Hale Pōhaku). It is possible that the *Silene* species at Hale Pōhaku are all *Silene struthioloides*, but this would need to be confirmed with a comprehensive vegetation survey.

All of the Threatened and Endangered plant species listed above have been impacted by grazing, habitat alteration, and invasive plant species.

Māmane woodlands are critical habitat for the endangered Palila (*Loxioides bailleui*), a bird now found only in māmane woodlands on Mauna Kea (Juvik and Juvik 1984). More information about the Palila can be found in Section 2.2.3. Information on the fauna found in the subalpine woodlands is presented in Sections 2.2.2 through 2.2.4.

2.2.1.1.2 Candidate Species and Species of Concern

The only federal and state Candidate species found in the subalpine community on Mauna Kea is makou (*Ranunculus hawaiensis*). Makou, an endemic buttercup, was once very plentiful in subalpine and alpine communities (Rock 1913; Hartt and Neal 1940). Makou populations have decreased due to predation by slugs and feral animals such as pigs, goats, cattle, and sheep, and competition with invasive plant species (USFWS 2006).

State Species of Concern in the subalpine community include ʻakoko (*Chamaesyce olowaluana*), Douglas' bladderfern (*Cystopteris douglasii*), Mauna Kea dubautia (*Dubautia arborea*), and Hawaii black snakeroot (*Sanicula sandwicensis*).

ʻAkoko, a small tree in the family Euphorbiaceae, was once common in the subalpine forest, but has been reduced in abundance, primarily due to fire and grazing of small trees and saplings by feral ungulates (Shaw 1997). Feral sheep and goats also girdle larger trees by stripping bark from their trunks (Shaw 1997).

Douglas' bladderfern is an endemic fern found in low densities in both subalpine and alpine communities. It was not recorded as occurring at Hale Pōhaku by Char (1985, 1999a) or Gerrish (1979). However, it was recorded by Smith et al. (Smith et al. 1982) as occurring on the summit. This species is discussed further in Section 2.2.1.2.5.

The Mauna Kea dubautia is a large shrub or small tree found in subalpine and alpine communities on Mauna Kea. Dubautia are closely related to silverswords *(Argyroxiphium)*, and often form hybrids with other *Dubautia* species and with members of the genus *Argyroxiphium* (Carr 1985).

Hawaii black snakeroot is an herb in the Apiaceae family. It is restricted to subalpine woodland and shrublands on Maui and Hawaiʻi (Wagner et al. 1990). Little information is available about this species.

Most of these species have been greatly reduced in abundance due to grazing by feral animals, habitat alteration, and competition with introduced plants (Wagner et al. 1990).

2.2.1.1.3 Vegetation Surveys at Hale Pōhaku

Since 1979, there have been four qualitative[9] botanical surveys at Hale Pōhaku: a 1979 study of the Hale Pōhaku area and two other locations by Grant Gerrish (Gerrish 1979), a 1985 study of the proposed construction camp site and staging areas by Char (Char 1985), a 1990 study of the proposed dormitory area for the Subaru Japan National Large Telescope (JNLT), also conducted by Char (Char 1990), and a 2004 survey of a small area in the construction staging area at the lower limit of the Hale Pōhaku facility (Pacific Analytics 2004). There have been no surveys at Hale Pōhaku for fungi or lichens.

Gerrish (1979) surveyed two areas: The area now occupied by the upper buildings at the Mid-Elevation Facilities (between approximately 9,260 ft and 9,330 ft elevation) is termed Zone 1. The second area immediately to the south (Zone 2 or "proposed park"), is now the parking lot, stone cabins, and storage buildings for the lower Mid-Elevation Support Facilities. Zone 2 comprises an area from approximately 9,200 ft to 9,260 ft elevation. Gerrish does not discuss his methodology other than to state that the area was explored by foot and that "each part of the site was visited several times." No quantitative data were recorded, except for a rough count of māmane trees on the site, although locations of several plants of interest (*Geranium cuneatum, Stenogyne rugosa,* and *Stenogyne microphylla*) were recorded on a figure (see Figure 2.2-5 for a reproduction of this figure).

In 1985, Winona Char and an assistant conducted botanical surveys of three areas proposed for the location of the temporary construction camp housing at Hale Pōhaku. The three areas consisted of an area northeast of the existing Mid-Elevation Support Facilities (Area II in Char 1985), and two areas immediately south of the Visitor's Information Station (Areas IA and IB in Char 1985). See Figure 2.2-6 for a reproduction of Char's survey transect figure. Char states that "an intensive walk-through survey method was used." Char recorded no quantitative data on species abundances; however, she noted species composition at the three areas surveyed, and presented these data in the species-list table included in her report. Thus it is possible to determine how widespread a given species was in the surveyed areas at Hale Pōhaku during that time period, and where areas of higher diversity were. For example, Area II of her report had 37 of the 42 species found, while area IA had 30, and Area IB had only 18.

Char's 1990 study consisted of an "intensive walk through survey" of the Hale Pōhaku Dormitory area, as part of an assessment conducted for the Subaru (JNLT) telescope mid-level facilities (Char 1990). The region covered was similar to that of Gerrish (1979), although she covered a little less area. See Figure 2.2-7 for a reproduction of Char's (1990) survey area. Much of the groundcover in the area of the actual dormitories had previously been removed for the construction of the Keck dormitory. No quantitative data on species abundances were recorded. No Threatened or Endangered species were observed during the survey, and Char does not mention the presence of *Silene hawaiiensis*, recorded in her earlier survey at Hale Pōhaku (Char 1985). Char mentions in the report that two weedy species previously not recorded from Hale Pōhaku were found during this survey: rabbit-foot clover (*Trifolium arvense*) and telegraph weed (*Heterotheca grandiflora*).

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[9] A qualitative botanical survey identifies the plant species in an area and may estimate abundances (e.g., common, rare) based on the observer's opinion, without recording actual data on population sizes or distributions. A quantitative study records the species and provides a measure of population sizes (or densities), usually by counting individuals in a given area such as a transect. Most of the botanical surveys conducted at Hale Pōhaku and in the MKSR have been qualitative.

In 1999, Char produced a report summarizing the findings of her previous three plant surveys and personal observations of the conditions at Hale Pōhaku (Char 1999a). She did no additional survey work for this report. Findings from this report are summarized above in Section 2.2.1.1.

In 2004, a botanical survey was conducted in the 0.5 acre (0.2 ha) construction staging area at the lower limits of the Hale Pōhaku facility. The survey was conducted to determine if using the staging area for construction of additional Keck telescopes would impact the native vegetation (and the endangered Palila habitat) (Pacific Analytics 2004). The survey area has been used for construction staging since 1990 and is also used for overflow parking at the Visitor Information Station. The survey covered the entire staging area and a buffer of 100 ft. (31 m) around the staging area (see Figure 2.2-8). Survey methodology is not described, and the survey found no māmane trees within the staging area (and, in fact, it found very little vegetation at all), but did find māmane in the 100 ft. buffer area. Groundcover at the site consisted mainly of the invasive ripgut brome (*Bromus diandrus*), scattered native alpine hairgrass (*Deschampsia nubigena)* and pili uka (*Trisetum glomeratum)*, and invasive needlegrass, *Nassella cernua* (called *Stipa cernus* in the report). Other species found in the survey include common groundsel (*Senecio vulgaris*), pin clover (*Erodium cicutarium*), common mullein (*Verbascum thapsus*). Pacific Analytics also recorded the presence of evening primrose (and included a photo), but mistakenly gave the scientific name for willow herb (*Epilobium billardierianum* ssp. *cinereum*), another non-native herb in the same plant family as evening primrose. The correct scientific name for evening primrose is *Oenothera stricta* ssp. *stricta*. Both willow herb and evening primrose are present at Hale Pōhaku. Other than the māmane trees and scattered native grasses, no native plants were observed within the surveyed area (Pacific Analytics 2004).

2.2.1.2 Alpine Plant Communities (Summit Access Road and MKSR)

Alpine plant communities on Mauna Kea begin just above the treeline, at approximately 9,500 ft (2,900 m), and rise to the summit of the mountain at 13,795 ft (4,205 m). The alpine plant communities can be divided into three basic types: shrublands, grasslands, and stone desert. There are no sharp lines of delineation between the plant community types; the three communities grade into one another, beginning with the alpine shrubland at the treeline, which grades into the alpine grasslands, and culminates with the alpine stone desert, at the summit (Mueller-Dombois and Fosberg 1998; Char 1999b; Conant et al. 2004; Aldrich 2005).

There have been few detailed studies of the alpine plant communities on Mauna Kea, although there are some useful descriptive historical accounts (Hartt and Neal 1940, and references therein). The three community types are all characterized as being predominantly barren rock and cinder with sparse vegetation (Aldrich 2005). Plant density decreases with increasing elevation, with the result that there are only scattered plants at the higher elevations. The alpine shrublands are inhabited mainly by low-lying shrubby species, while the upper elevations are inhabited by grasses and herbaceous species (Mueller-Dombois and Fosberg 1998). Heavy grazing by feral ungulates has decimated the plant communities in the alpine shrublands and grasslands (Hartt and Neal 1940; Mueller-Dombois and Fosberg 1998), and invasive plant species now compete with native plants for limited resources such as water and sheltered growing locations. The three plant communities are described in further detail in Sections 2.2.1.2.1 through 2.2.1.2.3. Threats to the alpine plant communities are described in Section 2.2.1.3, and information gaps are discussed in Section 2.2.1.4.

2.2.1.2.1 Alpine Shrubland

The alpine shrublands on Mauna Kea are dominated by pūkiawe (*Leptecophylla tameiameiae*), and are often referred to as Leptecophylla shrublands[10] or scrub desert (Mueller-Dombois and Fosberg 1998; Char 1999b; Aldrich 2005). Leptecophylla shrublands are the dominant plant community from the treeline at 9,500 ft (2,900 m) to around 11,150 ft (3,400 m) above sea level (Mueller-Dombois and Fosberg 1998). These shrublands are also found below the treeline in the subalpine zone, as mentioned in Section 2.2.1.1. The density and diversity of plant species found in the Leptecophylla shrublands decreases with increasing altitude, from the subalpine region to the alpine region. At the upper elevations of its range, the Leptecophylla shrublands consist mainly of scattered pūkiawe shrubs and tufts of native grasses (Mueller-Dombois and Fosberg 1998).

Native herbs and shrubs commonly found in Leptecophylla shrublands include ōhelo (*Vaccinium reticulatum*), alpine catchfly (*Silene struthioloides*), and Mauna Kea dubautia (*Dubautia arborea*). Native ferns found in this community include Douglas' bladderfern (*Cystopteris douglasii*), kalamoho (*Pellaea ternifolia*), ʻolaliʻi (*Asplenium trichomanes*), and ʻiwaʻiwa (bird's nest ferns, *Asplenium adiantum-nigrum*). Native grasses found in Leptecophylla shrublands include Hawaiian bentgrass (*Agrostis sandwicensis*), and pili uka (*Trisetum glomeratum*). Species historically common, but now uncommon, found in this community include ʻāhinahina (the Mauna Kea silversword, *Argyroxiphium sandwicense* ssp. *sandwicense*), lava dubautia (*Dubautia ciliolata* ssp. *ciliolata*), ʻōhelo papa (Hawaiian strawberry, *Fragraria chiloensis*), ʻena ʻena (*Pseudognaphalium sanwicensium*)[11], nohoanu (*Geranium cuneatum* ssp. *hololeucum*) and alpine tetramolopium (*Tetramolopium humile* ssp. *humile* var. *humile*). See Section 2.2.1.2.4 for more information about the silversword and other rare species found in the alpine shrublands.

There are several non-native plant species that have taken hold in the alpine shrublands on Mauna Kea. Non-native herbs found in this community include hairy cat's ear (*Hypochoeris radicata*), sheep sorrel (*Rumex acetosella*), common mullein (*Verbascum thapsus*), fireweed (*Senecio madagascariensis*), and the common dandelion (*Taraxacum officinale*). Historically recorded non-native herbs include big chickweed (*Cerastium fontanum*), bull thistle (*Cirsium vulgare*), hairy horseweed (*Conyza bonariensis*), and woodland groundsel (*Senecio sylvaticus*). Although they were not recorded in the MKSR by Char (1999), who did not survey below 12,000 ft (3,650 m), these species are likely still found in the alpine shrubland community on Mauna Kea. Non-native grasses found in the Leptecophylla shrublands include Kentucky bluegrass (*Poa pratensis*), and historically, annual bluegrass (*Poa annua*), and velvet grass (*Holcus lanatus*).

Common mullein (*Verbascum thapsus*) and sheep sorrel (*Rumex acetosella*) were observed to be abundant along the Summit Access Road in the lower regions of the alpine shrubland plant community in October 2007 (J. Garrison, personal observation), and have been found at the summit near the observatories (Ansari 2008). These species are discussed in more detail in Section 2.2.1.3.3.

[10] Formerly called Styphelia shrublands in older references, due to a name change for pūkiawe from *Styphelia tameiameiae* to *Leptecophylla tameiameiae*. Some scientists further divide the shrublands into *Leptecophylla* alpine-scrub (9,500–10,500 ft/2,900–3,200 m) and *Leptecophylla* low-scrub desert (10,500–11,150 ft/3,200–3,400 m) (Mueller-Dombois and Fosberg 1998). The *Leptecophylla* Alpine-scrub is composed of primarily of tall densely growing pūkiawe shrubs. The *Leptecophylla* Low-scrub Desert is composed of scattered, low-growing pūkiawe shrubs, two native grasses (*Agrostis sandwicensis* and *Trisetum glomeratum)*, three native fern species (*Pellaea ternifolia, Asplenium adiantumnigrum, A. trichomanes*), two native composites (*Tetramolopium humile, Pseudognaphalium sandwicensium*), and one invasive weed, hairy cat's ear, *Hypochoeris radicata* (Mueller-Dombois and Fosberg 1998; Conant et. al 2004).

[11] Called *Gnaphalium sandwicensium* in older references.

Alpine Fungal Communities

Very little information is available regarding the fungal communities present in the alpine regions on Mauna Kea. The stalked puff-ball *(Tulostoma fimbriata* var. *campestre)* can be found growing above the treeline, often in association with plants such as the silversword (Hemmes and Desjardin 2002). A study of the endangered silversword (*Argyroxiphium sandwicense* ssp. *macrocephalum*), and na'ena'e (*Dubautia menziesii*) on Haleakalā, Maui, found that both species formed associations with AM fungi, including *Entrophospora infrequens* and several unidentified species in *Glomus, Scutellosopra,* and *Acaulospora* (Koske and Gemma 2002). It can be assumed that similar relationships can be found between AM fungi and *Argyroxiphium* and *Dubautia* species found on Mauna Kea.

2.2.1.2.2 Alpine Grassland

Alpine grasslands replace Leptecophylla shrublands around 11,000 ft in elevation (3,400 m), although *Leptecophylla* (pūkiawe) shrubs can be found in all habitats, clear to the summit (Mueller-Dombois and Fosberg 1998). The alpine grasslands on Mauna Kea, which occur up to 12,800 ft (3,900 m) in elevation, are dominated by two native grasses, Hawaiian bentgrass (*Agrostis sandwicensis*), and pili uka (*Trisetum glomeratum*) (Mueller-Dombois and Fosberg 1998). Char (1999b) recorded that the Hawaiian bentgrass was more abundant than pili uka, although both are found at very low densities. Other native species found in the alpine grassland community include those found in the alpine shrubland communities, although at much lower densities.

Very few good stands of alpine grassland currently exist due to overgrazing by feral and domestic sheep and goats.

2.2.1.2.3 Alpine Stone Desert

The alpine stone desert plant community is found above 12,800 ft (3,900 m) on Mauna Kea (Mueller-Dombois and Fosberg 1998). This plant community consists of several species of mosses and lichens, an unknown number of species of algae, and a limited number of vascular plants, predominantly the same species found in the alpine shrublands and grasslands (Hartt and Neal 1940; Char 1999b; Aldrich 2005). Most of the species of plants found in the region are endemic (occurring only in Hawai'i) or indigenous (native to Hawai'i but occurring elsewhere). A few non-native plant species have also become established here, even at the summit (Hartt and Neal 1940; Char 1999b). The composition of this plant community is discussed in more detail below in Sections 2.2.1.2.3.1 and 2.2.1.2.3.2.

High wind speeds, high solar radiation, regular freezing and thawing cycles, low precipitation, high rates of evaporation, and the porosity of the substrate all limit the development of the plant and animal communities in this zone (Aldrich 2005). Plant density is extremely low in this high elevation climate, and plant distribution is determined primarily by substrate type (Smith et al. 1982). Cinder cones do not provide suitable growing habitat for most plants because of the instability of the surface material, which is destructive to plant root systems, and the high porosity of cinders, which allows for rapid water drainage (Hartt and Neal 1940; Char 1999b). Additionally, the absence of organic matter in the soil further decreases its ability to hold water (Hartt and Neal 1940), making water and available nutrients limiting resources in this region.

Mosses and lichens are found in protected areas on andesite (Hawaiite-mugearite) lava flows, in pits, fissures, small caves, overhangs and shaded pockets and crevices (Char 1999b). Vascular plants are found mainly at the base of rock outcrops where there is an accumulation of soil and moisture, and some protection from wind (Char 1999b). Aeolian and colluvial material found scattered throughout the lava flows in low-lying swale areas provide poor habitat for plants (Char 1999b).

2.2.1.2.3.1 Algae, Lichens, and Mosses

Algae species have not been extensively surveyed in the alpine stone desert on Mauna Kea. Several species of algae and diatoms are found in Lake Waiau (Massey 1978), and one species of algae (*Haematococcus* sp.) is known to occur on snow banks, staining the snow red (Smith et al. 1982; Aldrich 2005). There are undoubtedly species of algae present in the soils of Mauna Kea (Smith et al. 1982).

Lichens are a symbiotic relationship between a fungus (generally an Ascomycete) and a green alga, a blue green bacterium, or both (Hemmes and Desjardin 2002). A survey of lichens found on Mauna Kea was conducted in 1982 by Smith, Hoe, and O'Conner. They identified 21 species of lichens and five possible other species that could not be collected because they were crustose species imbedded in the andesite flows. A complete list of lichen species observed on Mauna Kea is presented in Table 2.2-4. Around half of the lichen species found on Mauna Kea are endemic, two of which (*Pseudephebe pubescens* and *Umbilicaria pacifica*) are limited to Mauna Kea alone (Smith et al. 1982; Char 1999b). *Pseudephebe pubescens,* a species primarily found in high altitude and alpine regions of the world (Smith et al. 1982), has not been recorded anywhere else in Hawai'i or on any other tropical island. The remaining species were indigenous to the Hawaiian Islands. *Lecanora muralis* is the most abundant lichen on Mauna Kea, and is found throughout the summit, on all substrate types, including cinders and colluvial material on the cinder cones up to the summit of Pu'u Wēkiu (Smith et al. 1982). Other common species on the summit are *Lecidea skottsbergii* and *Candelariella vitellina,* both of which are found on rocks "larger than a small fist" (Smith et al. 1982).

Lichens are found throughout the summit of Mauna Kea, but the highest densities and diversity of lichens tends to be found on andesite rocks, in north- and west-facing protected locations, away from direct exposure to the sun (Smith et al. 1982). Areas to the west of the major cinder cones have a low density and diversity of lichens, most likely due to a rain shadow effect created by the cinder cones (Smith et al. 1982).

Two areas of high lichen concentration and unique assemblages were identified by Smith et al. (1982): the southern slope of Pu'u Wēkiu, just below the Switchback Road (Intensively Studied Area 7), and the lava flows north of Pu'u Poli'ahu (Intensively Studied Areas 2, 3, and 4) (Smith et al. 1982). The southern slope of Pu'u Wēkiu has many large rocks, and it supports the "highest substantial colony of lichens in the state" (Smith et al. 1982). The lava flows north of Pu'u Poli'ahu are characterized by a high diversity of lichens, including *Pseudephebe pubescens* (Smith et al. 1982).

Using information from Smith *et al.* (1982), Char (1999b) identified four lichen communities on the summit of Mauna Kea, based on species composition, substrate, and orientation (north-south). These lichen communities include: 1) nearly vertical north-facing andesite rocks characterized by an association of *Umbilicaria hawaiiensis, Pseudephebe pubescens,* and *Lecanora muralis*; 2) vertical west-facing andesite rocks characterized by a mixed association of *Acarospora depressa, Candelariella vitellina, Lecanora muralis, Lecidea skottsbergii, Lecidea vulcanica, Physcia dubia, Rhizocarpon geographicum,* and *Umbilicaria hawaiiensis*; 3) south-facing rocks characterized by an association of *Umbilicaria pacifica, Physcia dubia, Lecanora muralis, Candelariella vitellina,* and *Lecidea skottsbergii*; and 4) cinder cones, deposits of aeolian or colluvial material on lava flows, and scattered rocks and cobbles. Diversity of species was low on cinder cones and on aeolian and colluvial materials on lava flows, with only the most common lichen species present, such as *Lecanora muralis*. *Candelariella vitellina* and

Lecidea skottsbergii are found on small rocks or cobbles scattered throughout the cinder and colluvial material (Char 1999b). In addition, there are numerous small caves throughout the summit region that are colonized by *Lepraria* species. *Lepraria* can tolerate deep shade and can be found up to three meters deep in some of the larger caves (Smith et al. 1982).

Mosses in the alpine stone desert occur in protected places where water is more consistently available, such as under overhanging rocks and in shaded crevices or caves where snow melts slowly (Smith et al. 1982). Mosses are predominantly found on the north-northeast and south-southeast facing sides of rocky mounds, generally in association with runoff channels from snow melt (Smith et al. 1982). Moss cover was much lower in the rain-shadow region west of the summit cone, due to the more arid conditions (Smith et al. 1982). Mosses have not been observed in loose cinders or on the aeolian or colluvial fields (Char 1999b).

Smith et al. (1982) conducted a survey of the mosses on the Mauna Kea summit area (above 13,000 ft, 3,960 m) and found approximately 12 species (some could not be identified with certainty to the species level), most of which are indigenous to the Hawaiian Islands. Two species, *Bryum hawaiicum* and *Pohlia mauiensis* are endemic (Smith et al. 1982). All the moss species found there are related to temperate species. The most common species of moss were a previously undescribed species of *Grimmia* and *Pohlia cruda* (Smith et al. 1982).

Grimmia are silvery-gray mosses that form clumps in run-off channels and semi-exposed rock faces. Members of this genus are the mosses most often seen at the summit (Smith et al. 1982). *Pohlia cruda* is a bright green moss found in well-protected, deeply shady locations. Pohlia species are so well hidden they are unlikely to be seen by the causal observer (Smith et al. 1982). The remaining moss species were not as abundant and tended to occur in habitats intermediate between the somewhat exposed *Grimmia* habitats and the protected *Pohlia* habitats (Smith et al. 1982). A complete list of mosses observed on the summit of Mauna Kea is presented in Table 2.2-5.

2.2.1.2.3.2 Vascular Plants

Very few species of vascular plants are found within the summit area (Smith et al. 1982; Char 1999b). The most abundant native vascular plant species found at this elevation are two grass species, Hawaiian bentgrass (*Agrostis sandwicensis*) and pili uka (*Trisetum glomeratum*), and two fern species, ʻiwaʻiwa (*Asplenium adiantum-nigrum*) and Douglas' bladderfern (*Cystopteris douglasii*). Of these four species, Hawaiian bentgrass is the most common. The grasses tend to be found at the bases of large rock outcroppings where fine substrate and moisture accumulate (Char 1999b). The native fern, ʻiwaʻiwa, is found on cinder plains and lava flows from the summit down to approximately 2,000 ft (610 m) (Valier 1995; NASA 2005). Douglas' bladderfern grows on weathered rocks up to 13,400 ft elevation (4,084 m) (Char 1999b). Historically, the Mauna Kea silversword (*Argyroxiphium sandwicense* ssp. *sandwicense*), pūkiawe (*Leptecophylla tameiameiae*), ōhelo (*Vaccinium reticulatum*), and alpine catchfly (*Silene struthioloides*) have been observed at or near the summit (Hartt and Neal 1940; Mueller-Dombois and Fosberg 1998). Some of these plants may still be present in more remote, unsurveyed areas.

Non-native species found in the alpine stone desert include Hairy cat's ear *(Hypochoeris radicata)* and common dandelion (*Taraxacum officinale*), both of which are temperate weed species with a world-wide distribution (Smith et al. 1982; Char 1999b). Non-native species historically observed in the alpine stone desert include annual bluegrass (*Poa annua*), Kentucky bluegrass (*Poa pratensis*), big chickweed (*Cerastium fontanum* ssp. *vulgare*), bull thistle (*Cirsium vulgare*), hairy horseweed (*Conyza bonariensis*), sheep sorrel (*Rumex acetosella*), and common chickweed (*Stella media*) (Hartt and Neal 1940). Individuals or populations of these species may still be present in the area.

Smith et al. (1982) observed fragments from other vascular plant species, including one grass and one legume species. As they were unable to locate the source of these fragments, they postulated that these species were blown up to the summit by wind. Wind-borne seeds and plant fragments from lower elevations may act as sources for invasive plant species to the alpine regions of Mauna Kea, although many lowland species will not be able to grow there due to the harsh conditions.

2.2.1.2.4 Threatened and Endangered Species

'Āhinahina (the Mauna Kea silversword, *Argyroxiphium sandwicense* ssp. *sandwicense*) is the only federally Endangered species found in the alpine vegetation communities on Mauna Kea. The Mauna Kea silversword is a subspecies of silversword found only on Mauna Kea, and historically occurred from 8,500 ft (2,700 m) to 12,300 ft (3,750 m) (Wagner et al. 1990; Robichaux et al. 2000). Hartt and Neal (1940) describe the silversword as being found as low as 6,000 ft (1,830 m) in elevation in historical times. 'Āhinahina is a spectacular plant, with thick, sword-shaped, shiny, silvery-green leaves growing in a giant rosette. When it flowers, the Mauna Kea silversword grows a large stalk, up to nine feet tall, that is covered with up to 600 pink to wine-red flowers (Wagner et al. 1990).

Although they are now extremely rare, the Mauna Kea silversword was once so common on Mauna Kea that the dry leaves and stems were used as fuel for campfires (Cuddihy and Stone 1990). The population size of the Mauna Kea silversword has been drastically reduced through grazing by feral sheep (*Ovis aries*), goats (*Capra hircus*), mouflon sheep (*Ovis musimon*), and cattle (*Bos taurus*) (Hartt and Neal 1940; USFWS 1994; Robichaux et al. 2000). Their numbers began decreasing after the introduction of grazing animals, and the species was already rare as early as 1892, only 99 years after the introduction of the first grazing animals on Hawai'i (Hartt and Neal 1940). By the 1970s there were only 34 individual silversword plants known to exist on Mauna Kea (Forsyth 2002). Although the impact of grazing ungulates on the silversword and other vegetation on Mauna Kea was recognized early on (Hartt and Neal 1940), the efforts to control feral ungulates on the mountain have waxed and waned over time, and grazing animals have never been eliminated from Mauna Kea (Juvik and Juvik 1984).

Recovery efforts for the Mauna Kea silversword are underway through the efforts of the U.S. Fish and Wildlife Service (USFWS), the Division of Forestry and Wildlife (DOFAW), and University of Arizona plant biologist Dr. Rob Robichaux. The recovery effort comprises an outcrossing program[12] in the field, greenhouse propagation of seeds, and outplanting seedlings into the wild (Aldrich 2005). To date over 4,000 seedlings have been outplanted in protected areas in the wild. There are currently five active, fenced outplanting exclosures of the Mauna Kea silversword in the alpine shrubland and grassland areas on Mauna Kea, and one naturally occurring population at Waipahoehoe gulch (USFWS 1994; Aldrich 2005). Recently, a small population of Mauna Kea silverswords was discovered in the MKSR (Nagata 2007; Tomlinson 2007).

Due to the drastic reduction in population size, and early propagation attempts using only three individual plants as founders for outplanted populations, the silversword has gone through a genetic bottleneck and lost some genetic diversity (Robichaux et al. 1997; Friar et al. 2000). Adding to the problem, there are

[12] Outcrossing is the process whereby the pollen from the flower of one plant is placed, by hand, on to the receptive area of the flower of another plant, usually some distance away. Because the Mauna Kea silversword is self-incompatible (meaning that it cannot pollinate itself), the outcrossing program ensures that each plant receives pollen from an unrelated (or at least less closely related) plant. This protects the genetic diversity in the species and ensures a higher output of viable seed from individual plants.

still feral ungulates on Mauna Kea, making establishment of the species outside of fenced areas difficult. The recovery of the Mauna Kea silversword is further hampered by its own biology. Silverswords only flower once in their lifetime, and then die. It takes from three to fifty years for the plant to reach maturity and flower (USFWS 1994). If the flower bud is eaten or destroyed prior to seed dispersal, the plant dies and does not produce another flowering stalk (Bryan 1973). Additionally, the silversword cannot pollinate itself, and must rely on insect pollination (Carr et al. 1986; USFWS 1994). The abundance and diversity of pollinating insects in high elevation areas on Mauna Kea is limited – only the native yellow-faced bee, *Hylaeus flavipes*, has been observed foraging in these areas in recent times (Daly and Magnacca 2003; Aldrich 2005). Although there are some moth species that visit the silversword (USFWS 1994), it is thought that their home ranges are too small to effectively cross-pollinate plants (Aldrich 2007). In areas with low silversword population density, pollinator activity may not be sufficient to allow for enough pollen exchange to produce viable seeds (USFWS 1994). To worsen the pollination situation, native insect populations may be being impacted by introduced ants and yellowjackets, further reducing pollinator movement between plants (Cole et al. 1992; Robichaux et al. 2000; Banko et al. 2002; Aldrich 2005).

2.2.1.2.5 Candidate Species and Species of Concern

There are no federal or state Candidate species found in the alpine regions of Mauna Kea. There are two state Species of Concern found in this region, Mauna Kea dubautia (*Dubautia arborea*) and Douglas' bladderfern (*Cystopteris douglasii*).

Dubautia arborea, or na'ena'e is a small tree or shrub found in subalpine and alpine communities on Mauna Kea. Dubautia are closely related to silverswords (*Argyroxiphium* spp.), and often form hybrids with other Dubautia species and with species of *Argyroxiphium* (Carr 1985). Its numbers have been reduced due to grazing by feral animals, habitat alteration, and competition with introduced plants (Wagner et al. 1990; World Conservation Monitoring Centre 1998).

Cystopteris douglasii is a small, endemic bladderfern that grows on weathered rocks exposed to trade winds (Char 1999b). *C. douglasii* on Mauna Kea is unusual because other members of this genus grow in more-protected microclimates (Char 1999b). It is found only from high elevation areas on Maui and Hawai'i. Char (1999b) believes that the Mauna Kea *Cystopteris douglasii* may represent a new variety or even a new species of *Cystopteris*. This already rare species is threatened by habitat alteration, invasive species, and grazing animals (Hawaii Biodiversity and Mapping Program n.d.).

2.2.1.2.6 Vegetation Surveys in MKSR

There have been no quantitative vegetation surveys in the MKSR. There are many descriptive historical accounts of the vegetation on Mauna Kea, dating back to 1826, and one of the more detailed historical vegetation accounts was conducted by Hartt and Neal in 1935 (Goodrich 1826; Baldwin 1890; Alexander 1892; Douglas 1914; Hartt and Neal 1940). The Hartt and Neal study lists all plant species collected on Mauna Kea during the 1935 botanical survey of the mountain, including the highest elevation at which each species was seen. This study provides valuable information on historical presence of species on the mountain that can serva as a baseline with which to compare modern day surveys.[13]

[13] Plant species recorded by Hartt and Neal (1940) can be identified in Tables II.2-3 through II.2-5 by the number 3 in the Reference (Ref.) column.

In the past 25 years there have been four qualitative botanical surveys conducted in the MKSR. In 1982, C.W. Smith, W.J. Hoe, and P.J. O'Conner conducted a thorough descriptive vegetation study in a limited region at the summit of Mauna Kea. Figure 2.2-9 shows the locations of their surveys, which were limited to "only those regions considered for future telescope construction to the year 2000 as described in the MKSR Master Plan (July 1982)" (Smith et al. 1982). This vegetation survey covered seven "intensively studied" areas, which were carefully searched to get a detailed record of the species of lichens, mosses, and vascular plants present. The report does not provide information on type of survey methods used (e.g., transects, random sample locations, wandering searches, systematic searches) in the intensively studied areas. Figure 2.2-9 also shows the "reconnaissance areas" included in the study, but provides no detail on what level of effort was put into detailing plant species found in these areas. The report does state that "no formal quantitative sampling was undertaken because the amount of cover was too low for conventional techniques" (Smith et al. 1982). Most of the information on moss and lichen species in the MKSR presented in this Natural Resources Management Plan comes from this report.

The other three recent plant surveys in the MKSR were conducted by Winona Char. In 1988, Char conducted a survey of the proposed site for the Very Long Baseline Array (VLBA) antenna facility, between 12,200 and 12,400 ft (3,720 and 3,780 m) elevation, and an for alternative site at 11,800 ft (3,600 m) elevation (MCM Planning 1988). A "walk-through" survey method was used in this study. The report provides a species list, recording present/absence of species at the proposed site, the alternative site, and the Summit Access Road near the site. Species recorded were a subset of those found by Smith et al. (1982). In 1992, Char conducted a rapid survey for lichen species in the future location of the Smithsonian Radio Telemetry Facility, to aid in placement of the pads to avoid areas of high lichen abundance (MCM Planning 1994). No data on species abundance or composition are presented in this report. In 1999, Winona Char produced another report on the plant communities of the summit area of Mauna Kea. Most of the information in the 1999 report came from the Smith et al. (1982) vegetation survey. Information was also gathered by Char on June 21, 1999, during a "reconnaissance-level field survey" of the "slope beyond the summit ridge and to the northwest of the summit ridge", in the areas proposed for the "Next Generation Large Telescope and the Optical Interferometer Array Site" (Char 1999b). No information on survey methodology is provided in the report, and no information is provided on the species located in these specific areas. Unfortunately, although the report states there is a map showing survey locations, no map was present in the copy of the reports provided with the Master Plan. A list of species observed, and their relative abundance is provided, although there is no information on how relative abundance was established.

There have been no studies of vegetation communities on Mauna Kea between the upper edge of Hale Pōhaku (9,340 ft/ 2,850 m) and 11,800 ft (3,600 m). No formal surveys have been conducted in the Ice Age Natural Area Reserve (NAR), although records are opportunistically kept when species of interest (particularly native species, or expansion of invasive species ranges) are noted.

2.2.1.3 Threats to Botanical Communities on Mauna Kea

Threats to the subalpine and alpine botanical communities on Mauna Kea include habitat alteration for development, agriculture and livestock grazing, fire (in the subalpine and lower alpine communities), invasive plant species, non-native animals (such as feral goats, sheep, rats and arthropods), human uses, and climate change.

2.2.1.3.1 Habitat Alteration

Habitat alteration threatens native plant communities by changing the growth environment to the extent that the species can no longer survive there. Examples of habitat alteration on Mauna Kea include agriculture, livestock grazing (in the subalpine zone), and development (buildings and infrastructure such as roads, parking lots, etc.). Invasive species may also alter habitat to make it unsuitable for native plant species. Invasive plant species are further discussed in Section 2.2.1.3.3. For Hale Pōhaku and the MKSR, most habitat alteration occurs through development such as building of new telescopes and associated facilities, use of unpaved areas for parking lots, off-road vehicle use, the spread of invasive plants, and grazing by feral ungulates. The effects of non-native animal species on the plant communities are further discussed in Section 2.2.1.3.4.

2.2.1.3.2 Fire

Subalpine communities on Mauna Kea are susceptible to fire because of the dry conditions there. Alpine communities are not as susceptible because of the low density of plants. Many native Hawaiian plants such as pūkiawe (*Leptecophylla tameiameiae*) are not fire tolerant (Hughes et al. 1991; Smith and Tunison 1992). Fires in subalpine woodland are rare natural events (Hess et al. 1999). However, fires from military training activities at Pohakuloa Training Area and accidental wildfires set along roadsides, near developments, and in recreational areas pose a threat to the subalpine dry forest and shrubland communities (Gagné and Cuddihy 1990). The presence of invasive grass species in the subalpine communities increases the risk of fire by providing a source of continuous fine fuels in areas that previously had naturally discontinuous fuel beds due to the patchy nature of the subalpine communities (Smith and Tunison 1992; Hess et al. 1999). Several species of invasive grasses also increase greatly in abundance after fires (Hughes et al. 1991), effectively inhibiting germination of native species such as māmane (Hess et al. 1999). Velvet grass (*Holcus lanatus*) and sweet vernalgrass (*Anthoxanthum odoratum*) are two species that increase rapidly after fires and provide fuels for further fires (Smith and Tunison 1992). Fountain grass (*Pennisetum setaceum*) is another extremely fire-prone species that grows in dense clumps and can alter the natural fire regime of an area (Smith and Tunison 1992; Benton 2006). This species, normally found at lower elevations, was recently discovered (and removed) at 9,000 ft (2,740 m) in Pohakuloa Training Area on Mauna Loa (Higashino 2008).

2.2.1.3.3 Invasive Plants

Non-native, invasive plant species can impact native plant communities by altering the environment, for example, by lowering groundwater table, changing fire regimes, increasing or decreasing shade, smothering plant growth. They also compete with native plants for limited resources such as nutrients, water and light, and can attract or support increased populations of herbivores and disease or parasite organisms. Invasive plants may also affect the mycorrhizal fungi that native Hawaiian plants rely on, and conversely, the presence of mycorrhizal fungi can either enhance or reduce an invasive species' success in colonizing a new area (Stampe and Daehler 2003). One study found that some non-mycorrhizal invasive plants release antifungal chemicals that destroy or weaken the mycorrhizal soil communities and thus negatively impact the native species that rely on these fungi (Stinson et al. 2006). Another recent study found that the presence of invasive plant species can alter the diversity and composition of mycorrhizal fungal communities, which in turn could impact native plant communities (Hawkes et al. 2006). Other studies have suggested that the presence of mycorrhizal fungi may enhance the ability of some non-native plants to invade and compete with native species, and in some cases actually aid in the transfer of nutrients from the native plants to the invasive ones (Marler et al. 1999; Carey et al. 2004).

There are 151 recorded species of non-native plants in the Hawaiian Islands that grow above 6,500 ft (2,000 m), of which around 14% (21 species) are reported as being disruptive to native plant communities (Daehler 2005). Invasive plants currently found in the subalpine and alpine plant communities at Hale Pōhaku and MKSR include the non-native grasses described in Section 2.2.1.3.3 and invasive herbs such as common mullein (*Verbascum thapsus*) and fireweed (*Senecio madagascariensis*). The most common invasive plant species found in the subalpine and alpine regions of Mauna Kea are discussed below. See Figure 2.2-4 for photos of common invasive species found at Hale Pōhaku and MKSR.

Grasses: Invasive grasses such as needlegrass (Nassella cernua), ripgut brome (Bromus diandrus), orchardgrass (Dactylis glomerata), velvet grass (Holcus lanatus), rye grass (Lolium sp.), Kentucky bluegrass (Poa pratensis), and sweet vernalgrass (Anthoxanthum odoratum) are common in the subalpine regions of Mauna Kea. As discussed in Section 2.2.1.3.2, dense growth of invasive grasses increases the risk of fire in the dry subalpine zone by providing a continuous fuel source. In addition to increasing the risk of fire, invasive grasses compete with native species for nutrients and water, and directly impede regeneration of native plants by smothering seedlings (Hess et al. 1999). A few grass species, including annual bluegrass (Poa annua), Kentucky bluegrass, and sweet vernalgrass were historically recorded in the alpine plant community (Hartt and Neal 1940). It is unknown whether these species are still present and if so, whether they are impacting native plant species in the alpine community. Even at low densities there remains the possibility that non-native grasses are competing with native plant species for limited resources and protected growth areas.

Common mullein: Common mullein (*Verbascum thapsus*) is a Hawai'i State Noxious Weed that is native to the temperate zone of Europe, and is adapted to disturbed dry and rocky sites (Juvik and Juvik 1992). It is a stout plant with thick, silvery, woolly or hairy leaves that grow in a rosette (somewhat similar to the Mauna Kea silversword). Common mullein produces a tall flowering stalk that produces thousands of seeds. Although bees often pollinate common mullein flowers, they are also able to self-pollinate (Ansari and Daehler 2000). This allows the spread of the plant in areas where pollinators are scarce. Like the Mauna Kea silversword, common mullein flowers once and then dies. However, it takes a little less than two years to reach maturity, while the silversword takes three to fifty years (USFWS 1994; Ansari and Daehler 2000). Mullein seeds can remain dormant in the soil for 100 years or more (Juvik and Juvik 1992). In an extreme example, mullein seeds from an archeological dig in Denmark dated 1300 AD were still viable in the 1960s (Odum 1965; Ansari and Daehler 2000). This means that even if adult plants are removed from an area, seedlings will continue to sprout and need to be removed for many years to come. Mullein is currently abundant at Hale Pōhaku and is present on roadsides and remote upland areas on Mauna Kea along the Summit Access Road, up to 12,460 ft (3,800 m) (Juvik and Juvik 1992; Ansari and Daehler 2000). No biocontrol insects or pathogens have been introduced to Hawai'i to control this species (Ansari and Daehler 2000). Mullein appears to be unpalatable to grazing ungulates, due to the density of leaf hairs (Juvik and Juvik 1992; Ansari and Daehler 2000). Mowing or clipping of the flowering stalk causes mullein to produce more flowering stalks. Chemical control can also prove difficult, although there are a few chemicals, such as a 10% Roundup solution, that can be used (Ansari and Daehler 2000). Removing the entire plant before it flowers, or cutting the taproot appear to be the most effective means of control, although care must be taken to remove most of the taproot, or resprouting can occur (Ansari and Daehler 2000; Loh et al. 2000).

Telegraph weed: Telegraph weed (*Heterotheca grandiflora*) is a weed of dry, disturbed areas that is native to California and the southwestern United States and Mexico (Wagner et al. 1990). Not much information is available on the impacts of telegraph weed in Hawai'i. Like mullein, telegraph weed has hairy, grey-green leaves and produces a long stalk. However, it is easily distinguished from mullein by the fact that it branches at the top of the stalk and has bright yellow, daisy-like flowers (Weed Society of

Queensland 2005). Telegraph weed is fairly abundant at Hale Pōhaku and can be found along the roadside of the Summit Access Road (Fox and IfA 2007). It was not recorded in plant surveys at Hale Pōhaku until 1990 (Char 1990).

Fireweed: Fireweed (*Senecio madagascariensis)* is a Hawai'i State Noxious Weed that originates from South Africa and was accidentally introduced to Hawai'i in the 1980s, possibly in contaminated fodder imported from Australia (Division of Plant Industry 1992; Le Roux et al. 2006). Fireweed competes with other plants for limiting resources such as nutrients and water, and is a heavy invader of pasturelands (Le Roux et al. 2006). Fireweed is poisonous to livestock (Le Roux et al. 2006). Although it was not recorded as present at Hale Pōhaku or MKSR in previous plant surveys (Gerrish 1979; Char 1985, 1990, 1999a), it is now common at Hale Pōhaku and can be found along the Summit Access Road (Fox and IfA 2007). Fireweed has also been observed in the Ice Age NAR up to 12,000 ft (3,660 m) elevation (Cole 2007). Currently the Hawai'i Department of Agriculture is working on a biological control program for this weed (Hawaii State Office of Environmental Quality Control 2008).

Hairy cat's ear: Hairy cat's ear (*Hypochoeris radicata)* is a widely distributed weed originating from Eurasia (Wagner et al. 1990). Its leaves grow in a rosette at the base of the plant. Yellow daisy-like flowers are found on the tips of leafless branching flowering stems. It is similar in appearance to the common dandelion (*Taraxacum officinale*), but can be distinguished by the fact that leaves of hairy cat's ear are covered with hairs and are shaped differently. The taproot is a popular food item for feral pigs, which may dig up large areas looking for them (Smith 1985). The plant is also a preferred forage item for grazing animals (Ohio Agriculture Research and Development Center n.d.). Hairy cat's ear, or gosmer, is found both at Hale Pōhaku and in the MKSR (Smith et al. 1982; Char 1999a). Little information is available about the impacts of this species on native plant communities, but as it attracts foraging feral ungulates and competes with other species for water and nutrients, it most likely has a negative impact.

Common dandelion: Common dandelion (*Taraxacum officinale*) is a cosmopolitan weed of temperate climates, that is generally found in higher elevation, wet, disturbed areas in Hawai'i (Wagner et al. 1990). On Mauna Kea it was found above 13,000 ft (3,900 m) by Smith et al. (1982), and was historically observed growing on the shores of Lake Waiau (Hartt and Neal 1940). Hartt and Neal (1940) also record it as occurring in the subalpine zone, down to 6,800 ft (2,000 m) on Mauna Kea, although it was not recorded as being present at Hale Pōhaku by Char (1985, 1999a) or Gerrish (1979). It is unknown what impact, if any, this weedy species has on native plant communities on Mauna Kea.

Future Invasions: A further threat to high elevation environments on Mauna Kea exists in invasion by new plant species not currently found there. Posing a particular threat are species that are adapted to subalpine, alpine, or arid environments. These may be introduced though deliberate introduction (plantings in landscaping), natural expansion by lower-elevation invasive species, or accidental introduction through human activities (such as seeds stuck to vehicles or visitors' shoes). Introductions of non-native species continue in Hawai'i, despite growing education about their destructive nature. Around 9% of non-native species found growing at high elevations in the Hawaiian Islands were first recorded in the past 30 years (Daehler 2005).

Over half (52%) of non-native species growing in high elevation areas in the Hawaiian Islands originate from Europe (Daehler 2005). While the number of non-native species drops off exponentially with increasing altitude, the proportion of temperate species increases linearly with elevation, up to 9,800 ft (3,000 m), at which point all the non-native species found are temperate in origin (and 80% are native to Europe or Eurasia). The vast majority (93%) of non-native species found in high elevation areas on the Hawaiian Islands are herbaceous (either grasses or herbs), and about one third (27%) are grasses (Daehler

2005). This may be due in part to the fact that many of the non-native plants in higher elevation zones are associated with ranching—a major source of introductions, as contaminants in feed and seed and as purposeful introductions for forage (Daehler 2005). However, despite the dominance of herbaceous species in the overall counts of high-elevation, non-native species, it is the woody species that make up the majority (73%) of disruptive invaders to high-elevation native plant communities (Daehler 2005). This information is important because it gives resource managers a tool to predict which new species may become invasive in the subalpine and alpine zones on Mauna Kea, and can help prioritize eradication efforts for those species. For example, resource mangers at Hale Pōhaku may prioritize eradication of a new species of shrub or tree originating from high-elevation areas in Europe over that of an herb originating from a low-lying tropical island. However, one must be careful not to over generalize, as there are some tropical introductions, such as fountain grass (*Pennisetum setaceum*), which are extremely harmful and aggressive invaders of high elevation areas (see below for more information on fountain grass).

There are several invasive plant species that may become established in the subalpine and alpine zone in the future, particularly if anthropogenic climate change affects the rainfall regimes in the Hawaiian Islands. One species which may pose a future threat to the subalpine communities on Mauna Kea is gorse (*Ulex europaeus*), an invasive shrub (and State Noxious Weed) currently found between 1,400 ft (450 m) and 7,870 ft (2,400 m) on Mauna Kea (Markin et al. 1988). Gorse thrives on soils derived from volcanic ash and does well in disturbed areas with low fertility (Leary et al. 2005), where it forms impenetrable thickets and smothers native plant growth (Daehler 2005). This species may be able to colonize the subalpine community through natural dispersal, accidental introduction of seeds, or through environmental changes brought about by climate change or by habitat alteration brought about by other invasive plant or animal species.

A second species that may invade the subalpine zone at Hale Pōhaku is fountain grass (*Pennisetum setaceum*). Although fountain grass grows and reproduces better at lower elevations, it is capable of surviving in the subalpine areas on Mauna Kea (Williams et al. 1995). It has already been observed at Pohakuloa Training Area at 9,000 ft (2,740 m) elevation (Higashino 2008), and it may just be a matter of time before it spreads further. Fountain grass is native to northern Africa, and in Hawai'i it occurs in dry open places such as barren lava flows and cinder fields (Wagner et al. 1990). It exhibits a broad ecological tolerance which enables it to survive at a variety of temperatures, although it does appear to be susceptible to freezing (Williams and Black 1993; Williams et al. 1995). The upper limit of fountain grass on Mauna Kea may be determined by freezing temperatures (rather than by drought) – as global climate change increases temperatures on the mountain, this species is likely to increase its elevational range. It is considered a serious pest in dry areas, because it alters the natural fire regime and because it is an aggressive colonizer that out-competes native species (Wagner et al. 1990; Tunison 1992; Daehler 2005; Benton 2006). Fountain grass seeds are primarily wind dispersed but can also be spread by water, livestock, humans, vehicles, and possibly birds (Benton 2006). The seeds may remain viable in soil for six years or longer (Tunison 1992), making control difficult.

It is impossible to accurately predict the exact plant species which will invade the subalpine and alpine zones on Mauna Kea in the future, but managers must be especially wary of plant species that are adapted to dry climates, early successional habitats, high elevation climates, have wind-dispersed seeds, and/or that originate from the temperate zone.

2.2.1.3.4 Non-native Animals

Introduced animals, ranging from insects to mammals to birds, can have a detrimental effect on native plant communities. This is demonstrated especially well by the impacts of feral ungulates on the subalpine woodland community on Mauna Kea. Many of the native plant populations have been reduced, and some (such as the Mauna Kea silversword) brought to the very brink of extinction through browsing pressure from introduced goats, sheep, and cattle. The threat from feral ungulates is not limited to the subalpine environment: damage to native plants such as ōhelo (*Vaccinium reticulatum*) has been recently observed at 12,600 ft (3,840 m) in the Ice Age NAR, adjacent to the MKSR (Hadway 2007). Interactions between non-native animals and plants may also negatively affect native subalpine plant communities. For example, sheep on Mauna Kea prefer māmane and native perennial grasses over introduced perennial grasses such as sweet vernalgrass (Scowcroft and Conrad 1992). This selective browsing not only directly reduces native plant abundance but also indirectly reduces them through increased competition and smothering of seedlings by the invasive grasses, which then have the competitive advantage as the less preferred food materials. More information on feral ungulates is provided in Section 2.2.4.

Non-native animals such as birds and mammals can also negatively impact native plant communities through dispersal of invasive plant seeds, and in some cases through direct predation of native seeds and seedlings (Bruegmann 1996; Cabin et al. 2000). Rodents and invasive insects are known to eat native plant seeds. Rodent predation of native plant seeds is implicated in the failure of native forest regeneration in the dry forests at Kaupulehu, Hawai'i, in areas where ungulates have already been excluded (Cabin et al. 2000), and in the dry forest of Kanaio Natural Area Reserve, on the leeward side of East Maui (Chimera 2004). On one positive note, Cabin et al. (2000) found that rodents did not forage on māmane seeds.

Non-native birds are thought to play an important role in the dispersal of invasive plant species in Hawai'i (Stone 1985; Woodward et al. 1990). Invasive and native bird species likely disperse different species because of differences in diet and foraging behavior (Woodward et al. 1990). Birds disperse seeds on their feet and feathers, in nesting material (Dean et al. 1990), and most commonly via their digestive systems as a result of fruit consumption (Stiles and White 1986; Wunderle 1997). Birds may either pass seeds through the digestive tract and excrete them or regurgitate them before they leave their stomach or gizzard. While most seeds are not carried for long distances (generally less than 100 m), a small fraction of seeds may be moved much longer distances (up to several kilometers) by birds (McDonnell and Stiles 1983; Stiles and White 1986; Debussche and Isenmann 1994; Wunderle 1997). Birds tend to retain smaller seeds longer than larger seeds (which they often regurgitate); thus, small seeds tend to be moved greater distances than large seeds (Levey 1986; Stiles and White 1986). Studies of seed dispersal by native and invasive birds in the Hawaiian Islands reveal that non-native birds are effective dispersers of invasive plant species (Stone 1985; Woodward et al. 1990; Garrison 2003; Chimera 2004). For example, in disturbed mesic forest and tree plantations on O'ahu, Japanese white-eyes were found to disperse seeds from most of the fruiting invasive plants in the area, and conversely, did not disperse seeds from native species (perhaps in part due to low density of native species) (Garrison 2003). In less disturbed native vegetation, non-native birds will also disperse native plant seeds, and may be important dispersers of native plants in areas where native bird populations are reduced (van Riper 1980b; Cole et al. 1995a; Chimera 2004). In native dry forests on Maui, Chimera (2004) found that Japanese white eyes dispersed seeds of several species of native plants, as well as non-native.

More information on non-native animals can be found in Sections 2.2.2 through 2.2.4.

2.2.1.3.5 Recreation & Other Human Uses

Human use can impact an area in many ways including wear and tear (e.g. increased erosion or soil compaction in areas that are frequently walked or driven on); direct reduction in plant and/or animal density (through the picking or collecting of plants or hunting of animals); introduction of new species of plants and animals (accidentally or on purpose); pollution (e.g. air pollution, chemical spills, oil dripping from vehicles, improper disposal of trash); habitat alteration (e.g. conversion of native habitat to buildings, roads, parking lots, and to agricultural areas or grassland for livestock foraging); and accidents (e.g. fires, landslides caused by construction activities and road building). Air pollution and dust can impact vascular plants in several ways, including greatly reducing photosynthesis, transpiration, and efficiency of water use; increasing leaf temperatures (with potentially serious effects during periods of high temperatures); and lowering primary production (growth) (Sharifi et al. 1997). Air pollution is also known to impact lichen and moss growth and community diversity (Hutchinson et al. 1996).

Human use impacts to the native plant communities in high elevation areas of Mauna Kea include (but are not limited to):

- Increased instability of the cinder areas caused by off-road vehicles and skiers (Smith et al. 1982)
- Soil erosion at Hale Pōhaku due to building construction (Gerrish 1979)
- Soil compaction and erosion on trails found on the summit and at Hale Pōhaku
- Habitat alteration through the development of telescopes and telescope facilities
- Habitat alteration through introduction of invasive species from ranching activities and landscaping (subalpine zone)
- Habitat alteration and reduction in native plant diversity and abundance, resulting from the introduction of ungulates (goats, sheep, mouflon, and cattle)
- Pollution from accidental oil spills, chemical spills, and vehicle leaks and exhaust
- Habitat degradation through improper disposal of trash by recreational users
- Increased dust from road grading and vehicles driving on dirt roads

The impacts of human use of Hale Pōhaku, the Summit Access Road, and the MKSR are discussed in more detail in Section 3.

2.2.1.3.6 Climate Change

Studies of ancient pollen from soil cores in the Hawaiian Islands suggest that Hawaiian plant communities responded to past climate changes with changes in community composition and in plant densities (Hotchkiss and Juvik 1999; Benning et al. 2002). Thus, there is little doubt that current plant communities will also respond to future changes in temperature, rainfall, and cloud cover that occur in the islands. However, there is currently a great deal of discussion about what effects climate change will have on trade wind and rainfall regimes in the Hawaiian Islands (Giambelluca and Luke 2007; Hamilton 2007). Although several climate models have been developed to study global climate change, most of the models are at too large a scale to accurately predict what will occur in Hawaiʻi, given the islands' steep topography, which has a strong effect on the weather patterns (Hamilton 2007).

Recent advances in climate modeling have allowed for a more fine-scale rainfall model, and the results from this model are currently under investigation (Hamilton 2007). Some of the early results from the work with the fine scale model include the prediction of an overall warming of the islands, leading to increased moisture in the air, an overall increase in rainfall, and possibly an increase in snowfall in the higher elevation areas. An additional finding is that the intensity of warming is positively related to altitude (Hamilton 2007). This means that the higher altitude areas on the islands will see greater gains in temperature than lower altitude areas. These findings suggest that high altitude areas may become wetter and warmer in the future, with greater snowfall on the summit.

Rainfall and cloud-base climate change scenarios for the neotropics developed in the late 1990s for montane cloud forests predict an increase in the height of cloudbanks, resulting in reduced cloud contact at the current elevation of most cloud forests (Pounds et al. 1999; Still et al. 1999; Benning et al. 2002). Cloud forests rely on contact with clouds to receive moisture, as do the māmane forests on Mauna Kea (Gagné and Cuddihy 1990; Gilbertson et al. 2001). Thus the raising of the cloud layer could seriously impact cloud forests. Provided there are no significant barriers to upward migration of plant species, the cloud forest should respond by moving to a higher elevation. These cloud base scenarios also predicted an increase in temperature in higher elevation areas, leading to faster melting of glaciers, a phenomenon that has been observed worldwide.

In opposition to the above predictions, other climatologists predict that conditions in high elevation areas in the Hawaiian Islands will become much drier (Giambelluca and Luke 2007). This prediction is based on changes in the trade wind inversion that have been observed in the last several decades. The dominant source of rain in Hawaiʻi is orographic lifting, by which air is forced up the mountain where trade winds meet the windward slopes (Giambelluca and Luke 2007). The trade wind inversion caps the upward motion of the wind, limiting cloud development in higher elevation areas. If the frequency of occurrence, or the height of the trade wind inversion is altered by climate change, this will have profound effects on rainfall in areas at or above the elevation of the trade wind inversion (Giambelluca and Luke 2007). Climate research over the past few decades suggests that the trade wind inversion has and will continue to become more persistent and lower in height, leading to a drier climate in Hawaiʻi, in particularly at high elevation areas (Cao 2007; Cao et al. 2007; Giambelluca and Luke 2007). The climatic changes associated with the changes in the trade wind inverstion include decreasing rainfall and streamflow, with given streams declining in annual flow by 50% in the last 90 years (Oki 2004). However, it is uncertain whether the changes in the trade wind inversion observed over the last few decades are part of the warming trend (climate change) or are a result of natural multi-decadal variability in rainfall and trade wind inversion occurrence (Giambelluca and Luke 2007).

Under the assumptions of the above models and scenarios, the potential effects of the various aspects of climate change on high elevation plant communities on Mauna Kea are discussed below.

1. Increase in temperature AND rainfall:
   a. Upwards movement of treeline, due to upwards movement of frost line (Flenley 1998; Benning et al. 2002; Kullman 2006; Baker and Moseley 2007)
   b. Movement of subalpine community into alpine community (Flenley 1998; Kullman 2006)
   c. Decrease in the area covered by alpine vegetation (Flenley 1998; Kullman 2006)
   d. Expansion of shrublands (Cannone et al. 2007)
   e. Increased plant growth by certain species (Danby and Hik 2007; Erschbamer 2007)
   f. Change in composition of plant communities (including local extinctions) due to differing response to changes in temperature, rainfall, etc. (Kullman 2006; Erschbamer 2007; Kazakis et al. 2007; Van de Ven et al. 2007)
   g. Invasion by new non-native species from lower elevations that were previously kept out by freezing temperatures (Benning et al. 2002; Weltzin et al. 2003)
   h. Shorter duration of snow pack before it melts in the higher elevation areas, leading to longer periods of time without snow pack, and drier soil conditions between periods of rain and snowfall (Kullman 2006; Bjork and Molau 2007)
   i. Higher plant densities in subalpine woodland and alpine shrubland and grassland

j. Increased invasion by non-native species previously kept out by low availability of moisture (Weltzin et al. 2003; Erschbamer 2007)
k. Increased growth rates of plants
l. Increased competitive edge by fast growing invasive plants (Weltzin et al. 2003; Erschbamer 2007)

2. Increase in temperature and decrease in rainfall:
   a. Drought in higher elevation areas (Loope and Giambelluca 1998; Calanca 2007; Giambelluca and Luke 2007)
   b. Raising of frost line to a higher elevation, which may lead to higher treeline. However, if treeline is more dependent on rainfall than on temperatures, treeline will move down the mountain because of increased drought conditions (Giambelluca 2008)
   c. Decreased snowfall in alpine region and shorter duration of snowpack (Giambelluca 2008)
   d. Decrease in plant densities in the subalpine and alpine zones (Giambelluca and Luke 2007)
   e. Loss of upper elevation subalpine forest to drier conditions (Loope and Giambelluca 1998; Giambelluca and Luke 2007)
   f. Increased rates of fire, carrying on dead/dying/desiccated vegetation

3. Increase in CO_2 concentration:
   a. Fertilization of all plants leading to increased growth (Weltzin et al. 2003)
   b. Further competitive edge by fast growing invasive species (Weltzin et al. 2003)

Although it is not yet possible to accurately predict what will occur on Mauna Kea, it seems likely that under the influence of climate change, the alpine communities on Mauna Kea will decrease in extent. The sub-alpine communities will either move upwards in elevation due to increased temperature and rainfall, or will be lost at upper elevations due a drier climate. Finally, the abundance of invasive species and their diversity may increase (especially under the higher rainfall scenario), leading to shifts in plant community composition in all regions. Drought resistant invasive species will be the primary invaders of high elevation areas.

2.2.1.4 Botanical Community Information Gaps

The following information gaps regarding the condition of the subalpine and alpine plant communities at Hale Pōhaku and the MKSR have been identified through review of the literature and consultation with local experts:

1. Quantitative botanical surveys
   a) Hale Pōhaku: Although several plant surveys have been conducted at Hale Pōhaku (Gerrish 1979; Char 1985, 1990, 1999a; Pacific Analytics 2004), no quantitative botanical studies documenting population size and distribution of native and non-native species have been conducted there. The last survey that involved more than a brief examination of field conditions was conducted by Char in 1990.
   b) Summit Access Road: No botanical surveys have been conducted along the Summit Access Road between Hale Pōhaku and MKSR.
   c) Mauna Kea Science Reserve: Limited botanical surveys have been conducted in the MKSR. Smith et al. (1982) surveyed only the plant species found above 13,000 ft (3,960 m) and only in areas considered for future telescope construction (as described in the 1982 Master Plan). A figure showing the areas covered by this study is included as Figure 2.2-9. Although the

study area was thoroughly searched, no quantitative sampling was conducted. Other studies conducted there were very limited in scope.

2. Status of invasive species

No information is available regarding the density, distribution, and effects of established invasive plant and animal species at Hale Pōhaku and the MKSR. There is a need for a comprehensive survey of invasive plant and animal species on the properties and identification of environmental problems they may be causing.

3. Protected species

While several Endangered and Threatened species are known to inhabit the subalpine and alpine regions of Mauna Kea, there is no mention of Threatened, Endangered, or Candidate species being present at Hale Pōhaku and the MKSR during the most recent botanical survey (Char 1999a). However, botanical surveys conducted in the MKSR have been limited in scope. Recent evidence suggests that there are isolated populations of some endangered and threatened species on the properties. For example, the Mauna Kea silversword was recently discovered in the MKSR (Nagata 2007). Additionally, Char (1985) found the threatened species, Hawaiian catchfly (*Silene hawaiiensis*), at Hale Pōhaku in 1985, but does not mention this species again in her 1990 or 1999 reports. More thorough inventories should be conducted.

2.2.2 Invertebrates

Invertebrates are animals lacking a backbone. This enormous group of organisms covers a wide range of terrestrial and marine forms such as the arthropods (insects, spiders, crustaceans), mollusks (snails, bivalves, squid, octopus), annelids (segmented worms such as earthworms), echinoderms (starfish, sea urchins, sea cucumbers), lampshells, bryozoans, sponges, cnidarians (jellyfish, coral, sea anemones), ctenophores (comb jellies), and many phyla of worms (priapulid worms, flatworms, roundworms, nematodes, horsehair worms, velvet worms, and acorn worms). Invertebrates constitute approximately 97% of all known species on earth. New species are still being discovered regularly. Because of their sheer numbers, wide diversity of forms and functions, and (often) small sizes, invertebrates are generally poorly known and even more poorly understood. There are undoubtedly many hundreds (or even thousands) of species of invertebrates that await discovery in the Hawaiian Islands.

Invertebrate species known from the subalpine and alpine regions of Mauna Kea are presented in Table 2.2-6. This table was compiled from a variety of sources, including the review of invertebrate species found in high elevation areas of Mauna Kea presented in Aldrich (2005) and searches of scientific literature and databases. This table does not represent a complete list of species found in the area. There have been relatively few studies of invertebrates done in the region. Because of the sheer number of species, and wide diversity of forms, a detailed survey of invertebrates on Mauna Kea would take many years (or even decades), and would no doubt fill several volumes. Because of this diversity and complexity, this plan focuses primarily on the arthropods (primarily insects and spiders) found in the upper elevations of Mauna Kea. A second important group of invertebrates, the land snails, are also discussed. Arthropods comprise more than 75% of the native Hawaiian biota, and include some of the world's best known species radiations (Roderick and Gillespie 1998). Discoveries about this group of animals are still being made on Mauna Kea (Brown 2008; Medeiros 2008). For example, the wēkiu bug, the now-famous insect found at the summit of Mauna Kea, was only discovered in 1979 (Howarth and Montgomery 1980), and is still being studied. Photos of selected native invertebrates are presented in Figure 2.2-10 and photos of common invasive invertebrates are presented in Figure 2.2-11.

2.2.2.1 Subalpine Invertebrate Communities (Hale Pōhaku and Lower Summit Access Road)

Arthropods: The māmane forests on Mauna Kea have high arthropod diversity—more than 200 species have been collected there, and many more are likely to be found should additional studies be done (NASA 2005).

Lepidoptera (Moths and Butterflies). An important group of arthropods found in the subalpine māmane forests are the Lepidoptera (moths and butterflies), including several moth species that feed on māmane (*Sophora chrysophylla*) seeds (NASA 2005). Although moths and butterflies have been intensively studied world-wide, there is still much to learn about the species that inhabit the higher elevation areas on Mauna Kea. Recently a new species of flightless *Thyrocopa* moth was discovered above the treeline on *Dubautia ciliolata* near Hale Pōhaku by Matt Medeiros (Medeiros 2008; Oboyski 2008). This new species is diurnal (most moths are nocturnal), appears to forage on dead leaves of shrubs and clumps of grass, and has lost the ability to fly (Medeiros 2008). It moves around by jumping, and could easily be mistaken for a grasshopper by the casual observer. So far, it appears that this species is limited to Mauna Kea, but more research is needed (Medeiros 2008). Other *Thyrocopa* species that can be found in the subalpine zone at Hale Pōhaku include *Thyrocopa indecora* and *T. adumbrata* (Medeiros 2008). Other moth species found the subalpine area includes moths in the genus *Mestolobes*. These are small brown moths that are thought to be endemic to the Hawaiian Islands (Zimmerman 1958). Not much is known about these moths, including diet and habitat preferences (Medeiros 2008).

The māmane-feeding Lepidoptera include moths from the genus *Cydia* (of which there are at least seven species on Mauna Kea), *Peridroma*, and *Scotorythra*. These moths are the most important prey items for the endangered Palila (*Loxioides bailleui*; see Section 2.2.3, Birds), and are likely an important protein source for developing Palila chicks (Brenner et al. 2002). Parasitism of *Cydia* moths by several wasp species may be reducing moth abundance in the māmane woodlands. Parasitic wasps have been implicated in the decline or extinction of at least 16 Lepidopteron species in Hawai'i (Oboyski et al. 2004). Brenner *et al.* (2002) found four common parasitoid wasps that attack larval *Cydia* moths: *Calliephialtes grapholithae*, *Diadegma blackburni*, *Pristomerus hawaiiensis*, and *Euderus metallicus*. The first three species appear to be accidental introductions to Hawai'i (including the deceptively named *P. hawaiiensis*), while the fourth (*E. metallicus*) appears to be native to the islands (Brenner et al. 2002). However, the actual origins of the latter three species are still under debate (Oboyski et al. 2004). In their study of parasitism of *Cydia* larvae, Oboyski et al. (2004) found an additional common parasitic species, *Brasema cushmani*, which is an introduced biological control agent for the pepper weevil, *Anthonomus eugenii* (Oboyski et al. 2004).

Brenner et al. (2002) found that parasitism rates were lower in the high-elevation populations of the *Cydia* moths than in the lower elevation populations: only 20% of *Cydia* larva were parasitized at 8,860 ft (2,700 m), while 94% were parasitized at 5,900 ft (1,800 m). *Cydia* larva abundance in māmane pods increased with elevation, peaking at around 8,695 ft (2,650 m) (Banko et al. 2002). However, a subsequent study found no difference in parasitism rates for *Cydia* species at differing elevations (Oboyski et al. 2004), although this study did not include *Cydia* larvae from below 6,889 ft (2,100 m), where the highest rates of parasitism occurred in the Brenner et al. (2002) study. Although overall parasitism rates did not differ with elevation in their study, Oboyski et al. (2004) found that parasitism rates by native and introduced wasp species differed with elevation. Parasitism by the native wasp, *Euderus metallicus*, increased with elevation, while parasitism by *Calliephialtes grapholithae* (non-native) and *Pristomerus hawaiiensis* (origin unknown) decreased (Oboyski et al. 2004). Parasitism rates by two other species, *Diadegma blackburni* and *Brasema cushmani*, did not vary significantly with elevation.

Other moth species with larva that feed on māmane seeds include *Peridroma albiorbis* and an undescribed species of *Scotorythra* (Banko et al. 2002). These moths, too, are vulnerable to attacks from predatory wasps and ants and by parasitic wasps and flies (Banko et al. 2002). *Scotorythra* moths are parasitized by *Hyposoter exiguae*, *Diadegma blackburni*, *Meteorus laphygmae*, and a fly, *Chaetogaedia monticola*. *Peridroma albiorbis* is also parasitized by the above species, with the exception of *M. laphygmae* (Banko et al. 2002). At least three of the parasitoid species, *Brasema cushmani, Chaetogaedia monticola* and *Meteorus laphygmae*, were originally introduced to Hawai'i as biological control agents (Banko et al. 2002).

Another native moth species, *Uresephita polygonalis virescens*, was previously a common prey item for the Palila but is no longer observed to be part of the Palila diet. Banko et al. (2002) suggest that this species has been reduced in abundance by parasitism. Finally, the black-veined *Agrotis* noctuid moth (*Agrotis melanoneura*) is known to reside on Mauna Kea (Bishop Museum 2007c). Very little information is available regarding this species. It has been observed at light traps at Hale Pōhaku in recent years, and is uncommon but widespread on Mauna Kea (Giffin 2009).

Hymenoptera (Bees, Wasps, and Ants). There are no native ants (or social insects of any kind) in the Hawaiian Islands. However, other members of the hymenoptera are present, and represent a diverse group that has undergone much radiation in the islands. Native bees, such as those found in the family Colletidae, are important pollinators, while most of the native wasps are arthropod parasites, often helping to keep herbivorous insect populations in check (Mitchell et al. 2005a). The yellow-legged yellow-faced bee (*Hylaeus flavipes*) is the only *Hylaeus* observed at high elevations on Mauna Kea (Aldrich 2005), where it is found associated with māmane (Magnacca 2008). It is also thought to be a potential pollinator of the Mauna kea Silversword (Aldrich 2005). Other native bees that may be found in the subalpine zone (but which have not been confirmed for Hale Pōhaku) include *H. ombrias, H. difficilis* and *H. volcanicus* (Magnacca 2008). Invasive hymenoptera found in the subalpine zone on Mauna Kea include the five parasitoid wasp species and one parasitoid fly species, ants, honeybees (*Apis mellifera*) and yellowjackets (*Vespula pensylvanica*) (Banko et al. 2002; Oboyski 2008). These are discussed in more detail in Section 2.2.2.1.2.

True bugs (Heteroptera): A new species of plant bug, *Orthotylus sophorae*, was recently discovered in association with māmane woodlands from 3,200–9,000 ft (1,000–2,750 m) above sea level on Hawai'i. It is often found in association with other māmane-associated Heteroptera species, including the endemic nabid *Nabis kahavalu* and endemic lygaeid *Nesius (Icteronysius) ochriasis* (Polhemus 2004). Other lygaeid bugs (relatives of the wēkiu bug, which lives at the summit) found in the subalpine region include *Neseis nitida comitans, Nysius coenosulus, Nysius palor* and *Nysius terrestris* (Englund et al. 2002).

Other arthropod species of interest found in the subalpine region include the Hawai'i long-horned beetle (*Plagithmysus montgomeryi*), koa bug (*Coleotichus blackburniae*), and wolf spiders (*Lycosa* species).

Snails: The Hawaiian Islands has an impressive diversity of land snails, with at least 779 species found in ten families (Cowie et al. 1995; Hadway and Hadfield 1999). Many of these species are endemic (found no where else in the world). Land snail abundance and diversity has been greatly impacted by the arrival of humans on the islands, due to habitat destruction, introduction of predators and diseases, and overcollecting. Up to 90% of the species are now thought to be extinct (Hadway and Hadfield 1999; Rundell and Cowie 2003). Introduced predators, including rats (*Rattus rattus*), rosy wolfsnail (*Euglandina rosea*), garlic snail (*Oxychilus alliarius*), and the predatory flatworm *Platydemus manokwari*, have heavily impacted native snail populations (Meyer 2006). The highest diversity of land snails is found in wetter forests below the subalpine zone on the Island of Hawai'i. Even so, there are several species of land snail that occur, or once occurred, in the subalpine māmane woodlands on Mauna Kea (Hadway and Hadfield 1999).

No surveys for snails have been conducted in the subalpine regions as high as Hale Pōhaku. However, a survey for snails at Pu'u La'au Forest Reserve from 6,200 to 8,600 ft (1,890 to 2,621 m) elevation conducted in 1995–1997 found four species of snails: two endemic, one of unknown origin, and one invasive species. The endemic snails found at Pu'u La'au include *Succinea konaensis* and *Vitrina tenella*. The snail of unknown origin was an unidentified species in the genus *Striatura*. The non-native snail found was the garlic snail, *Oxychilus alliarius* (Hadway and Hadfield 1998; Hadway and Hadfield 1999). This species is discussed further in Section 2.2.2.1.1. Historically, *Partulina confusa*, a tree-dwelling snail endemic to the Island of Hawai'i, was found in māmane-naio forests such as those found at Pu'u La'au Forest Reserve. However, none were located during the survey of this area, and this species may be extinct (Hadway and Hadfield 1998; Hadway and Hadfield 1999).

Succinea konaensis and *Vitrina tenella* are federal Species of Concern and are discussed in Section 2.2.2.1.1. There are three *Striatura* species of snail on the federal Species of Concern list, but it is unknown whether the species found at Pu'u La'au is one of them.

2.2.2.1.1 Threatened and Endangered Species, Candidate Species and Species of Concern

There are no federal or state listed Threatened or Endangered Species of invertebrates known to be present at Hale Pōhaku or in the subalpine zone of Mauna Kea.

Federal Species of Concern include the koa bug (*Coleotichus blackburniae*), the flightless brown lacewing (*Micromus usingeri*), the black-veined Agrotis noctuid moth (*Agrotis melanoneura*), several species of native *Hylaeus* bees including *H. flavipes, H. difficilis,* and *H. ombrias*, and two species of snails (*Succinea konaensis* and *Vitrina tenella)*. The black-veined *Agrotis* noctuid moth and the *Hylaeus* bees are also listed as Hawai'i state Species of Concern.

The koa bug is the only native herbivorous stink bug in Hawai'i (Roderick and Gillespie 1998). It was quite common until the 1960s, when several parasites were released in Hawai'i to control *Nezara viridula*, a pest stinkbug. These parasites have decimated koa bug populations, and it is now rare in the wild (Asquith 1995). Higher elevation areas may provide a refuge for koa bug from introduced biological control agents (Oboyski 2008). The flightless brown lacewing has recently been collected on *Dubautia arborea* on Mauna Kea (Tauber et al. 2007). The black-veined *Agrotis* noctuid is uncommon but widespread on Mauna Kea, and has been observed at Hale Pōhaku. The current status of the native bee populations at high elevation areas on Mauna Kea is unknown, as no formal surveys have been conducted there. *Hylaeus flavipes* has been observed foraging on māmane (*Sophora chrysophylla*) trees at Hale Pōhaku (Aldrich 2005; Magnacca 2008). The other species of bees listed above are thought to be found in dry forests and shrublands but have not been studied at Hale Pōhaku or the vicinity.

Succinea konaensis and *Vitrina tenella*, both listed as federal Species of Concern, are ground dwelling snails. In the survey conducted at Pu'u La'au on Mauna Kea, both of these species were found beneath rocks at approximately 8,500 ft (2,590 m) (Hadway and Hadfield 1998). Predators of these high elevation snails include ground foraging birds such as Ring-necked pheasants and rodents, primarily rats (Schwartz and Schwartz 1951; Hadway and Hadfield 1999). Ring-necked pheasants may eat the snails mainly during breeding season to provide calcium for eggshells (Schwartz and Schwartz 1951). Other than for some snails in the family Achatinellinae, very little is known about the life history of Hawaii's endemic terrestrial snails (Rundell and Cowie 2003), and little information is available regarding *Succinea konaensis* and *Vitrina tenella.*

2.2.2.1.2 Invasive Invertebrate Species

Invasive invertebrates are a serious threat to Hawai'i. The Hawai'i Invasive Species Council estimates that two or more serious arthropod pests arrive in the islands every year. Infamous new arrivals to Hawai'i include the little fire ant, which has a very painful sting; the Erythrina gall wasp, which is destroying native wiliwili trees; and the Varroa mite, which is a threat to the multimillion-dollar queen bee, honey, and pollination industries (Wilson 2008).

Invasive arthropods found in the subalpine region of Mauna Kea include (at a minimum) the five parasitoid wasp species and one parasitoid fly species, European earwig (*Forficula forficularia*), ants, honeybees (*Apis mellifera*) and yellowjackets (*Vespula pensylvanica*) (Banko et al. 2002; Oboyski 2008; Englund et al. 2009). Both ants and yellowjackets are known to have detrimental affects on native arthropod populations, which in turn can affect the native plant and bird communities.

Honeybees (*Apis mellifera*) were introduced to the Hawaiian Islands in 1875 (Barrows 1980). They are thought to compete with native nectarivorous insects such as native bees, but their impact on native pollinators in Hawai'i has not been fully studied (Magnacca 2007). In areas where native pollinators are few or missing, honeybees may provide pollination services to some native plant species.

Yellowjackets were first introduced to Kaua'i in 1919, and have since spread to all the other major Hawaiian Islands except Kaho'olawe and Ni'ihau (Gambino et al. 1990; Gruner and Foote 2000). Yellowjackets were found by Banko et al. (2002) at 9,186 ft (2,800 m) on Mauna Kea. There appears to be no relationship between yellowjacket numbers and elevation on Mauna Kea, suggesting that this species is able to survive equally well in the subalpine zone as in lower elevations (Banko et al. 2002). Currently yellowjacket densities are low on Mauna Kea (Banko et al. 2002). However, yellowjackets are known to seriously impact native arthropod communities (Gambino et al. 1987; Stone and Anderson 1988; Gambino et al. 1990; Aldrich 2005), and they could pose a threat in the subalpine woodlands and shrublands if their densities increase. On Maui, yellowjacket nests in high elevation areas were primarily found beneath pūkiawe (*Leptecophylla tameiameiae*) bushes, which also support a honeydew producing mealybug, *Pseudococcus nudus*, a food source for the yellowjackets (Gambino et al. 1990). Pūkiawe are fairly abundant in the subalpine zone on Mauna Kea, and the mealybug species is also found on the island of Hawai'i. Therefore it is possible that yellowjackets may enjoy the same accommodations and food source in the subalpine zones on Mauna Kea as they do at Haleakalā.

There are no native ants in Hawai'i (Loope et al. 2001). Wetterer *et al.* (1998) conducted a survey of ant species on the western flank of Mauna Kea, from 5,500 to 10,300 ft elevation (1,680 to 3,140 m). They found that ants were abundant up to 6,600 ft (2,010 m), and were found at low densities above that (Wetterer et al. 1998). Five species of invasive non-native ants have been found on Mauna Kea: *Linepithema humile, Cardiocondyla venustula, Pheidol megacephala, Tetramorium bicarinatum,* and *Monomorium pharaonis*. Another study of Mauna Kea ant species, conducted in 1999 by Banko et al., found similar species to Wetterer *et al*, but at even higher elevations (Banko et al. 2002). The species with the highest elevational range and highest densities are *Cardiocondyla venustula* (8,038 ft/2,450m) and *Linepithema humile* (9,186 ft/2,800 m) (Wetterer et al. 1998; Banko et al. 2002). *Pheidol megacephala, Tetramorium bicarinatum,* and *Monomorium pharaonis* were found in fewer locations and at lower densities (Wetterer et al. 1998). *Pheidol megacephala* are found up to 6,725 ft (2,050 m), *Tetramorium* *bicarinatum* are found up to 5,970 ft (1,820 m), and *Monomorium pharaonis* are found up to 6,332 ft (1,930 m) (Wetterer et al. 1998; Banko et al. 2002). A study of invasive invertebrates present at Hale Pōhaku and the MKSR conducted in 2007-2008 by Bishop Museum entomologists indicate that there are no ants currently established at Hale Pōhaku or in the MKSR (Englund et al. 2009).

Linepithema humile, or the Argentine ant, was first discovered at Fort Shafter, O'ahu, in 1940 (Zimmerman 1941) and has since spread to the other islands. While it has not yet been found at Hale Pōhaku, it is known to occur at similar elevations on other parts of Mauna Kea (9,186 ft/2,800 m) and at 9,450 ft (2,880 m) on Haleakalā, Maui (Cole et al. 1992; Wetterer et al. 1998), and is able to colonize dry upland areas (Krushelnycky et al. 2005). The Argentine ant is a serious threat to native flora and fauna because of its appetite for arthropods, seeds, and nectar (Aldrich 2005). It is a predator of many endemic arthropods, including noctuid moths and *Hylaeus* bees, which are the pollinators of rare subalpine plants such as the Haleakalā silversword, *Argyroxiphium sandwicense macrocephalum* (Stone and Anderson 1988; Cole et al. 1992). Cole et al. (1992) found that many invertebrate populations on Haleakalā were smaller in areas infested with Argentine ants than in areas not infested. As Mauna Kea silverswords (*Argyroxiphium sandwicense sandwicense*) are thought to be pollinated by *Hylaeus* bees, the establishment of a colony of Argentine ants in the subalpine zone on Mauna Kea could further inhibit recovery of the small population of silverswords found there.

In 2007-2008, Bishop Museum scientists observed European earwigs (*Forficula forficularia*) in high numbers around the Onizuka Visitor Information Station at Hale Pōhaku (Englund et al. 2009). It appears to be restricted in elevation and has not become established above the Visitor Information Station (Englund et al. 2009). This species is predatory, and could potentially impact native invertebrate species in the subalpine zone (Englund et al. 2009). Monitoring of the distribution and impact of this species on native invertebrates should be conducted.

The garlic snail, *Oxychilus alliarius,* is an introduced terrestrial snail that was first recorded in the Hawaiian Islands in 1937 (Hadway and Hadfield 1998). It can be very abundant, especially in moist ground in forested areas (Hadway and Hadfield 1998). This species is an omnivore and opportunistic predator, and appears to negatively impact native snail populations (Howarth 1985). Garlic snails consume other snails with shells less than 0.11 inches (3 mm) in length, including native succineid snails (Meyer 2005, 2008). It has been found at 8,600 ft (2,621 m) elevation on Mauna Kea, but its true elevational limit is unknown.

2.2.2.1.3 Invertebrate Surveys at Hale Pōhaku

There have been no quantitative studies of invertebrate communities at Hale Pōhaku. Englund et al. (2002) conducted a brief visual survey of Lygaeid bugs found at Hale Pōhaku and the Summit Access Road in September 2002. In 2007-2008, Englund et al. (2009) conducted qualitative (presence/absence) sampling for invasive invertebrates at Hale Pōhaku. This important study increased understanding of the species of invasive invertebrates present in the subalpine region of Mauna Kea. Interest in invertebrate communities in the subalpine zone on Mauna Kea is increasing and several researchers have recently collected specimens at Hale Pōhaku (Medeiros 2008; Oboyski 2008).

2.2.2.2 Alpine Invertebrate Communities (MKSR and Upper Summit Access Road)

There is little information available regarding invertebrate communities in the alpine shrublands and grasslands of Mauna Kea, as very few studies have been conducted in this region. In the summers of 2007 and 2008, Bishop Museum entomologists conducted surveys for invasive invertebrate species along the

Summit Access Road and in the MKSR, providing data on presence of several new species in the region (Englund et al. 2009). Other research is currently underway on the insect communities in the shrublands found in the upper subalpine and lower alpine zones on Mauna Kea, and more information should be available in the near future (Oboyski 2008). J.M. Brown is conducting a study of *Trupanea arboreae*, a native Tephritid fruit fly that is associated with *Dubautia* and other members of the silversword alliance on Mauna Kea (Brown 2008). Tephritid flies are herbivorous flies that feed on plant material and form galls in plant tissues (Brown et al. 2006). Since so little information is available on the alpine shrublands and grasslands on Mauna Kea, the remainder of this section will focus on the invertebrate community found on the summit of Mauna Kea.

Invertebrate communities in the alpine stone desert have received a fair amount of attention since the discovery of the wēkiu bug and other resident species at the summit of Mauna Kea, in 1980. The arthropod community on the summit of Mauna Kea can be divided into two parts: those species that are blown up the mountain by the wind and die there in the cold (referred to as aeolian drift), and those cold-adapted species that are permanent residents and that feed on the dead and dying arthropods found in the aeolian drift or on one-another (Howarth and Montgomery 1980; Howarth and Stone 1982). All species that have been found on the summit are listed in Table 2.2-6, and the aeolian drift species are distinguished from the resident species in the 8th column of the table. Although the aeolian-drift species provide an important food source for the resident species, they are not discussed in detail here, because so long as they continue to blow up the mountain in large numbers, their exact species composition is probably not important to the survival of the residents. Through the various studies conducted at the summit of Mauna Kea, 21 resident species and 21 species of undetermined status (unknown if they are resident or aeolian) have been recorded as occurring in the alpine stone desert. An additional 67 species (47 non-native, 12 native, and eight of unknown origin) have been recorded in the aeolian drift, although this number will no doubt continue to climb over time as more collecting is done.

The 21 resident species include 12 native species, five species of unknown origin, and four non-native species. Of the 21 species with unknown status (whether they are resident or aeolian), four are native species, seven are unknown, and ten are non-native species. These numbers are approximate because of the uncertainty of many species identifications.

Native resident (and potential resident) species include the wēkiu bugs (*Nysius wekiuicola*), a noctuid moth (*Agrotis* sp.), a hide beetle (*Dermestes maculatus*), a large wolf spider (*Lycosa* sp.), two sheet web spiders (*Erigone* species), an unidentified Linyphiid sheet web spider (Family Linyphiidae), two unknown Entomobryid springtails (Family Entomobryidae), a Collembola springtail (Class Collembola, family and species unknown), two species of mites (Families Anystidae and Eupodidae), a bark louse (*Palistreptus inconstans*) and a centipede (*Lithobius* sp.). The wēkiu bug (*Nysius wekiuicola*) is the best-studied invertebrate at the summit – there is little information available regarding the habits of most of the other summit species. The wēkiu bug is discussed in more detail in Section 2.2.2.2.1. The remainder of the native resident species are discussed below.

Lycosid spider: Invertebrate surveys at the summit discovered a large (up to 2 cm body length), black wolf spider (*Lycosa* sp.). This wolf spider is thought to be endemic to the Hawaiian Islands, although its distribution elsewhere is not known (Howarth and Montgomery 1980; Howarth and Stone 1982). Many lycosid species are capable of 'hang gliding' or long-distance dispersal by wind (Howarth and Montgomery 1980). The wolf spider is an ambush predator, hiding under large rocks until an active prey comes within range (Howarth and Stone 1982; Howarth et al. 1999). It likely preys on any actively moving arthropod including the wēkiu bug (Englund et al. 2002). The female wolf spider builds nests of silk and earth under rocks, and remains with the nest to protect the developing eggs (Howarth and Stone

1982). The wolf spider is found in low densities across the summit in a wider variety of areas than the wēkiu bug (Howarth et al. 1999).

Other spiders: Three presumably native Linyphiid spiders (*Erigone* sp.) were collected in 1982, but were not seen in 1997–1998 surveys (Howarth et al. 1999). One *Erigone* species (Species A in Howarth and Stone 1982) is described as being a "small, brown, sheet web spider which builds its sheet-like web across vesicles and other indentations on the undersides of rocks in the summit area" (Howarth and Stone 1982). This species makes small (2–3 mm diameter) flat, white, circular egg cases that are placed on the undersides of rocks, and was abundant wherever there were suitable rocks (Howarth and Stone 1982). The second *Erigone* species (Species B in Howarth and Stone 1982) was a single distinctive male located near 13,000 ft (3,960 m) on the northwest slope of the surveyed area (See Figure 2.2-12). The third species belonged to an unknown genus in the Linyphiidae family, and had similar range and habitats to the *Erigone* Species A.

Centipede: A small black centipede in the genus *Lithobius*, presumed to be endemic, occurs primarily on lava flows with large outcrops of andesitic rock. The centipede burrows in the silt and aeolian debris in cracks and under rocks at the base of lava cliffs (Howarth and Stone 1982). Like many of the other species encountered on Mauna Kea's summit, the centipede is thought to feed on aeolian drift (Richardson 2002). Few individuals of this species have been collected or observed, and little is known of its ecology.

Agrotis moth: This undescribed species, originally identified as an *Archanarta* species in 1982 (Howarth and Stone 1982), is a black moth whose larvae feed on foliose lichens, dead arthropod remains, and even the remains of larger animals (including the skin of mummified sheep) (Howarth et al. 1999). Adults have been observed from approximately 10,000 ft (3,048 meters) to the summit (Howarth and Stone 1982). Very little is known about this species.

Resident (and possible resident) species of uncertain origin include an unidentified rove beetle (Staphylinidae), an unidentified Hydrophilid beetle (family Hydrophilidae), a moth fly (*Psychoda* species), an unidentified scuttle fly (family Phoridae), a fungus gnat (*Sciara* sp.), an unidentified ichneumonid wasp (family Ichneumonidae), unidentified micro-hymenoptera, and several unknown species of mites (Families Bdellidae, Laelapidae, Phytoseidae, and one unknown family). No information is available regarding the distribution of these species, their abundance, or behavior at the summit.

Non-native resident (and potential resident) species include: a book louse (*Liposcelis divinatorius*), big-eyed bug (*Geocoris pallens*), a hunting spider (*Meriola arcifera*), a sheet web spider (*Lepthyphantes tenuis*), and an unidentified jumping spider (family Salticidae). One non-native species of fly, the blue bottle fly (*Calliphora vomitoria*), a predatory carabid beetle (*Agonum muelleri*), and two species of diving water beetle (*Rhantus pacificus*, which is endemic to the Hawaiian Islands, and an undetermined Hydrophilid of unknown origin), were recorded as occurring in Lake Waiau (Englund and Preston 2008; Englund et al. 2009). Non-native species are discussed further in Section 2.2.2.2.2 (Invasive Species).

2.2.2.2.1 Threatened and Endangered Species, Candidate Species, and Species of Concern

The wēkiu bug (*Nysius wekiuicola*) is a federal Candidate species. No other Species of Concern, Candidate, Threatened or Endangered species are known to reside in the MKSR. Currently a Candidate Conservation Agreement (CCA) is being developed by the U.S. Fish and Wildlife Service in cooperation with OMKM, the University of Hawaiʻi Institute for Astronomy, and other agencies and organizations involved in astronomical activities on Mauna Kea (Richardson 2002; Wada 2008). The goal of the CCA is to provide long-term protection to endemic arthropods at the summit of Mauna Kea (including the wēkiu bug). CCA activities would include monitoring of species status and habitat quality, removing some of the known threats, educating personnel, habitat restoration, and incorporation of species conservation measures into planning and management activities. If completed and properly implemented, the CCA may remove the need to list the wēkiu bug under the Endangered Species Act, and should help protect other endemic invertebrates at the summit as well (Richardson 2002).

The wēkiu bug (*Nysius wekiuicola*) was first recognized as a new species in 1979 and was formally described by Ashlock and Gagne in 1983 (Ashlock and Gagne 1983). It is a true bug in the family Lygaeidae (order Heteroptera), and is approximately the size of a grain of rice (Ashlock and Gagne 1983; Richardson 2002). Wēkiu bugs reside under rocks and cinders on the summit of Mauna Kea, where they feed diurnally (during the day) on dead and dying insects blown up the mountain from lower elevations (Howarth and Montgomery 1980; Ashlock and Gagne 1983; Howarth 1987). Wēkiu bugs use their straw-like beaks to suck the hemolymph (a fluid comparable to blood) from other insects (Richardson 2002). They do not appear to feed on healthy, living individuals of the other resident arthropod species (Ashlock and Gagne 1983). The wēkiu bug (*Nysius wekiuicola*), and its sister species, *Nysius aa*, which resides on the summit of Mauna Loa, differ from other species in the genus *Nysius* in being scavengers and predators of dead and dying arthropods. All other known species in the genus are seed and/or plant feeders (Ashlock and Gagne 1983; Polhemus 1998). Food resources alone probably do not greatly influence the distribution of wēkiu bugs, as arthropod diversity and abundance in the aeolian drift was found to be similar in areas where wēkiu bugs are found and those where they are not (Howarth et al. 1999). However, it is possible that abundance of flies and other weak-flying aeolian waifs is higher along ridge crests and in areas where wind eddies drop their particulate loads (Howarth et al. 1999). Snowfields may chill and store insects for consumption by resident scavengers such as the wēkiu bug, and the bugs can often be seen foraging on the edge of snow banks (Englund et al. 2006). Permafrost is believed to be a critical source of moisture for the wēkiu bug, however there is no evidence suggesting that permafrost availability or distribution is different between areas inhabited by wēkiu bug and those not inhabited by them (Howarth et al. 1999). In addition, Howarth *et al.* (1999) found moist substrates at most sites studied, especially within the sandy ash layer below the surface scoria.

Habitat type and abundances: Howarth and Stone (1982) found that wēkiu bugs were abundant above about 13,450 ft (4,100 m) on undisturbed areas on Pu'u Wēkiu and Pu'u Hao Oki, on stable accumulations of loose cinders and tephra rocks, where the interstitial spaces are large enough to allow the bug to migrate downwards to moisture and shelter. These habitat types were found on the ridges and craters of the cinder cones (Howarth and Stone 1982). Areas that had accumulated aeolian dust and silt, such as Pu'u Poliahu, had fewer wēkiu bugs. Howarth and Stone (1982) did not survey areas outside of Pu'u Wēkiu, Pu'u Hau Oki, and Pu'u Poliahu (see Figure 2.2-12 for survey area). Howarth et al. (1999) had high trap capture rates on Pu'u Hau Oki, where the inner crater walls and crater bottom had been modified by observatory construction activity. This suggested that observatory construction and other human activities had not impacted wēkiu bug distributions at the summit outside of the immediate vicinity of paved and covered areas (Howarth et al. 1999). Polhemus (2001) found a high density of wēkiu bugs on Pu'u Hau Kea in the Ice Age NAR. He found that the bugs were most abundant on the rim and inner crater of the pu'u. Englund et al. (2002) found that wēkiu bugs are restricted to the rims and inner craters of each alpine cone, and, with only one exception, were found within 150 ft (50 m) of the peak elevation of each pu'u. Englund *et al.* (2002) found wēkiu bugs on Pu'u Hau Kea, Pu'u Māhoe, Pu'u Poepoe, Pu'u Ala, Pu'u Mākanaka, and an unnamed Pu'u near VLBA (at 11,920 ft/3,630 m). In their study, the highest capture rate of wēkiu bugs occurred on Pu'u Poepoe (33 bugs), and the second highest capture rate occurred on Pu'u Hau Kea (nine bugs); capture rates were low on all other pu'u (Englund et al. 2002). In 2004, wēkiu bugs were found only on Pu'u Hau Oki and Pu'u Pōhaku (Englund et al. 2005). In 2005, the wēkiu bug research team found additional wēkiu bug populations on Pu'u Hau Kea, Pu'u Pōhaku, Pu'u Wēkiu, Pu'u Poli'ahu, and Pu'u Lilinoe. This final location represented a significant extension of known wēkiu bug core habitat (Englund et al. 2006).

In 2006, Porter and Englund published a report further clarifying habitat preferences by wēkiu bugs. This study found that wēkiu bugs mainly reside on or near the crater rims of cinder cones that formed nunataks (ice free areas rising above the surrounding glacier) or that lay at the glacier limit during the last glaciation, and that the bug is most abundant on the north- and east-facing slopes (and on slopes shaded by local topography), where seasonal snow remains the longest (Porter and Englund 2006). Crests of glacially overridden cones and inter-cone expanses of glacial till appear to lack suitable wēkiu bug habitat (Porter and Englund 2006). Wēkiu bug surveys conducted in 2006 seem to support this theory (Englund et al. 2007). This study identified several new wēkiu bug populations, including a significant population around cinder cones immediately adjacent to the VLBA facility and at Pu'u Ko'oko'olau, and at a nunatak southeast of the VLBA facility. This latter nunatak was approximately 0.4 ha in size and was located at the very small outlying cone southeast of the VLBA facility. Wēkiu bugs appear to be restricted to non-glaciated habitats as they were not caught in traps in the glaciated regions of the same 11,910 ft (3,630 m) cone, even though such areas were less than 20–30 m away (Englund et al. 2007). Surprisingly, wēkiu bugs were not found in what appeared to be suitable habitat at the remote Pu'u Māhoe cone area.[14]

Jesse Eiben, a PhD candidate at the University of Hawai'i, has been researching wēkiu bug genetics and natural history since Fall 2005 and has discovered that wēkiu bugs are found not only on the summits of the pu'us, as described by Englund et al., but also on the flanks and at the bases of the cones where cinders have accumulated to sufficient depths (Eiben 2008). Figure 2.2-20 shows the potential and known wēkiu bug habitat in the Mauna Kea Science Reserve, as determined by Eiben.[15]

There has been some discussion about whether wēkiu bug populations have decreased, increased, or remained the same over time since the first survey in 1982 (Howarth et al. 1999; Polhemus 2001; Englund et al. 2002). Many insect populations naturally undergo cycles of low and high abundance over long periods of time (Howarth et al. 1999). Most of the studies were not designed to calculate population densities of wēkiu bugs, and instead measured activity levels. Trap methodologies differed between studies, which no doubt affected capture rates. Perhaps most importantly, wēkiu bug capture rates appear to be heavily influenced by climactic conditions such as presence of snow (Englund et al. 2006; Porter and Englund 2006; Englund et al. 2007), and thus it may not be appropriate to compare capture rates across studies that were conducted during different conditions or time of year. Because of these reasons it is difficult to draw any firm conclusions regarding changes in abundance of wēkiu bugs, and to subsequently identify any cause. Changes in population size, if they have occurred, could be due to a variety of causes including weather patterns, habitat disturbance, presence of invasive species, and long-term population cycling (Howarth et al. 1999). However, ten years of study following the 1997–1998 surveys suggest that wēkiu bugs are still found in all locations from the original studies, and more, and that they are able to live in both undeveloped and developed areas at the summit that have the appropriate cinder type and depth (Polhemus 2001; Englund et al. 2002; Englund et al. 2005; Englund et al. 2006; Porter and Englund 2006; Englund et al. 2007; Eiben 2008).

[14] The absence of wekiu bug in traps from one trapping season does not necessarily indicate that the species does not occur in an area. Additional efforts would need to be made to truly determine if the bug was present or absent in any particular area.

[15] Known wēkiu bug habitats are locations where wēkiu bugs have been captured in the high elevation regions of Mauna Kea by Jesse Eiben or the Bishop Museum teams. Potential habitats are areas that contain the correct type of cinder for wēkiu bugs, but where the bugs have not yet been captured.

2.2.2.2.2 Invasive Species

Two spiders, *Lepthyphantes tenuis* and *Meriola arcifera* have invaded the Science Reserve since 1982. The first (*L. tenuis*) is a sheet web spider from Europe that may compete with the native sheet web spiders (Howarth et al. 1999). The second (*M. arcifera*) is a non web-building, ground hunting spider native to Argentina, Bolivia, and Chile (Howarth et al. 1999). This species was first collected in Hawai'i in 1995 and is limited to upper elevations on the Saddle Road to the summit of Mauna Kea (Howarth et al. 1999). It is possible this species may prey on or compete with the wēkiu bug and other arthropods at the summit (Howarth et al. 1999).

Hippodamia convergens, a non-native beetle introduced in 1896 as a biological control agent of aphids, has been recently discovered at Pu'u Pōhaku in the Ice Age NAR (Ramsdale 2004; Englund et al. 2005). This species is tolerant of alpine conditions, and in addition to feeding on aphids can feed on dead insects. It therefore may compete directly with the wēkiu bug for food (Englund et al. 2005). Englund et al. also found several other non-native beetle species known to eat dead invertebrates in 2004. These species (which include *Aleochara verna, Creophilus maxillosus, Tachyporus nitidulus, Sphaeridium scarabaeoides Necrobia rufipes,* and *Dermestes frischii*) may also compete with wēkiu bug for food, although there remains some question as to whether these species feed on isolated dead insects in a similar way to wēkiu bugs (Ramsdale 2004; Englund et al. 2005).

In a study of invasive invertebrates conducted by the Bishop Museum in 2007-2008, a non-native species of predatory carabid beetle, *Agonum muelleri*, was discovered around Lake Waiau (Englund et al. 2009). Englund et al. (2009) state that it appears to be restricted to the region immediately around Lake Waiau. As this is not favorable wēkiu bug habitat, it is unlikely this species is currently impacting the wēkiu bug. However, this predatory beetle may be impacting other native invertebrates found in the area (Englund et al. 2009).

2.2.2.2.3 Invertebrate Surveys at MKSR

Although there have been sporadic mentions of arthropods occurring at the summits of Mauna Kea and Mauna Loa over the last 110 years, the first comprehensive arthropod inventory at the summit of Mauna Kea was not conducted until 1982, following the discovery of the wēkiu bug (*Nysius wekiuicola*) in 1979 (Guppy 1897; Bryan 1916; Meinecke 1916; Bryan 1923, 1926; Swezey and Williams 1932; Howarth and Montgomery 1980; Gagne and Howarth 1982; Howarth and Stone 1982). Since then, there has been a fairly steady stream of research on the arthropods at the summit, with the focus being on the activity, distribution, and abundance of the wēkiu bug (Ashlock and Gagne 1983; Howarth 1983; Gagne 1986; Edwards 1987; Howarth 1987; Edwards 1988; Duman and Montgomery 1991; Howarth et al. 1999; Polhemus 2001; Brenner 2002; Englund et al. 2002; Smith 2003; Englund et al. 2005; Englund et al. 2006; Porter and Englund 2006; Englund et al. 2007; Englund et al. 2009). In addition to these studies (discussed below), several project specific wēkiu bug mitigation and monitoring plans have been created (Pacific Analytics 2000, 2001a, b). Management recommendations made in these studies and plans are incorporated into Section 4 (Component Plans) of this Mauna Kea Natural Resource Management Plan.

Invertebrate Studies:

1. Howarth, F. G. and F. D. Stone. 1982. An assessment of the arthropod fauna and aeolian ecosystem near the summit of Mauna Kea, Hawai'i. Submitted to Group 70. Bernice P. Bishop Museum, Honolulu. 18 p.
2. Montgomery, S. L. 1988. A report on the invertebrate fauna found on the proposed NRAO VLBA antenna facility site, Mauna Kea Science Reserve, Mauna Kea, Hāmākua, Hawai'i. Appendix G

in: MCM Planning. 1988. Final supplemental environmental impact statement VLBA Antenna Facility, Mauna Kea, Hāmākua, Hawai'i, September, 1988. Amendment to the Mauna Kea Science Reserve Complex Development Plan. Prepared for The National Radio Astronomy Observatory, Socorro, New Mexico. 4 p.

3. Howarth, F. G., G. J. Brenner and D. J. Preston. 1999. An arthropod assessment within selected areas of the Mauna Kea Science Reserve. Final Report. Prepared for the University of Hawai'i Institute of Astronomy. Appendix J in Group 70. 2000. Mauna Kea Science Reserve Master Plan. Bishop Museum and Pacific Analytics, Honolulu. 65 p.
4. Polhemus, D. A. 2001. A preliminary survey of wēkiu bug populations at Pu'u Hau Kea, in the Mauna Kea Ice Age Natural Area Reserve, Hawai'i Island, Hawai'i. Smithsonian Institution, Washington, D.C. 4 p.
5. Englund, R. A., D. A. Polhemus, F. G. Howarth and S. L. Montgomery. 2002. Range, habitat, and ecology of the wēkiu bug (*Nysius wekiuicola*), a rare insect species unique to Mauna Kea, Hawai'i Island. Final report. Prepared for Office of Mauna Kea Management, University of Hawai'i. Hawai'i Biological Survey Report 2002–023. Bishop Museum, Honolulu, Hawai'i. 49 p.
6. Englund, R. A., A. Ramsdale, M. McShane, D. J. Preston, S. Miller and S. L. Montgomery. 2005. Results of 2004 wēkiu bug (*Nysius wekiuicola*) surveys on Mauna Kea, Hawai'i Island. Final Report. Prepared for Office of Mauna Kea Management. Hawai'i Biological Survey, Bishop Museum, Honolulu, Hawai'i. 37 p.
7. Englund, R. A., A. E. Vorsino, H. M. Laederich, A. Ramsdale and M. McShane. 2006. Results of 2005 wēkiu bug (*Nysius wekiuicola*) surveys on Mauna Kea, Hawai'i Island. Final Report. Prepared for Office of Mauna Kea Management. Hawai'i Biological Survey Report 2006–010. Hawai'i Biological Survey, Bishop Museum, Honolulu, Hawai'i. 63 p.
8. Porter, S. C. and R. A. Englund. 2006. Possible geologic factors influencing the distribution of the wēkiu bug on Mauna Kea, Hawai'i. Hawai'i Biological Survey Report 2006-031. Prepared for the Office of Mauna Kea Management. Hawai'i Biological Survey, Bishop Museum, Honolulu, HI. 29 p.
9. Englund, R. A., A. E. Vorsino and H. M. Laederich. 2007. Results of the 2006 wēkiu bug (*Nysius wekiuicola*) surveys on Mauna Kea, Hawai'i Island. Final Report. Prepared for Office of Mauna Kea Management. Hawai'i Biological Survey Report 2007-003. Hawai'i Biological Survey, Bishop Museum, Honolulu, Hawai'i. 66 p.
10. Englund, R.A., D.J. Preston, A.E. Vorsino, S. Meyers, and L. L. Englund. 2009. Results of the 2007–2008 Invasive Species and Wēkiu Bug (*Nysius wekiuicola*) Surveys on the Summit of Mauna Kea, Hawai'i Island. April 2009 Draft Report. Hawaii Biological Survey Report prepared for the Office of Mauna Kea Management. 73 pp.
11. Eiben, J.A. In progress. The life history and genetics of the wēkiu bug (Ph.D. research project). Plant and Environmental Protection Sciences, College of Tropical Agriculture and Human Resources, University of Hawai'i at Manoa.

Howarth and Stone (1982) conducted the first general survey of arthropods in the summit area of Mauna Kea. Methodology used in the survey included visual surveys (walking transects, turning over rocks) and placement of 100 pitfall traps at 88 different sites within the study area. Figure 2.2-12 shows the location of their survey points, which were limited to part of the plateau between Pu'u Poli'ahu and Pu'u Wēkiu, Pu'u Hau Oki, and the hillock sites near the end of the road to the north slope, at approximately the 13,000 ft (3,960 m) elevation (Figure 2.2-12). The pitfall traps were baited with fermented fish or shrimp paste (to attract scavenger species such as the wēkiu bug), buried so that their lips were flush with the ground surface, and filled with an insect preservant (ethylene glycol) that killed all invertebrates entering the traps (e.g. death traps). A cover rock was placed over the trap. The traps were left open for a long period of time, ranging from three to eight weeks. This study provided a list of species found at the site, identified to the lowest taxonomic level possible; distribution and abundance data for the wēkiu bug and lycosid spider; and notes on different habitat types (based on substrate type, size, and terrain) on the summit. Observations on species behavior and habitat types were noted when observed. Nearly 12,000 wēkiu bugs were collected in traps during this study (Porter and Englund 2006).

In 1988, Montgomery completed a visual survey, conducted on foot, of the proposed site for the VLBA antenna facility, between 12,200 and 12,400 ft (3,720 and 3,780 m) elevation; the nearby Summit Access Road; and an alternative site at 11,800 ft (3,600 m) (Montgomery 1988). No pit traps were utilized for this project. The undersides of rocks, and the areas beneath rocks were examined for the presence of arthropods, moisture, and debris. Only three native species were observed at the proposed VLBA site: the Agrotis moth, a sheet-web spider (*Erigone* sp), and a springtail in the family Entomobryidae. Three non-native species were also observed at the site: two species of flies (*Hydrellia tritici* and *Pollenia rudis*), and one parasitoid wasp in the family Chalcidoidea. No wēkiu bugs were observed during the survey. The native wolf spider (*Lycosa* species) was observed only at the alternative site. Because these sites were flat and uniformly bedded with ash and cinders, they were not considered prime habitat for the native arthropods found at the summit (Montgomery 1988).

In 1997–1998, Howarth, Brenner and Preston conducted the second general arthropod survey for the summit area (Howarth et al. 1999). Sampling techniques utilized in the study were different from the 1982 survey. Live pitfall traps (where food, water, and shelter were provided) were used during sampling activities, and traps were left open for only three days at a time. Pitfall traps were placed on Pu'u Wēkiu, Pu'u Hau Oki, Pu'u Māhoe, Pu'u Kea Ridge, Pu'u Lilinoe, and the north slope plateau road. Sampling locations are presented in Figures 2.2-13 through 2.2-15. The 1997–1998 sampling activities increased the area surveyed from that of the 1982 study, in order to determine if wēkiu bugs were found in other areas and habitat types, and to further study the distribution of lycosid spiders and other invertebrates of interest. A much lower number of wēkiu bugs (0.16 wēkiu bugs per trap) were captured in this study than in the 1982 study (60 bugs per trap). Because of the differences in trap methodology it is not possible to directly compare wēkiu bug abundances found in the 1982 study to the 1997–1998 study. Among the reasons for this, live traps leave open the possibility of escape and, also, predation of arthropods within the traps by predators such as the lycosid spider. Also, shorter trap times are less likely to reflect arthropod responses to variations in weather (and other factors) (Howarth et al. 1999). This study was useful, nonetheless, in refining information known about the distribution of wēkiu bugs, and added to the list of species known to reside at the summit and to arrive as aeolian drift.

In 2001, due to concern about possible reduction in wēkiu bug habitats due to astronomy-related development, and to learn more about their distribution elsewhere on the summit, Dan Polhemus conducted a preliminary survey of wēkiu bug populations at Pu'u Hau Kea, in the Mauna Kea Ice Age NAR. Polhemus used ethylene glycol pit fall traps (death traps) similar to those used in 1982. Ten traps were distributed across the outer slope, rim, and inner crater, and were left open for a period of four days. A large number of individual wēkiu bugs were caught (47 bugs/trap). Of these, 20% were adults, and the remainder were instars[16] of various stages. Most of the bugs were caught on the rim and inner crater. This study raised interest in conducting a comparison of various trapping methods (live vs. death) to help determine which method would be most productive for use in future studies.

In response to Polhemus' 2001 findings, Englund, Polhemus, Howarth and Montgomery conducted further investigations into the elevational distribution of wēkiu bugs and their presence/absence on various unstudied pu'u (cinder cones) on Mauna Kea (Englund et al. 2002). Areas surveyed during this study included Pu'u Mākanaka, Pu'u Māhoe, Pu'u Ala, Pu'u Poepoe, Pu'u Keonehehe'e, and adjacent unnamed cones, and several unnamed cones near the VLBA facility. Sample locations are shown in

[16] Instars are the life stages of insects that occur between molts.

Figure 2.2-16. The study used trapping methodologies similar to those used in 1997–1998 (Howarth et al. 1999). The investigators placed 83 traps during the study. This study found wēkiu bugs in low numbers (only 47 bugs were captured, a rate of 0.04 to 2.5 bugs per trap, depending on location). Some interesting results from this study include capture of wēkiu bugs at lower elevations than previously recorded and confirmation that Pu'u Hau Kea had the highest concentration of wēkiu bugs. Wēkiu bugs were captured (at very low numbers) at elevations as low as 11,715 ft (3,572 m). Englund et al. (2002) found that wēkiu bug abundance in traps increased with elevation, and that they were mainly restricted to the rims and inner craters of the pu'u (within 150 ft of the peak elevation of each cone). Comparison of capture rates at Pu'u Hau Kea in September 2002 to those of July 2001 indicated that seasonality (weather, abiotic factors, substrate moisture) appears to play an important role in wēkiu bug catch rates (Englund et al. 2002).

The Englund et al. (2002) study also compared trapping methodologies used in previous studies to determine if information obtained from studies using different methodology is comparable. To assess the effectiveness of various trapping methods on wēkiu bug capture rates, Englund et al. (2002) placed eight live pitfall and eight ethylene glycol (death) traps in a pair-wise fashion in windblown areas near the upper rim of Pu'u Hau Kea. This allowed direct comparison of trapping methods during the same time period. Both sets of traps were left undisturbed for three nights. Unfortunately only nine wēkiu bugs total (five in live traps, four in death traps) were captured during the study. The capture rates were essentially the same for both trap types; however, one important note from the study was that the live traps actually had a 56% mortality rate. This finding was also true for previous studies using live traps (Brenner et al. 1999). For the following reasons, Englund et al. determined that for baseline monitoring of wēkiu bugs, and for general assessments of invertebrate diversity, ethylene glycol (death) traps were preferable over live traps because:

1. Large predators such as lycosid (wolf) spiders can consume items within live traps. This makes it difficult to determine whether traps with no wēkiu bugs were truly empty or whether the wēkiu bugs had been consumed.
2. Because insects cannot escape the ethylene glycol traps, they provide a better measure of wēkiu bug presence and the presence of other species of interest, including invasive species.
3. Judicious use of ethylene glycol traps will have little or no negative long-term impacts on wēkiu bug populations.

In April and July 2004, Englund, Ramsdale, McShane, Preston, Miller and Montgomery returned to Mauna Kea for additional wēkiu bug surveys, and to continue research begun in the 2002 study (Englund et al. 2005). Areas included in the survey included Pu'u Kanakaleonui (9,594 ft/2,925 m), Pu'u Pōhaku, Pu'u Hau Oki, Lake Waiau, Red Hill, and Pu'u Hau Kea. The investigators placed 55 pitfall traps (similar to those used in 2002) in the field: five were placed at Pu'u Hau Oki in April and the remainder (50 traps) at Pu'u Kanakaleonui, Pu'u Pōhaku, Lake Waiau, Red Hill, and Pu'u Hau Kea in July. Figure 2.2-17 shows the locations of the survey efforts. Only ten bugs were captured at Pu'u Hau Oki in April and only one was captured at Pu'u Pōhaku in July. No wēkiu bugs were captured at Pu'u Hau Kea (previously known to have a high number of wēkiu bugs), Lake Waiau, Red Hill, or Pu'u Kanakaleonui in July 2004. As in 2002, a comparative test of five ethylene glycol (death) and five shrimp pitfall (live) traps was conducted at Pu'u Hau Kea in July 2004. However, no wēkiu bugs were captured in either set of traps in July 2004. Although this study did not provide much information about wēkiu bugs (except that they were not active in July 2004), it did provide information on the presence of eight new species of introduced beetle unknown to reside on Mauna Kea (three of which were new records for the island of Hawai'i). These are described in Section 2.2.2.2.2.

In addition to the above work, Englund et al. (2005) placed temperature and humidity loggers in the field to obtain microhabitat data on wēkiu bug habitats. These were placed in 1) areas known to have high wēkiu bug densities, 2) areas disturbed by development that previously had high wēkiu bug densities, and 3) areas adjacent to high-quality habitat that lack wēkiu bugs. A total of eight data loggers (two subsurface data loggers, and six surface data loggers) were installed in July (at Pu'u Pōhaku and Pu'u Hau Kea). In December, 18 data loggers (nine pairs of subsurface and surface) were installed along a "transect starting at the bottom of the northwest rim and extending in a southeasterly direction to the cinder cone and down the slope to the bottom of the Pu'u Hau Kea cinder cone" (Englund et al. 2005). In addition to the transect line, several data loggers were placed in a variety of areas throughout the Mauna Kea Summit (for a total of 45 data loggers placed in December). Initial results from this study include recording of the extreme fluctuations of temperature and humidity that occur at the surface of the substrate on Mauna Kea. The one subsurface probe that was discussed showed a much lower variation in temperature and humidity than the surface probes, thus indicating a more stable environment and reinforcing the idea that wēkiu bugs can find refuge in subsurface areas during great fluctuations in the surface conditions.

In 2005, Englund, Vorsino, Laederich, Ramsdale and McShane continued investigations into wēkiu bug distribution on Mauna Kea, expanding the total area of Mauna Kea surveyed and greatly increasing the field time and number of traps placed (Englund et al. 2006). Some of the most remote areas of the Mauna Kea summit were sampled in 2005. Sampling locations (using the names given in the report, (Englund et al. 2006)) included:

- Pu'u Hau Kea
- Pu'u Wēkiu
- Red Hill
- Pu'u Hoaka
- "Below sub millimeter array"
- Pu'u Pōhaku
- Unnamed N. Pu'u VLBA
- Unnamed S. Pu'u VLBA
- Pu'u #1 S.E. of VLBA
- Pu'u #2 S.E. of VLBA
- Horseshoe Crater (very large unnamed crater downslope of Pu'u #2 S.E. of VLBA)
- The plateau where the 30 m telescope has been proposed (northeast of Pu'u Poliahu)
- Pu'u Lilinoe and the cinder cones surrounding it
- Skiing area called "Poi Bowl" that is down slope of Pu'u Hau Oki
- "11,672 ft Pu'u" at northwest summit
- Unnamed pu'u at northwest summit
- Cone at terminal moraine.

Sampling locations are shown in Figure 2.2-18. The investigators used live traps baited with shrimp paste and a smaller number of ethylene glycol (death) traps, similar to those described in Englund et al. (2002). A total of 153 traps were placed in sampling locations (90 in May and 63 in June). In addition, the investigators tested a new survey technique involving timed visual surveys, mainly in areas around snow banks. A total of 70 wēkiu bugs were observed or collected in 2005, with nearly equal amounts collected in traps in May and June (17 in May, 16 in June; the remaining 37 bugs were collected during visual observations). Many wēkiu bugs were observed during timed visual collections along snow banks at the summit of Pu'u Hau Kea (May) and Pu'u Poliahu (June), indicating that the populations there remain robust (Englund et al. 2006). An important finding of the 2005 study was that visual collection along snow banks was more time-efficient than either shrimp (live) or ethylene glycol (death) traps. For example, 13 wēkiu bugs were observed in 20 minutes of observation time in May, while the traps in the nearby areas collected only 11 wēkiu bugs in a 10-day period. One limitation of visual surveying along snow banks is that snow banks are patchily distributed in time and space, and they are not present in all locations where wēkiu bugs live. Therefore this method may not be appropriate as a sole survey methodology. However, it is a useful and quick way to survey for the presence of bugs during the right climatic conditions.

Another important finding of the 2005 study was that sampling efforts confirmed that wēkiu bugs were found only in cinder cone areas and were never in glacial floor areas between cinder cones, such as the proposed location of the 30-meter telescope facility and the Poi Bowl ski area (Englund et al. 2006).[17] Pu'u Lilinoe was the only area where new populations of wēkiu bugs were found. However, this represents a significant extension of their known core habitat. Wēkiu bugs were also found at Pu'u Hau Kea, Pu'u Pōhaku, Pu'u Wēkiu and Pu'u Poliahu. No wēkiu bugs had been observed at Pu'u Poliahu between 1982 and 2005, but in 2005 a large snow bank was found along the northeastern side of Pu'u Poliahu during sampling activities, which probably increased wēkiu bug activity and trapping success. No wēkiu bugs were trapped or observed around "Horseshoe Crater" despite the presence of a large snow bank and large amounts of aeolian drift, or at the western summit cones above Pu'u La'au cabin, indicating these areas may either not be good wēkiu bug habitat or that they have yet to be colonized by wēkiu bugs.

As in 2002 and 2004, a comparative test of ethylene glycol (death) and shrimp pitfall (live) traps was conducted at Pu'u Hau Kea in May and June 2005. Five wēkiu bugs were captured in glycol traps and three in shrimp traps in May, indicating no difference between the effectiveness of the two. However, in June, eleven bugs were collected in glycol traps, while only one was collected in the shrimp traps. Thus the results from June suggest that perhaps glycol traps are more efficient, at least during times of reduced snow cover (June). However, overall the results from the trap efficiency studies remain inconclusive due to low capture rates.

The collection of temperature and humidity data begun in 2004 continued through 2005. Initial analysis of the thermal data indicated that areas inhabited by wēkiu bugs seem to be both colder and have more stable temperatures than those not inhabited by wēkiu bugs. Englund et al. (2006) also found that spring months when wēkiu bugs are most active exhibited dramatic daily temperature shifts, with temperatures dropping below freezing every night. Another finding was that the telescopes do not seem to have warmed (or affected the thermal regimes of) nearby Pu'u Hau Oki. These initial findings will be further investigated over time.

In addition to the above study conducted by Englund et al., Porter and Englund conducted another important study of wēkiu bug distribution in 2005. This study was a collaboration between a geologist (Steven Porter, University of Washington) and wēkiu bug expert Ron Englund (Bishop Museum), to determine whether wēkiu bug distribution is influenced by the geology of the summit. By analyzing historical wēkiu bug capture data, Porter and Englund found that glaciation that occurred around 20,000 years ago seems to have influenced current wēkiu bug distribution. Wēkiu bugs are predominantly found on or near the crater rims of cinder cones that formed nunataks (ice-free areas rising above a surrounding glacier) or that lay at the glacier limit during the last glaciation (Porter and Englund 2006). Porter and Englund (2006) determined that the bugs prefer to reside in cinder and spatter near the unmodified crests of cinder cones, and that they are concentrated in areas where seasonal snow remains the longest (on the north- and east-facing slopes, and on slopes shaded by local topography). Snow patches appear to increase in area and number with increasing altitude above the limit of glaciation. Aeolian drift is concentrated along the margins of snow packs. Snowpacks thus provide an important source of food and moisture for the wēkiu bugs. Crests of glacially overridden cones and inter-cone expanses of glacial till appear to lack suitable wēkiu bug habitat, and seasonal snow tends to disappear quickly in these areas

[17] However, see discussion of Jesse Eiben's work at the end of this section. Eiben has consistently found wēkiu bugs on crater flanks and bases, such as at Poi Bowl.

(Porter and Englund 2006). Porter and Englund recommend that further wēkiu bug surveys be conducted in geologically promising unstudied pu'u.

Porter and Englund (2006) also conclude that wēkiu bugs are capable of living on the unmodified snowy slopes near the telescope facilities, and that telescopes sited on glacially modified lava flows (unsuitable wēkiu bug habitat) would not likely affect wēkiu bug populations on the summit. This information can be used to help plan the locations of future telescope development or modifications of existing telescopes on the mountain.

In 2006, Englund, Vorsino, and Laederich continued the Bishop Museum study of wēkiu bugs on the summit of Mauna Kea (Englund et al. 2007). This study continued along the line of the 2002–2005 studies and included visual surveys, shrimp bait (live) pitfall traps, and ethylene glycol (death) traps. Sampling was conducted in April and May 2006, and the trap effort was increased above previous year's efforts (158 traps, total; 70 in April and 88 in May). Areas sampled include: Pu'u Hau Kea, Pu'u Waiau, Pu'u Ko'oko'olau, Pu'u Hoaka, Pu'u Poli'ahu, "11,989 ft Pu'u" (near Pu'u Hoaka), Glacier Cone, Horseshoe Crater, pu'u near Māhoe, pu'u north of VLBA, pu'u south of the VLBA, far pu'u beyond VLBA, 1st pu'u beyond VLBA, "below Keck & Subaru," and Pu'u 11,605. Locations of traps are presented in Figure 2.2-19. Englund et al. found that the snowy conditions in 2005–2006 provided favorable conditions for wēkiu bugs, and a large number of individuals (114) were trapped or observed around snowbanks. Interestingly, Englund et al. trapped no wēkiu bugs during a period of heavy snowfall and snow cover in April, suggesting that wēkiu bugs may remain inactive for some time during and after heavy snowfall.

During the 2006 field season, the "nunatak hypothesis" put forth by Porter and Englund (2006) was tested by conducting sampling for wēkiu bugs at the various locations suggested as promising in the 2006 report (Porter and Englund 2006). Several significant new bug populations were found using these predictions, most notably in areas adjacent to the VLBA facility and areas around the Adze Quarry (Englund et al. 2007). Surprisingly, wēkiu bugs were not found in what appeared to be suitable habitat at the remote Pu'u Māhoe area.

As in 2002–2005, the 2006 study included a comparative test between shrimp (live) pitfall traps and ethylene glycol (death) traps. This year, ethylene glycol traps were found to be much more effective than shrimp pitfall tests (43 wēkiu bugs captured in ethylene glycol traps and only one captured in shrimp traps). Because of the effectiveness of the ethylene glycol traps over two years of testing, Englund *et al.* state that no further pitfall-trap testing will be done (Englund et al. 2007)[18].

Englund et al. (2007) also conducted a brief survey of *Nysius aa*, the Mauna Loa bug, which is the sister species to the wēkiu bug (*Nysius wekiuicola*). They found that the Mauna Loa bug, although it too resides in cinder habitats, appears to be much more abundant within a broader range of habitat types than the wēkiu bug.

In 2007 and 2008, Englund et al. continued the wēkiu bug sampling studies from previous years, although with some modifications to the methods. The number of trap hours was reduced, fewer locations were included, and no ethylene glycol kill traps were deployed (Englund et al. 2009). Despite lower effort, a large number of wēkiu bugs were captured in 2007, indicating a robust population. Comparison of wēkiu bug density and mean annual temperatures were conducted to help understand wēkiu bug distribution. Results suggest that the wēkiu bug is most abundant in the areas with coldest annual temperatures, and

[18] Despite this, live trapping continues to be the preferred method utilized by Bishop Museum.

less abundant in warmer areas such as Lake Waiau (Englund et al. 2009). However, there could be factors other than temperature (such as aspect and wind-flow patterns) that may result in the same distribution.

An important study of the life history and genetics of the wēkiu bug is currently being undertaken by Jesse Eiben and Dr. Dan Rubinoff, at the University of Hawai'i. They are rearing the bug in the laboratory in order to study the developmental stages of the bug, and to develop a temperature-dependent growth curve for the bug. The egg and immature stages have never been described in the literature. One interesting observation made is that the wēkiu bug is much more "heat-tolerant" than previously described and in some ways does better (i.e., grows faster) at warmer temperatures than commonly found on the mountain. The temperature of wēkiu bug microhabitat on the mountain varies widely over the course of each day, with surface temperatures of up to 110 degrees F commonly seen in full sun, even when the air temperature is at freezing. The growth-rate observations support the idea that the bug takes advantage of solar heating in some form at the microhabitat level to aid in growth and egg development. The genetics component of the project was devised to study population-level issues, such as whether bugs regularly migrate between various pu'u, or if movement between the pu'u is limited to a very few bugs (effectively changing the amount of "inbreeding" that occurs in each small population of bugs). The first round of genetic analysis showed very little variation within the species, suggesting the possibility of a recent genetic bottleneck. Further investigations (using nuclear DNA microsatellite analyses) are underway to further study population genetics in the wēkiu bug (Eiben 2008).

Based on results of his fieldwork, and those of the Bishop Museum Study, Jesse Eiben has prepared a map of potential and known wēkiu bug habitat in the Mauna Kea Science Reserve. This map is reproduced in Figure 2.2-20. The map shows the extent of wēkiu bug habitat across the summit of Mauna Kea, and highlights areas of existing disturbance (infrastructures such as observatories and roads). Further investigation of the distribution of wēkiu bugs on the summit is needed to increase the accuracy of this map. However, the map is useful in delineating areas that should be considered for protection from further development.

2.2.2.3 Threats to Invertebrate Communities on Mauna Kea

2.2.2.3.1 Habitat Alteration

Habitat alteration threatens native invertebrate communities by directly removing habitat (through development) or changing it to the extent that the invertebrates are no longer able to live there (for example, by changing host-plant abundances). At both Hale Pōhaku and the MKSR, habitat alteration occurs through development of astronomy facilities and support structures (such as parking lots), every-day use, and (primarily in the subalpine zone) introduction of invasive species.

A prime example of habitat loss through development is the loss of wēkiu bug habitat on the summit through construction of telescope facilities. In some cases, site preparation for telescope facilities included bulldozing the cone summit to create a level surface, the removal or flattening of rims, and filling of craters with debris (Porter and Englund 2006). For example, during the construction of the Keck Observatory, the top ten meters of Pu'u Hau Oki was removed and the crater was filled with approximately 12 meters of pyroclastic debris (Porter and Englund 2006). All told, the development of W. M. Keck and Subaru Observatories filled or buried about one-third of the within-crater habitat of Pu'u Hau Oki (Pacific Analytics 2000).

Wēkiu bug habitat is easily altered by vehicular traffic and construction activity, as the tephra cinders preferred by the bug are easily crushed into dust-sized particles. Prime habitat can be quickly degraded to compacted silt and mud by use of off-road vehicles (Richardson 2002). It has been estimated that since 1963, approximately 62 acres (25 hectares) of potential arthropod habitat have been lost to astronomy-related development on the summit (Richardson 2002; Smith 2003).[19] Wēkiu bug habitat may also be altered by dust blown up from road grading and other construction activities on the summit (Pacific Analytics 2000). This dust can reduce surface porosity and fill pockets between cinders, inhibiting movement by arthropods and perhaps affecting wēkiu bug food sources by decreasing the accumulation of aeolian drift (dead and dying insects blown from lower elevations) in these surface pockets (Pacific Analytics 2000). The true level of impact from dust is unknown at this time, as it has not been studied.

Grazing by introduced mammals has heavily altered habitats in the subalpine woodlands, by changing the composition of plant species in favor of invasive weed species. Many of the native plants previously used by native invertebrates, such as Hylaeus bees, have been reduced in abundance to the point that the small and widely dispersed native plant populations are no longer able to support pollinator populations (USFWS 1994; Aldrich 2007). Regarding the situation with native bees, Magnacca (2007) states that

> "The strong dependence of all species of Hylaeus on native plants to the near-complete exclusion of exotics (with the sole exception of Tournefortia among the latter) means that to conserve them native forests and shrublands must be preserved. Conservation of the plants and bees is a reciprocal situation, given the likely status of Hylaeus species as primary pollinators of many important plants. Based on current distributional information, it is clear that for bees to be present, at least some level of vegetation diversity is required. This is probably due to a combination of temporal (i.e., year-round availability of floral resources) and nutritional factors."

Thus, habitat alteration through removal of plant species can seriously impact populations of pollinators and other animals that rely on the plants as source of food or shelter. The destruction of their pollinators can, in turn, can make it difficult or even impossible for these plant species to repopulate the area. Once started, this vicious cycle can be difficult to eliminate.

2.2.2.3.2 Invasive Species

As described above, grazing mammals and invasive plant species can reduce populations of native plants, effectively reducing food and shelter for native pollinators and the other arthropods that rely on them, and thus indirectly reducing native arthropod populations. Other invasive animals, such as rats and non-native birds, can impact arthropod populations directly through predation. In fact, several species of flightless insects no longer occur on the main Hawaiian Islands where rats are common (Gagne and Christensen 1985). However, invasive invertebrates are perhaps the greatest threat to native invertebrates in Hawaiʻi. Invasive invertebrates threaten native invertebrate populations through competition, predation, habitat alteration, and parasitism. Nearly 4,000 species of invertebrates have been introduced to the Hawaiian Islands, 75% of which are arthropods (including 2,400 insects and 500 other arthropods) (Loope et al. 2001). Most non-native invertebrates arrive unintentionally, and the remainder (about 1/5) are introduced as biological control agents (Loope et al. 2001).

Invasive parasitoid wasps and flies are likely reducing Cydia moths and other moth species that live in the subalpine māmane woodlands (Brenner et al. 2002; Oboyski et al. 2004). The larvae of these moths are an important source of protein for the endangered Palila (Brenner et al. 2002). Thus the parasitoid wasps not only directly affect the moths they attack but also indirectly affect predators of the moths such as the

[19] Actual habitat loss is unknown. The 62 acres represents the total area at the summit disturbed through observatory and infrastructure development.

Palila. In another example, invasive parasites (introduced as biological control agents) have nearly wiped out the once common koa bug (Asquith 1995).

Invasive yellowjackets and ants are also likely affecting native invertebrate populations in the māmane woodlands. Cole et al. (1992) found that many invertebrate populations on Haleakalā were smaller in areas infested with Argentine ants than in areas not infested, and Gambino et al. (1987) found that yellowjackets prey on native arthropods. Wetterer et al. (1998) conducted bait surveys for ants along the "Observatory Road" on Mauna Kea from 8,005 ft (2,440 m) to 9,250 ft (2,820 m) elevation. One Argentine ant, *Linepithema humile*, was trapped at Kalepeamoa at 8,497 ft (2,590 m).

The predatory European earwig (*Forficula forficularia*) was found in high numbers around the Onizuka Visitor Information Station at Hale Pōhaku (Englund et al. 2009). This could potentially impact native invertebrate species in the subalpine zone (Englund et al. 2009).

Invasive snail species such as the garlic snail (*Oxychilus alliarius*) have a direct negative impact on native snails through predation. Native terrestrial snails are also impacted by invasive mammals such as rats and birds such as Ring-necked pheasants.

At the summit of Mauna Kea, the greatest threat to the native arthropod populations is introduction of invasive arthropods that are adapted to alpine conditions. In recent decades two alpine-adapted spider species have invaded the summit of Mauna Kea. One, a sheet web spider from Europe, *Lepthyphantes tenuis,* may compete with the native sheet web spiders, although this has yet to be studied. The other, greater, threat is *Meriola arcifera*, a ground hunting spider native to Argentina, Bolivia, and Chile that may prey on or compete with the wēkiu bugs and other arthropods at the summit (Howarth et al. 1999). There are also several non-native beetle species that may have become established on the summit (Englund et al. 2005; Englund et al. 2009). The primary beetle species that may impact native arthropods are *Agonum muelleri* and *Hippodamia convergens*. *Agonum muelleri* is a predatory carabid beetle that likely preys on native invertebrates in the summit region. It appears to be currently limited to Lake Waiau, and may not have an impact on wēkiu bugs unless it spreads to other regions of the summit (Englund et al. 2009). *Hippodamia convergens* is a non-native alpine-adapted beetle introduced in 1896 as a biological control agent of aphids. *H. convergens* is known to feed on dead insects and therefore may compete directly with the wēkiu bug for food. The impact of these species, if any, has yet to be determined. If food (in the form of aeolian drift) is not limiting, then scavengers such as *H. convergens* are not likely to pose as great a threat as do predators such as *Agonum muelleri* and *Meriola arcifera*.

There is always potential for the introduction of new invasive species to both Hale Pōhaku and the summit through importation of goods from similar climates (such as astronomical equipment); accidental transport on vehicles, clothing, and equipment; and the inevitable spread of biological control agents. Perhaps the most threatening introduction to the summit would be a predator or parasitoid that is small enough to fit into the interstitial spaces in the cinders that are used by the wēkiu bugs to escape such predators as the native wolf spider (Pacific Analytics 2000).

2.2.2.3.3 Human Use

Human use can impact native invertebrate populations by altering their habitats, introducing invasive species, increasing pollution (through spills of hazardous material, vehicle emissions, etc.), improper disposal of trash, and collecting of plant and animal specimens for both scientific research and hobbies.

The tephra habitats utilized by wēkiu bugs are easily degraded to compact, silty habitats during construction activities, off-road vehicle use, and trampling (Howarth and Stone 1982). Erosion is a common problem in construction and heavy use areas at Hale Pōhaku (Gerrish 1979). Erosion and soil impaction can limit native vegetation relied upon by native arthropods in the subalpine zone, and can also directly impact soil-dwelling species.

Chemical spills can occur both at Hale Pōhaku and the summit area. Several oil spills have occurred at the summit (Smith et al. 1982), and hazardous chemicals are used to clean the mirrors at several observatories (Pacific Analytics 2000; NASA 2005). Spills of petroleum products and hazardous chemicals will most likely kill most of the native ground-dwelling arthropods in the immediate vicinity. Oil spills, in particular, will take a long time to biodegrade at the summit because of the cold and dry conditions found there (Howarth and Stone 1982).

The impacts of human use of Hale Pōhaku, the Summit Access Road, and the MKSR are discussed in more detail in Section 3.

2.2.2.3.4 Climate Change

For a discussion of potential ramifications of climate change on weather patterns and native plant communities see Section 2.2.1.3.6.

It is very difficult to predict just what impacts global climate change will have on Mauna Kea in the future. Currently it is believed (and this is supported by recent climate data) that temperatures will increase and that the greatest increases will occur at Mauna Kea's highest points. Climate change scenarios variously predict an increase in rainfall associated with the increase in temperatures (Hamilton 2007), or a decrease in rainfall at high altitudes due to a depression of the inversion layer (Loope and Giambelluca 1998; Calanca 2007). Either rainfall scenario will spell change for the invertebrate communities on Mauna Kea.

An increase in temperature at the summit may lead to:

1. Upwards movement into the subalpine and alpine zone of both native and non-native invertebrate species from lower elevations that were previously kept out by freezing temperatures, possibly increasing competition with and/or predation on the current subalpine and alpine arthropods (Benning et al. 2002; Weltzin et al. 2003).
2. Shorter duration of snow pack before it melts in the higher elevation areas, leading to longer periods of time without snow pack. This could affect wēkiu bugs because they often forage on the edges of snow banks and tend to do well in years of heavy snowfall (Englund et al. 2006). However, if warming temperatures lead to an increase in snowfall at the summit (Hamilton 2007), this may have a beneficial effect on arthropods such as the wēkiu bug that feed on the edges of snow banks.

If wind patterns change, the summit of Mauna Kea could see a change in the amount of aeolian drift deposited. This could have serious impacts on the arthropod community at the summit, which is almost entirely dependent on the aeolian drift as a food source.

2.2.2.4 Invertebrate Community Information Gaps

There is still much to be learned about the invertebrate communities at both Hale Pōhaku and the MKSR. Of the two areas, the MKSR summit has had more intensive research conducted, with most of the research focusing on the wēkiu bug. Through research conducted over the past ten years, a clearer picture of wēkiu bug distribution, habitat preferences, and biology is beginning to appear. However, very little information is available on the other arthropods found at the summit, and next to no information is available about arthropod communities at Hale Pōhaku and in the MKSR below the summit.

The following information gaps regarding the condition of the subalpine and alpine arthropod communities at Hale Pōhaku and the MKSR have been identified through review of the literature and consultation with local experts:

1. Quantitative invertebrate surveys
   a) Hale Pōhaku: No comprehensive quantitative studies have been conducted at Hale Pōhaku documenting the composition of the invertebrate community, population sizes or distribution of native and non-native species. However, the Bishop Museum has completed a presence/absence study of invasive invertebrates in this area (Englund et al. 2009). Additionally, a brief visual survey for other species of Lygaeid bugs (relatives of the wēkiu bug) was conducted at Hale Pōhaku in 2002 (Englund et al. 2002). Some species- or genus-specific work has recently been conducted on lepidopteron and tephritid fly species (Brown 2008; Medeiros 2008).
   b) Summit Access Road: No comprehensive invertebrate surveys have been conducted along the Summit Access Road between Hale Pōhaku and MKSR, with the exception of the invasive invertebrate survey, and the brief surveys for lygaeid bugs and ants described above.
   c) Mauna Kea Science Reserve: Two comprehensive arthropod surveys have been conducted in the MKSR (Howarth and Stone 1982; Howarth et al. 1999). Both of these surveys were limited in the area covered, but produced a good baseline list of species found in the community. Since then, research has been ongoing into the status and biology of the wēkiu bug (Englund et al. 2002; Englund et al. 2005; Englund et al. 2006; Englund et al. 2007; Eiben 2008; Englund et al. 2009). Since ten years have passed since the last comprehensive survey, it may be time to conduct another. If available, information on by-catch from the last six years of Bishop Museum wēkiu bug studies and the 2007-8 invasive species surveys, may provide a relatively accurate species list.

2. Status of Invasive Species

Limited information is available regarding density, distribution, and effects of established invasive invertebrate species at Hale Pōhaku and the MKSR. Wetterer et al. (1998) conducted bait surveys for ants along the "Observatory Road" from 8,005 ft (2,440 m) to 9,250 ft (2,820 m) elevation and found one Argentine ant (*Linepithema humile*) at Kalepeamoa at 8,497 ft (2,590 m). The recent survey of invasive arthropods completed by the Bishop Museum (Englund et al. 2009) has provided an update on invasive species present at Hale Pōhaku and the MKSR, although it does not provide densities or distribution maps. There is a continuing need for ongoing inspections for and monitoring of invasive invertebrate species on the properties and identification of environmental problems they may be causing. There currently exists no information on whether any of the invasive invertebrate species present are impacting native species of plants and animals. Species of concern include, at a minimum, yellowjackets, ants, parasitoid wasps, predatory beetles, and the two invasive spiders at the summit.

3. Protected Species/Species of Concern
Several Species of Concern (including snails, bees, moths, and true bugs) are known to inhabit the subalpine and alpine regions of Mauna Kea. With the exception of the wēkiu bug (and very limited information on the distribution of the lycosid spider), little or no information is available about these species. For example, there have been no surveys for native snails, bees or moths conducted at Hale Pōhaku. Next to nothing is known about the native moth, spiders, and centipedes that inhabit the summit. More information is needed on what native pollinators, if any, are visiting the scattered individual Mauna Kea Silverswords found at Hale Pōhaku and in the MKSR, and how invasive species are impacting species of concern.

2.2.3 Birds

Hawai'i has an incredible diversity of birds, a great number of which are endemic species (meaning they are found only here). This amazing diversity of species evolved from a few different species of birds that managed to colonize the islands. For example, the Hawaiian honeycreepers, a diverse group of approximately 50 species (including extinct forms), are thought to have evolved from a single species of cardueline finch that arrived 15 to 20 million years ago, on the islands that now make up the northwestern Hawaiian island chain (Freed et al. 1987; James 2004). Hawaiian birds have been greatly affected by the arrival of man and his associated animal species on the islands – in fact, only 35 of more than 100 species present before man arrived are still alive today (Olson and James 1982; Pratt et al. 1997). Most Hawaiian bird species went extinct before European contact, but 27% of endemic Hawaiian birds have gone extinct since 1778 because of human activities (Fancy and Ralph 1998). A large percentage of extant native bird species are endangered due to habitat loss, non-native predators (cats, rats, and mongoose), disease (avian malaria and pox), hunting and over-collection (historically for feathers, meat, or specimens), and competition with non-native birds and insects for food (Scott et al. 1986). There are numerous non-native species of birds in the islands. The first avian introduction came with the arrival of the early Polynesians, who brought the Red junglefowl (*Gallus gallus*) for food, but most introductions came after Western contact, either as intentional introductions or escaped pets (Moulton et al. 2001).

2.2.3.1 Subalpine Bird Communities (Hale Pōhaku and Lower Summit Access Road)

The māmane woodlands have a fairly diverse bird community, including frugivores, nectarivores, insectivores, and two raptor species. The māmane trees themselves are the primary food source for birds in the region, providing nectar and seeds on a seasonal basis (Hess et al. 2001). Several bird species also prey in the insects that utilize the māmane trees. Māmane woodlands have been severely degraded by non-native browsing animals (cattle, sheep, goats), and consequently native bird populations have declined in this forest type (Juvik and Juvik 1984). See Section 2.2.3.3 for more information on the threats to avian communities on Mauna Kea and Sections 2.2.1.3.4 and 2.2.4 for more information about the effects of non-native mammals on the māmane woodland and its inhabitants. Photos of native bird species found in the subalpine zone are presented in Figure 2.2-21 and photos of non-native bird species are found in Figure 2.2-22.

Native bird species found in māmane woodlands on Mauna Kea include the Palila (*Loxioides bailleui*), 'Amakihi (*Hemignathus virens*), 'Apapane (*Himatione sanguinea*), 'Elepaio (*Chasiempis sandwichensis sandwichensis*), 'Akiapola'au (*Hemignathus munroi*), 'I'iwi (*Vestiaria coccinea*), 'Io (*Buteo solitarius*), Kolea (*Pluvialis fulva*) and Pueo (*Asio flammeus sandwichensis*) (Scott et al. 1986). Each of these species is discussed in more detail below, in Sections 2.2.3.1.1 and 2.2.3.1.2. The Hawaiian petrel or 'Ua'u (*Pterodroma sandwichensis*), has been observed in subalpine lava flows on Mauna Loa, at 8,000–9,200 ft

(2,440–2,800 m), and occasionally in subalpine and alpine habitats on Mauna Kea (Conant 1980; Kjargaard 1988; Hu et al. 2001). The ʻUaʻu is discussed further in Section 2.2.3.2. Of the above species only the Palila, ʻAmakihi, ʻApapane and ʻIʻiwi have been observed at Hale Pōhaku in recent times (see Section 2.2.3.1.4).

Non-native birds found in māmane and māmane-naio woodlands on Mauna Kea include Black Francolin (*Francolinus francolinus*), Erckel's Francolin (*Francolinus erckelii*), Chukar (*Alectoris chukar*), Japanese Quail (*Coturnix japonica*), Ring-necked Pheasant (*Phasianus colchicus*), Wild Turkey (*Meleagris gallopavo*), California Quail (*Callipepla californica*), Eurasian Skylark (*Alauda arvensis*), Melodious Laughing-thrush (*Garrulax canorus*), Red-billed Leiothrix (*Leiothrix lutea*), Northern Mockingbird (*Mimus polyglottos*), Common Myna (*Acridotheres tristis*), Japanese White-eye (*Zosterops japonicus*), Northern Cardinal (*Cardinalis cardinalis*), House Finch (*Carpodacus mexicanus*), House Sparrow (*Passer domesticus*), Warbling Silverbill (*Lonchura malabarica*), Nutmeg Mannikin (*Lonchura punctulata*), and Yellow-fronted Canary (*Serinus mozambicus*) (van Riper 1978; Scott et al. 1986). Of these, only eight species (Erckel's Francolin, California Quail, Eurasian Skylark, Red-billed Leiothrix, Japanese White-eye, House Finch, House Sparrow, and Yellow-fronted Canary) have been recorded as occurring at Hale Pōhaku during limited survey work conducted there. However, it seems likely that the most of the non-native species listed above can be found at or near Hale Pōhaku, at least seasonally. See Section 2.2.3.1.3 for information on invasive bird species at Hale Pōhaku.

Birds found in the subalpine community at Hale Pōhaku are listed in Table 2.2-7. Species that are likely to occur, but have not been observed (as recorded in literature or observed by experts), are indicated with a "??" under the Hale Pōhaku column.

2.2.3.1.1 Threatened and Endangered Species

Federally listed Endangered species that occur in māmane woodlands on Mauna Kea include the Palila (*Loxioides bailleui*), ʻAkiapolaʻau (*Hemignathus munroi*), ʻIo (*Buteo solitarius*) and Nēnē (*Branta sandvicensis*). The latter three species have not been recorded at Hale Pōhaku. There are no federally listed Threatened species known to be found at Hale Pōhaku.

ʻAkiapolaʻau (*Hemignathus munroi*) are honeycreepers with a strongly decurved upper bill and a stout, woodpecker-like lower bill that can be used to drill holes in trees and loosen bark (Scott et al. 1986). The ʻAkiapolaʻau then uses its upper bill as a tool to pick out insects (primarily moth larvae and beetles) from under the bark (Pejchar and Jeffrey 2004). ʻAkiapolaʻau are primarily insectivorous, but also supplement their diet with sap from ʻōhiʻa trees (Pejchar and Jeffrey 2004). Prior to disturbance by man and deforestation by introduced grazing mammals, mesic and dry forest cover was nearly continuous from eastern Mauna Kea to Hāmākua. During this time, ʻAkiapolaʻau were most likely common and widespread (Scott et al. 1986). In the 1970s, ʻAkiapolaʻau were still found in low numbers in māmane and māmane-naio woodlands on Mauna Kea from 6,200 to 9,500 ft (1,900 to 2,900 m) elevation (Scott et al. 1986). Currently ʻAkiapolaʻau very rare in (and perhaps even extirpated from) the subalpine communities on Mauna Kea (VanderWerf 2008), and are primarily found in koa-ʻōhiʻa forests (Pejchar 2005).

Palila (*Loxioides bailleui*) are seed-eating finches with stout beaks and a yellow head and breast (Hawaii Audubon Society 1997). The Palila is one of three remaining seed-eating honeycreepers in the Hawaiian archipelago, and the only one left on the main islands—the other two species are limited to the Northwestern Hawaiian Islands of Nihoa and Laysan (Banko 2006). They are also the only remaining species of Hawaiian bird that relies solely on dry forest for habitat (Pratt et al. 1997). Palila feed on the green seedpods of māmane trees, eating the seeds inside and preying on caterpillars of *Cydia* and other moth species that also feed on the seeds. Palila also eat naio fruits as well as māmane flowers, buds, and young leaves (Hawaii Audubon Society 1997; Banko 2006). Palila were once common in lowland dry forests on several of the Hawaiian Islands, but due to habitat alteration, first by humans, and subsequently by grazing mammals, the Palila's range has decreased to a small band around Mauna Kea, in the last remaining stands of māmane woodlands. Most Palila are found in the southwestern portion of the mountain (Banko 2006). Given their reliance on māmane, the main threat to current Palila populations is habitat degradation and loss, caused by grazing of māmane seedlings by non-native mammals; smothering by invasive plant species (such as grasses); increased frequency and intensity of fires (fueled by invasive grasses); and development (Banko 2006). Availability of māmane seeds is an important limiting factor, and Palila may not breed during drought years when fewer māmane seedpods are produced (Pratt et al. 1997). Predation by non-native mammals is also a threat to Palila, although predators are not as abundant in the subalpine zone on Mauna Kea as they are in lowland areas. Predation rates (of all birds) may be higher around developed areas, such as Hale Pōhaku, where human activities provide an addition source of food and water for predators. Invasive parasitoid wasps are also thought to impact the moth species upon whose caterpillars Palila feed, thus reducing an important food source for Palila adults and chicks (Brenner et al. 2002; Oboyski et al. 2004). An additional threat to the Palila is the presence of avian malaria at lower elevations. Even if māmane woodlands were restored in lowland areas, Palila would most likely remain limited to high elevation sites, due to their lack of resistance to avian diseases spread by invasive mosquitoes. Mosquitoes are rare or absent at high elevation sites on Mauna Kea (Banko 2006). Palila were recognized as endangered in 1966 and were included in the original Endangered Species Act, in 1973 (Banko 2006). Hale Pōhaku falls within the critical habitat of the Palila (Figure 2.2-23), which extends to 10,000 ft on Mauna Kea (Stemmerman 1979). Habitat restoration, translocation of Palila to suitable habitats that are currently unoccupied, and captive breeding are all part of the management activities currently directed at helping bolster Palila populations and keeping the species from going extinct (Banko 2006).

'Io (*Buteo solitarius*), or Hawaiian hawk, are territorial, monogamous raptors that feeds on birds, mammals, insects, and spiders (Scott et al. 1986; Mitchell et al. 2005b). They occur from sea level to approximately 8,500 ft (2,600 m) on the Island of Hawai'i and are known to utilize a broad range of forest habitats. 'Io avoid unforested areas and are most abundant in native forests (Klavitter et al. 2003). They have been observed in subalpine māmane-naio woodlands in the past (Scott et al. 1986), but recent survey work suggests that 'Io do not utilize māmane-naio forests much, if at all (Klavitter et al. 2003). There is no evidence that avian malaria, introduced predators, or environmental contaminants are seriously affecting the 'Io population (Griffin et al. 1998). Survey work indicates that 'Io populations are stable, and the species may be a candidate for down-listing from Endangered to Threatened, or removal from the Endangered Species list altogether (Klavitter et al. 2003).

The Nēnē (*Branta sandvicensis*) is the only remaining species of goose in the Hawaiian Islands from the seven or more species that existed prior to the arrival of Polynesians (Olson and James 1982). Nēnē historically inhabited grasslands, grassy shrublands, and dryland forest, from sea level to the subalpine and alpine zones (USFWS 2004). They likely inhabited high-elevation sites such as the māmane woodlands in the subalpine zone on Mauna Kea during the non-breeding season (USFWS 2004). Nēnē feed on leaves, buds, flowers and seeds of grasses and herbs, and the fruits of 'ōhelo (*Vaccinium reticulatum*), 'aiakenēnē (*Coprosma ernodeoides*), and other plants (Scott et al. 1986). Nēnē are ground nesting birds and their numbers have been greatly reduced by non-native mammalian predators (USFWS 2004). Nēnē populations are small and are currently sustained by a captive breeding program. They may suffer from inbreeding depression (USFWS 2004). Their present distribution reflects locations of release sites of captive-bred birds (Banko et al. 1999). On the Island of Hawai'i, Nēnē are currently found in a number of areas from sea level to 7,900 ft (2,400 m). Population centers of Nēnē in the wild include:

Hakalau Forest National Wildlife Refuge; Hawai'i Volcanoes National Park; Kahuku; Keauhou area including Kulani; Kipuka 'Ainahou area including Pu'u 'O'o Ranch and Pu'u 6677; Pohakuloa area including Saddle Road, and the Pu'uwa'awa'a area including Pua Lani and Pu'uanahulu (USFWS 2004). Nēnē were not observed at Hale Pōhaku during the 1979 and 1985 bird surveys, and no evidence suggests they are currently using the area (Stemmerman 1979; Stemmerman Kjargaard 1985).

2.2.3.1.2 Candidate Species and Species of Concern

There are no federal Candidate species of birds found at Hale Pōhaku. Federal Species of Concern found at Hale Pōhaku include the Hawai'i 'Amakihi (*Hemignathus virens*), 'Apapane (*Himatione sanguinea*) and 'I'iwi (*Vestiaria coccinea*). Other federal Species of Concern that may occur at Hale Pōhaku (but have not been recorded there) include the Hawai'i 'Elepaio (*Chasiempis sandwichensis sandwichensis*), Kolea (*Pluvialis fulva*), and Pueo (*Asio flammeus sandwichensis*).

'I'iwi (*Vestiaria coccinea*), are bright vermillion (red with a touch of orange) honeycreepers with a long, strongly curved salmon-colored bill and black wings, and have a squeaky call that sounds like "a rusty hinge" (Hawaii Audubon Society 1997). 'I'iwi wings produce a distinctive whirring noise in flight (Fancy and Ralph 1998). They feed primarily on nectar and secondarily on insects (especially butterflies and moths). They were once one of the most common forest birds in the islands, present in forests from sea level to the tree line (Fancy and Ralph 1998). 'I'iwi are thought to be monogamous during the breeding season, and will defend small breeding territories. The breeding season coincides with peak 'ōhi'a flowering, with most breeding occurring between February and June (Fancy and Ralph 1998). During the non-breeding season, they can be found foraging in flocks, or may defend a territory in areas of intermediate flower density (Fancy and Ralph 1998). 'I'iwi abundance in subalpine forests is tied to nectar availability, as measured by māmane flower abundance (Hess et al. 2001). Hess et al. (2001) found that while there is a small resident population of 'I'iwi in the subalpine māmane woodlands most 'I'iwi move between māmane woodlands and their primary habitats, mesic to wet koa and 'ōhi'a forests. 'I'iwi are mostly likely uncommon visitors to Hale Pōhaku, and are most likely to be observed there while māmane are flowering (VanderWerf 2008). 'I'iwi are highly susceptible to avian malaria (with mortality rates over 90%) and viable populations of these birds persist only in high elevation areas where mosquitoes are rare or absent. Japanese white-eyes compete with 'I'iwi for food, and studies have found a negative relationship between the abundance of 'I'iwi and Japanese white-eyes (Fancy and Ralph 1998). In addition, non-native mammalian predators (rats and cats) are though to impact 'I'iwi populations.

'Apapane (*Himatione sanguinea*) are bright crimson honeycreepers with black wings and tail. They have a long decurved bluish-black bill, and feed primarily on nectar, but also take insects and spiders (Fancy and Ralph 1997). Like the 'I'iwi, 'Apapane make a whirring noise during flight. 'Apapane breed in mesic and wet 'ōhi'a forests. They make seasonal and daily movements from wet forest to subalpine woodland and leeward dry woodlands when nectar is available there, mainly in September through November (Fancy and Ralph 1997; Hess et al. 2001). In the breeding season, 'Apapane maintain small breeding territories, are monogamous, and lay clutches of one to four eggs (three on average). Breeding activity begins October-November and peaks in February through June. During the non-breeding season, 'Apapane forage together in small flocks, or in mixed flocks with other species of honeycreeper (Fancy and Ralph 1997). 'Apapane are susceptible to avian pox and malaria, and have the highest prevalence of malaria (*Plasmodium*) parasites of any native or alien bird species in the Hawaiian Islands (van Riper et al. 1986; Fancy and Ralph 1997). However, some believe that 'Apapane may be developing an immunity to malaria (Atkinson et al. 1995). Birds that survived initial malaria infections seemed to be resistant to new infections (Yorinks and Atkinson 2000). Other factors that likely impact 'Apapane populations are habitat loss and degradation (including habitat alteration by invasive plants) and predation by non-native mammalian predators. It is unknown whether competition with non-native birds and insects is affecting ʻApapane populations (Fancy and Ralph 1997).

Hawaiʻi ʻAmakihi (*Hemignathus virens virens*) are yellowish-green honeycreepers with a thin, slightly decurved beak that feed on insects, nectar, and fruit (Hawaii Audubon Society 1997). They are the most common native birds remaining, ranging from 2,100 ft to 9,840 ft (650 m to 3,000 m) elevation, and have a strong association with dry and mesic forests, including māmane and māmane-naio woodlands (Kern and van Riper 1984; Scott et al. 1986). ʻAmakihi in subalpine woodlands nest primarily in māmane trees and choose trees that are taller than average (Kern and van Riper 1984). Because of their varied diets, ʻAmakihi populations in subalpine woodlands do not fluctuate as greatly on a seasonal (or daily) basis as do ʻApapane and ʻIʻiwi populations (Hess et al. 2001). However, ʻAmakihi are highly dependent on nectar availability, especially during the breeding season, and will not breed in areas that do not have sufficient densities of māmane flowers (van Riper 1984). ʻAmakihi retain mates for more than one season, are territorial, and breed from November through July, with the most nesting occurring in March through May (van Riper 1987). Generally two to three eggs are laid during a breeding attempt. Overall reproductive success of the ʻAmakihi is average for open-nesting passerines (around 35%), with the greatest causes of failure being nest desertion and failure of the eggs to hatch (van Riper 1987). High survival rates and relatively long life of adult birds (van Riper 1987) may aid in population stability. Hawaiʻi ʻAmakihi are susceptible to avian malaria, and low elevation populations have fairly high infection rates (Woodworth et al. 2005). Despite this, ʻAmakihi populations have recently been increasing in lowland areas on Hawaiʻi. It is currently unknown whether these populations are being supplemented by movement of ʻAmakihi from higher elevation populations, or if the ʻAmakihi is developing some level of resistance to avian malaria and is thus able to reproduce and maintain stable populations despite high infection rates (Woodworth et al. 2005).

ʻElepaio (*Chasiempis sandwichensis*) are insectivores that often catch their prey in the air (Conant 1977). They were once very abundant in forested areas of Oʻahu, Kauaʻi, and Hawaiʻi, and are still widespread, but not abundant, in many areas. They are found primarily in koa-ʻōhiʻa forests. The Hawaiʻi ʻElepaio (*Chasiempis sandwichensis sandwichensis*) is a federal Species of Concern. Some authorities recognize the Mauna Kea subalpine ʻElepaio as a separate subspecies, *Chasiempis sandwichensis bryani* (Pratt 1980). Habitat degradation has reduced their densities in māmane woodlands, and they are most abundant in this habitat type on the southwestern slope of Mauna Kea, with highest densities near Puʻu Laʻau (Scott et al. 1986). In subalpine environments, ʻElepaio nest primarily in māmane trees, preferring taller trees than average (van Riper 1995). Nest predation by feral cats and rats is less common in ʻElepaio nesting on Mauna Kea than in ʻElepaio that nest in other habitats, due to the low density of predators in this habitat type (Amarasekare 1993; van Riper 1995). ʻElepaio are territorial and monogamous, and stay in their territories year-round (van Riper 1995). Nesting occurs from February to August (van Riper 1995). C. van Riper (1995) found that the Mauna Kea ʻElepaio eggs had unusually high hatching failure (25% vs. around 7% for other passerines), which may limit their productivity. Even so, overall reproductive success was fairly high, with 80% of nests fledging at least one young (van Riper 1995), suggesting that perhaps ʻElepaio populations in subalpine māmane forest on Mauna Kea may be limited primarily by lack of adequate habitat. ʻElepaio are also negatively affected by the presence of invasive birds such as the Japanese white-eye (Mountainspring and Scott 1985).

Kolea, or Pacific Golden Plovers (*Pluvialis fulva*), are migratory shorebirds that spend the winter in Hawaiʻi and the summer in the arctic, where they breed. Generally Kolea arrive in August or September and leave by early May (Hawaii Audubon Society 1997). While they are in Hawaiʻi they maintain foraging territories, which most birds return to year after year (Johnson et al. 2001). Some non-breeding birds will stay for the summer. Kolea forage on lawns, fields, and grassy mountain slopes for invertebrates and occasionally eat leaves and flowers (Hawaii Audubon Society 1997). They are found up to approximately 10,000 ft (3,048 m) elevation, and utilize open areas in the subalpine zone on Mauna Kea (Hawaii Audubon Society 1997; Pratt 2008).

Pueo, or Hawaiian Owls (*Asio flammeus sandwichensis*), are ground-nesting owls found on all the major Hawaiian Islands, in shrublands, grasslands, and montane parklands (Scott et al. 1986). Pueo hunt at dawn and dusk (and sometimes during the day) and feed on small mammals (mostly rodents), birds (native and non-native), and insects (Snetsinger et al. 1994; Hawaii Audubon Society 1997). Breeding occurs throughout the year and three to six eggs are laid (Snetsinger et al. 1994). Because Pueo build their nests on the ground, they are extremely susceptible to predation by non-native mammals such as cats and mongoose, and habitat alteration (development, agriculture). Non-native barn owls and feral cats may also compete with Pueo for food (primarily small rodents and birds). Pueo nests have been observed at 9,022 ft (2,750 m) elevation on eastern Mauna Kea, in māmane woodlands at Kanakaleonui and above Pu'u La'au Cabin, on the western slope, at the bases of māmane trees (Snetsinger 1995).

2.2.3.1.3 Invasive Species

Black Francolin (*Francolinus francolinus*), Erckel's Francolin (*Francolinus erckelii*), Chukar (*Alectoris chukar*), Japanese Quail (*Coturnix japonica*), Ring-necked Pheasant (*Phasianus colchicus*), Wild Turkey (*Meleagris gallopavo*), and California Quail (*Callipepla californica*) are all game birds that were introduced and managed for hunting in grasslands, shrublands, and open woodlands. Most of the game birds are generalists and feed on plants, invertebrates (especially insects), fruits, and seeds. The impacts of these non-native birds are both positive and negative. On the positive side, Cole et al. (1995) found that Chukar and Ring-necked Pheasants on Haleakalā, Maui were at least partially filling the ecological role of extinct and rare native birds (such as the Nēnē) as the primary dispersers of seeds of native plants such as pūkiawe (*Leptecophylla tameiameiae*), 'ōhelo (*Vaccinium reticulatum*), nohoanu (*Geranium cuneatum*), 'aiakenēnē (*Coprosma ernodeoides*), pilo (*Coprosma montana*), and a native sedge, *Carex wahuensis*. All these species are found at Hale Pōhaku or in the subalpine zone on Mauna Kea. Pūkiawe seeds are notoriously difficult to germinate without treatment, yet those found in game bird droppings had high germination rates. This suggests that these birds may play an important role in maintaining pūkiawe populations in upland areas (Cole et al. 1995b). Although māmane seeds were eaten by the introduced game birds in the Haleakalā study, there were no māmane seedlings germinated from game bird droppings, suggesting that the birds do not aid in the regeneration of māmane through seed dispersal, and in fact, may reduce māmane regeneration if enough seeds are consumed. In addition, invasive plant parts in Chukar and Ring-necked Pheasant diets consisted mainly of flowers and leaves rather than fruits and seeds. Arthropods (primarily non-native species such as ladybugs) made up a relatively small portion of the game bird diets. On the negative side, these birds did disperse some seeds of invasive species, including common velvetgrass (*Holcus lanatus*), hairy cats-ear (*Hypochoeris radicata*), mouse ear chickweed (*Cerastium vulgatum*), common catchfly (*Silene gallica*), and common evening primrose (*Oenothera biennis*). All these plant species, or closely related ones, are found at Hale Pōhaku. However, native seed germinations from Chukar and Ring-necked pheasant droppings outnumbered invasive species five to one in the Haleakalā study (Cole et al. 1995a). Introduced game birds may well be spreading both native and invasive species at Hale Pōhaku, and the extent of their impacts there is unknown. Studies conducted in other locations have found that non-native birds are often the vectors of invasive plant seeds (Vitousek and Walker 1989; Garrison 2003; Chimera 2004). For example, another game bird, the Kalij Pheasant (*Lophura leucomelana*), which is not present at Hale Pōhaku, is a major disperser of banana poka (*Passiflora molissima*), an invasive weed in wetter forests on Hawai'i (Lewin and Lewin 1984). See Section 2.2.1.3.4 for more information of the spread of invasive plants by non-native animals.

Non-native birds compete with native birds for food, shelter, and nesting locations. This is especially true for native honeycreepers and non-native passerines[20] that consume nectar. Each of the non-native passerine species found in the subalpine zone on Mauna Kea are described below.

Japanese White-eyes (*Zosterops japonicus*) were introduced to Hawai'i in 1929, and are now the most abundant land birds in the Hawaiian Islands. They occur in almost every habitat type, up to 10,170 ft (3,100 m) on Hawai'i (Scott et al. 1986). They are most abundant at forest edges and open forests, and prefer habitats with invasive species in the understory (Scott et al. 1986). They consume nectar, fruit, and invertebrates and may compete directly with most of the native honeycreepers found in māmane woodlands. 'Elepaio, 'Amakihi and 'I'iwi abundances are negatively related to abundance of Japanese White-eyes in Hawai'i (Mountainspring and Scott 1985). Japanese White-eyes are present at Hale Pōhaku, although their current status is unknown.

Red-billed Leiothrix or Pekin Nightingale (*Leiothrix lutea*) feed primarily on fruits, but also eat arthropods and seeds. They are found in low densities throughout Mauna Kea, reaching high densities only in denser woodlands with naio or water sources, up to 9,500 ft (2,900 m) (Scott et al. 1986). Their spread above 9,500 ft is probably limited mainly by the availability of water. They are generally not found in high densities in māmane forest without naio, and in general, tend to be more common in areas with a higher abundance of fruit. Red-billed Leiothrix were observed at Hale Pōhaku in 1979 but not in 1985 (Stemmerman 1979; Stemmerman Kjargaard 1985). Their current status at Hale Pōhaku is unknown. However, an OMKM Ranger, Pablo McCloud, found a dead Red-billed Leiothrix in the summit area of MKSR in November 2006, indicating that they are still found at lower elevations in the region (Nagata 2007).

House Finches (*Carpodacus mexicanus*) are omnivorous, but feed extensively on seeds, buds, fruits (Scott et al. 1986). They are common in developed and agricultural areas, high elevation ranchlands, disturbed wet forest, and māmane-naio forest. They are found in low densities at Hale Pōhaku and reach greatest numbers in naio woodlands and areas with available water. The highest House Finch densities on Mauna Kea are associated with water seeps (Scott et al. 1986). They chiefly inhabit forest edges, pastures, open woodland and scrub. House Finch nest in māmane and naio trees in subalpine woodlands, and will also nest in introduced tree species (van Riper 1976). They may actively disperse invasive plant seeds, but also eat fruits of pūkiawe (*Leptecophylla tameiameiae*), 'aiakenēnē (*Coprosma ernodeoides*), pilo (*Coprosma montana*), 'ōhelo (*Vaccinium reticulatum*), and naio (*Myoporum sandwicense*) (Scott et al. 1986). House finches are found at Hale Pōhaku, primarily in the developed areas (Stemmerman 1979; Stemmerman Kjargaard 1985).

House Sparrows (*Passer domesticus*) are omnivorous, and will eat almost anything edible (Scott et al. 1986). They are common on all islands especially in urban and agricultural areas. House sparrows are almost always found in association with human disturbance (houses, buildings, ranches paddocks, feedlots, campgrounds), and at Hale Pōhaku they are associated with buildings such as the Visitors Information Station (Stemmerman 1979; Stemmerman Kjargaard 1985).

Northern Cardinals (*Cardinalis cardinalis*) eat seeds, fruits, and arthropods. They are widely dispersed (primarily in introduced and disturbed native forests) but are not as abundant as Japanese White-eyes. They are limited to the western and southwestern portions of Mauna Kea, and do not occur in māmane forests that have bare or open understories. They seem to prefer forests with introduced shrub and

[20] Passerines are birds in the order Passeriformes, usually called perching birds or songbirds. This order contains more than one-half of all bird species.

Passiflora understories that form dense tangled thickets (Scott et al. 1986). They feed on koa, naio, sandalwood, and māmane seeds, and almost any kind of fruit and weed seeds. They have not been recorded at Hale Pōhaku and it seems unlikely they would utilize this area due to the open nature of the forest.

Eurasian Skylarks (*Alauda arvensis*) are insectivores that inhabit dry scrub, savanna, and woodlands, primarily degraded, fragmented and deforested habitats (Scott et al. 1986; Hawaii Audubon Society 1997). Skylarks primarily forage in grass and on the ground. They were observed at Hale Pōhaku during the last bird survey there, in 1985 (Stemmerman Kjargaard 1985). Their current status at Hale Pōhaku is unknown.

Melodious Laughing-thrush, or Hwamei (*Garrulax canorus*), eat arthropods and fruits (Mountainspring and Scott 1985). On Mauna Kea they are restricted primarily to woodlands with naio (whose fruit they eat), from sea level to 9,500 ft (2,900 m), and are more common at low elevations. They seem to prefer brushy understories with structural and floristic diversity (Scott et al. 1986). They were not recorded as occurring at Hale Pōhaku during the 1979 and 1985 surveys (Stemmerman 1979; Stemmerman Kjargaard 1985).

Northern Mockingbirds (*Mimus polyglottos*) are primarily insectivores, but also feed on fruits and seeds (Scott et al. 1986; Chimera 2004). They are well established in dry areas on Hawai'i, and occupy a wide range of elevations and vegetation types, including in naio forest and māmane woodlands. The Mauna Kea population was established after 1978 (Scott et al. 1986). They were not recorded as occurring at Hale Pōhaku during the 1979 and 1985 surveys (Stemmerman 1979; Stemmerman Kjargaard 1985), and their current status at Hale Pōhaku is unknown.

Common Mynas (*Acridotheres tristis*) eat insects (Hawaii Audubon Society 1997), and are found in association with forest edges, pastures, and disturbed areas, up to 7,550 ft (2,300 m). They are cavity nesters (Scott et al. 1986). They were not recorded at Hale Pōhaku during the 1979 and 1985 surveys (Stemmerman 1979; Stemmerman Kjargaard 1985), and it seems unlikely that they will become established at Hale Pōhaku unless they expand their elevational range.

Warbling silverbill (*Lonchura malabarica*) feed almost exclusively on seeds. They were first discovered in Hawai'i in 1972, are common in coastal mesquite woodlands, and range up to 10,170 ft (3,100 m) on Mauna Kea (Scott et al. 1986). In their native Africa they are found in dry savannas, thorn-scrub, grasslands, and desert areas near water. Their habitat in Hawai'i is similar (Scott et al. 1986). They were not recorded as occurring at Hale Pōhaku during the 1979 and 1985 surveys (Stemmerman 1979; Stemmerman Kjargaard 1985), but it seems likely they could inhabit the area.

Nutmeg Mannikin (*Lonchura punctulata*), also known as Ricebirds or Spotted Munia, are very small seed eating estrildid finches, and can often be seen perched on a sturdy stalk of grass. They are highly nomadic, and occupy very open or disturbed sites and forest edges. Nutmeg Mannikins are mainly associated with introduced trees in low elevation areas, but can occur up to 9,500 ft (2,900 m) on Mauna Kea (Scott et al. 1986). They often travel in large flocks. They were not recorded at Hale Pōhaku during the 1979 and 1985 surveys (Stemmerman 1979; Stemmerman Kjargaard 1985), and their current status there is unknown. However it is likely that Nutmeg Mannikins are found at Hale Pōhaku.

Yellow-fronted Canary (*Serinus mozambicus*) forage in the grass and on the ground for seeds and insects (Hawaii Audubon Society 1997). They were first reported in 1964 on O'ahu and 1977 on Hawai'i, on the upper slopes of Mauna Kea (van Riper 1978; Scott et al. 1986). Yellow-fronted Canaries are common in low elevation forests, but can go as high as 9,200 ft (2,800 m) in māmane woodlands. They prefer open, dry parkland habitat and open woodlands (Hawaii Audubon Society 1997). Their native habitat in Africa is lightly wooded country, savanna, brush and cultivated areas (Scott et al. 1986). Yellow-fronted canaries were observed at Hale Pōhaku in 1977, but were not recorded in the 1979 and 1985 bird surveys (van Riper 1978; Stemmerman 1979; Stemmerman Kjargaard 1985). Their current status at Hale Pōhaku is unknown.

In addition to competing with native birds for food, invasive birds can also act as a source and reservoir of avian diseases, such as avian malaria and pox, and act as a food source for invasive mammalian predators, which also prey on native species. Section 2.2.3.3.2 has more information on avian diseases and non-native predators.

2.2.3.1.4 Bird Surveys at Hale Pōhaku

In 1975, van Riper et al. conducted a comprehensive census of Palila habitat (māmane and naio forests in the subalpine zone on Mauna Kea) to determine the distribution of Palila on the mountain (van Riper et al. 1978). This survey area included Hale Pōhaku. Although no specific numbers are mentioned for Hale Pōhaku, Palila did occur in the region and were found primarily near the tree line, in large trees (van Riper et al. 1978).

In 1979, prior to construction of the mid-elevation facilities, Maile Stemmerman conducted bird surveys in three areas: Hale Pōhaku, Hawaiian Homes Commission Lands, and Humu'ula Sheep Station (Stemmerman 1979). Of the three areas, Stemmerman found that the undeveloped areas of Hale Pōhaku presented some of the best bird habitat, primarily because of the relatively intact nature of the māmane woodlands. Both Hawaiian Homes Commission Lands and the Humu'ula Sheep Station were considered marginal bird habitat. Eight species of birds were observed during the Hale Pōhaku survey: two native species ('Apapane and 'Amakihi) and six non-native species (House Finch, House Sparrow, Japanese White-eye, Red-billed Leiothrix, Erckel's Francolin, and California Quail). The House Finch and House Sparrow were primarily associated with the developed areas. Stemmerman speculated that Hale Pōhaku habitat may be suitable for Pueo (*Asio flammeus sandwichensis*), 'Io (*Buteo solitarius*) and Hawaiian Petrel (*Pterodroma sandwichensis*), but did not observe these species. However, Stemmerman noted that known nesting sites for the Hawaiian Petrel were considerably higher on Mauna Kea, and it seemed unlikely this species would use the area for nesting. Stemmerman also noted that while Nēnē (*Branta sandvicensis*) are known to roost on Mauna Kea, none had been observed at Hale Pōhaku. Although Stemmerman did not observe 'I'iwi (*Vestiaria coccinea*) and Palila (*Loxioides bailleui*) at Hale Pōhaku, she states they most likely use the area when the māmane trees are flowering ('I'iwi) or have green seed pods (Palila), and that Palila had been observed at Hale Pōhaku regularly over the previous five years. Finally, Stemmerman commented that although Chukar (*Alectoris chukar*) were not observed during the survey, they are most likely at Hale Pōhaku.

In May 1985, Maile Stemmerman Kjargaard conducted an additional bird survey at Hale Pōhaku (Stemmerman Kjargaard 1985). Species observed during this survey included 'Apapane, 'Amakihi, House Finch, House Sparrow, California Quail, Japanese White-eye, and Skylark.

In addition to the above bird surveys, several observations of species at Hale Pōhaku have been recorded in the literature, or in field records by experienced birders. In 1977, Mae Mull and associates observed three Palila foraging on māmane seed pods in māmane trees "close to the restrooms and the United Kingdom Dormitories" (Mull 1977). Although this was not part of a formal bird survey of Hale Pōhaku, Mull was able to observe the birds up close for more than half an hour. In 1978 C. van Riper III observed

Yellow-fronted Canary (*Serinus mozambicus*) at Hale Pōhaku, as well at as other locations in māmane forests on Mauna Kea (van Riper 1978). Eric VanderWerf observed ʻIʻiwi at Hale Pōhaku in 2006, and describes them as seasonal/uncommon visitors to the area (VanderWerf 2008).

2.2.3.2 Alpine Bird Communities (MKSR and Upper Summit Access Road)

The harsh conditions in the alpine zone on Mauna Kea make it difficult for most vertebrate species to make a living there. No birds are known to currently inhabit or regularly use the summit area or the alpine shrubland and grasslands. An occasional bird may be observed flying through the area, and sometimes birds are blown up the mountain during strong winds and die there (Munro 1945; Montgomery and Howarth 1980). Several mummified Red-billed Leiothrix have been found at or near the summit, one as recently as November 2006 (Montgomery and Howarth 1980; Nagata 2007).

2.2.3.2.1 Threatened and Endangered Species, Candidate Species and Species of Concern

There are no federal Threatened Species, Candidate Species, or Species of Concern known to inhabit the alpine community on Mauna Kea. There is one federal Endangered species, the Hawaiian Petrel (*Pterodroma sandwichensis*)[21] or ʻUaʻu (Banks et al. 2002), which may have historically utilized lower portions of the alpine zone on Mauna Kea.

The ʻUaʻu is a pelagic seabird that historically nested in the mountains of all main Hawaiian Islands (Conant et al. 2004). ʻUaʻu nest in underground burrows and feed at sea. Prior to human contact the ʻUaʻu was widely distributed from sea level to at the least mid-elevations on all the main islands (Hu et al. 2001). On the Island of Hawaiʻi, it was once abundant on the saddle area between Mauna Loa and Mauna Kea (Conant et al. 2004). A breeding colony of ʻUaʻu is known from Hawaiʻi Volcanoes National Park from 8,000 ft (2,440 m) to 9,200 ft (2,800 m) elevation (Hu et al. 2001). In 1954, Richardson and Woodside found five freshly dug ʻUaʻu burrows at Puʻu Kole, east of Hale Pōhaku, and in the 1960s and 1970s there were observations of ʻUaʻu from Puʻu Kole around the eastern flank of Mauna Kea to Puʻu Kanakaleonui (Kjargaard 1988). Currently they are thought to be located on Mauna Loa along the summit trail, and on Mauna Kea above 9,850 ft (3,200 m) near Puʻu Kanakaleonui (NASA 2005). Kjargaard (1988) notes that skeletal remains of ʻUaʻu were found on the Mauna Kea at elevations up to 12,400 ft (3,780 m), possibly indicating presence of the birds in the alpine zone. However, Conant *et al.* (2004) point out that Hawaiian petrels were used as food by the ancient Hawaiians, and the presence of the bones at these high elevations could represent either petrel activity or the remains of an ancient Hawaiian meal. No ʻUaʻu were observed during bird surveys conducted (in a rather limited area) on the summit of Mauna Kea in 1988 (Kjargaard 1988).

Modern day threats to the ʻUaʻu include predation by non-native mammals, especially feral cats, trampling of colonies by feral ungulates such as sheep, and possibly avian malaria and pox (Hu et al. 2001; Day et al. 2003).

[21] Although it is listed as the Dark-rumped Petrel (*Pterodroma phaeopygia sandwichensis*) under the Endangered Species Act, this species has recently undergone a name change and is referred to as the Hawaiian Petrel (*Pterodroma sandwichensis*) in recent literature.

2.2.3.2.2 Invasive Species

Other than the mummified remains of several Red-billed leiothrix found near Lake Waiau and at the summit, no invasive bird species have been found at or near the summit (Montgomery and Howarth 1980; Nagata 2007).

2.2.3.2.3 Bird Surveys at MKSR

Very few bird surveys have been conducted in the MKSR. In 1988, Maile Kjargaard conducted a vertebrate (bird and mammal) survey at two proposed sites for the VLBA antenna, located between 11,800 ft and 12,400 ft (3,600 and 3,780 m) elevation (Kjargaard 1988). Both diurnal and nocturnal observations were made. The primary goal of the survey was to look for signs of Hawaiian Petrels. No birds or evidence of petrel burrows were observed.

There are no other records of bird surveys for the MKSR. No formal bird surveys have been conducted in the Ice Age NAR, however opportunistic sightings of birds are recorded in their GIS database (Hadway 2008).

2.2.3.3 Threats to Bird Communities on Mauna Kea

Because native birds are mainly found below the treeline on Mauna Kea, the following discussion of threats to bird communities on Mauna Kea will focus primarily on the subalpine zone, and in particular, on māmane woodlands.

2.2.3.3.1 Habitat Alteration

Habitat alteration is one of the primary causes of extinction of native birds in Hawai'i, and remains one of the biggest threats to the survival of the remaining native species. In the subalpine forests of Mauna Kea, habitat alteration is primarily responsible for the current endangered status of the Palila (*Loxioides bailleui*), and the reduced population sizes of several other Hawaiian honeycreepers found there. Habitat alteration has occurred through the activities of man (e.g. clearing of land for ranching, and limited development); grazing by introduced ungulates on māmane seedlings, saplings, and mature trees (thus preventing forest regeneration); and invasion by non-native weeds and grasses (which compete with native plants for resources, smother native seedlings, and increase the risk of fire). Although time-consuming and expensive, it is feasible to reduce the threat of habitat loss to native birds in the subalpine forests on Mauna Kea through combined efforts of fencing, ungulate extirpation, and controlling invasive grasses. Spreading seeds or planting seedlings of native species would help speed the process of recovery.

2.2.3.3.2 Invasive Species

Invasive species can affect native bird populations through habitat alteration, competition, predation, and disease transmission. Native birds are threatened by a variety of invasive species, including plants, microbes, invertebrates, and vertebrates. While each of these groups damaged native bird populations outright, it is likely the combination of these threats, working together, that is driving current native bird populations toward extinction. Land managers face the challenge of addressing these multiple threats in an integrated manner, rather than piecemeal, to successfully protect native species. The piecemeal approach can lead to serious negative outcomes. For example, the removal of feral ungulates on Sarigan Island (Commonwealth of the Northern Mariana Islands), while allowing for native forest recovery, also instigated the rapid expansion of an invasive vine that had previously not been a problem. This vine now covers much of the native forest (Kessler 2002). This is not an isolated example. As Zavaleta (2002) points out, "the most common secondary outcome of a single-species eradication is the ecological release of a second (plant or prey) exotic species previously controlled by the removed species (herbivore or predator) through top-down regulation." On Mauna Kea, removal of feral pigs (*Sus scrofa*) and sheep (*Ovis aries*) from exclosures allowed for some native plant regeneration but also increased competition between invasive and native plants (Scowcroft and Conrad 1992). Eradications of feral cats (*Felis catus*) on small islands in New Zealand have led to increased populations of introduced rats, and removal of the rats possibly lead to an irruption of crazy ants (*Anoplolepis gracilipes*) on Bird Island in the Seychelles (Zavaleta 2002). While these interactions between invasive species make management more difficult, being aware of them, planning accordingly, and using adaptive management techniques can help overcome these obstacles.

Invertebrates and Disease Organisms

Invasive invertebrates that can affect native bird populations include parasitic worms (Phyla Platyhelminthes, Acanthocephala, and Nematoda); parasitic and blood feeding species such as mosquitoes, mites, fleas, and flies; and nectarivorous and insectivorous species that compete with birds for food, such as honeybees, yellowjackets and ants (Loope et al. 2001). Parasitic and blood feeding species (such as mosquitoes) not only affect the host through the taking of blood or flesh, but also by spreading diseases (Loope et al. 2001).

Currently there are two avian diseases that are impacting native bird populations: avian poxvirus (*Poxvirus avium*) and avian malaria (*Plasmodium relictum*) (Freed 2005). Avian pox is a virus that causes skin lesions, and in more serious cases necrotic lesions in mucous membranes of the mouth and upper respiratory tract. In most cases avian pox does not kill the bird, although mortality rates are higher in birds that develop lesions in the oral or respiratory cavities (van Riper et al. 2002). Pox can be transmitted via biting insects (mosquitoes, midges, flies) or directly through contact with infected birds (or contact with a perch or other material touched by an infected bird). Native birds are more susceptible to avian pox than introduced birds, and avian pox is more common in mesic than dry forests (van Riper et al. 2002). High-elevation dry forests such as māmane woodlands may provide native birds a refuge from the avian pox virus.

Avian malaria is a disease caused by protozoan in the genus *Plasmodium*. Malaria cannot be transmitted directly between birds and requires a vector (mosquitoes) to move between hosts. The parasite uses the mosquito to reproduce and its offspring then infect a new bird host when it is bitten by the mosquito. Avian malaria was not present in Hawai'i until mosquitoes were introduced in 1827 (Freed 2005). Native forest birds are extremely susceptible to infection with *P. relictum*, and in lab experiments, 65–90% of birds die after being bitten by a single infective mosquito (Woodworth et al. 2005). According to Woodworth et al., the effects of avian malaria include "severe anemia, the destruction of mature erythrocytes, declines in food consumption, and activity levels, and loss of up to 30% of body weight. Individuals that survive acute infection develop concomitant immunity to homologous strains of the parasite, but remain infective to mosquitoes, probably for life" (Woodworth et al. 2005). In Hawai'i, malaria is spread mainly by the southern house mosquito (*Culex quinquefasciatus*), which is limited in elevation because of cold intolerance. However, recent evidence indicates that the mosquitoes are moving up the mountain, perhaps in response to a warming climate (Freed 2005). Native birds are more susceptible to avian malaria than are introduced birds, and the prevalence of avian malaria is higher in mesic and wet forests than dry forest (van Riper et al. 1986).

The vectors for avian malaria and pox are not found in the subalpine zone on Mauna Kea (Pratt et al. 1997), and avian malaria (*P. relictum*) has a threshold temperature of around 59° F (15°C), below which it is not transmitted to birds (Benning et al. 2002). However, birds such as ʻIʻiwi and ʻApapane that frequently travel between lower elevation forests and the subalpine zone can be infected while in the lower elevation habitats. Protection and restoration of high elevation forests, including māmane woodlands, may allow individuals of these species to persist without being exposed to malaria, and in the face of global warming may provide the only disease free habitat for forest birds (Benning et al. 2002).

Invasive invertebrates with the potential to impact native bird populations include honeybees, yellowjackets, parasitoid wasps and ants. The latter three could impact bird populations by reducing native arthropod populations upon which the birds feed. See Section 2.2.2.1.2. Honeybees, and some ant species, may compete with native birds for nectar (Hansen et al. 2002; Traveset and Richardson 2006). Honeybees are present up to the treeline, but pollinator interactions have not been studied in māmane forests (Oboyski 2008).

Invasive Plants

Invasive plants such as grasses and vines can impact native bird populations on Mauna Kea through displacement of native subalpine forest and shrublands (Banko et al. 2002). Invasive grasses and weeds can prevent forest recovery by smothering the seedlings of māmane and other native plants. Invasive grasses can also change the fire regime. See Section 2.2.1.3.2 for more information on the relationship between invasive grasses and fire regimes. A large wildfire in the māmane forest would seriously reduce available habitat for the endangered Palila (Banko et al. 2002).

Invasive Predators

Invasive predators such as cats, rats, barn owls, and mongoose have a direct impact on native bird populations. Cats and mongoose eat both adult birds and chicks, while rats primarily consume eggs (and sometimes chicks). Although rats, cats, and mongoose are not abundant in māmane woodlands, they still impact Palila populations (Banko et al. 2002). Although rats (*Rattus rattus*) are rare in māmane woodlands, they do depredate Palila nests, and Banko *et al* (2002) state that their impact is out of proportion to their numbers. Feral cats (*Felis catus*) are thought to be the most serious predator of Palila, particularly at their nests (Banko et al. 2002). Mongoose (*Herpestes auropunctatus*) are thought to have less of an impact on Palila, because they do not climb trees (Banko et al. 2002). However, mongooses, along with feral cats, have had a serious impact on ground nesting birds such as the Pueo and Nēnē. Barn Owls (*Tyto alba*) prey primarily on rodents, but do consume a small number of native birds and insects (Snetsinger et al. 1994). Their status in the māmane woodlands near Hale Pōhaku is unknown. Although mice (*Mus musculus*) are present in māmane woodlands, they do not appear to depredate Palila nests. They do, however, eat seeds and seedlings of native plants and can therefore indirectly impact native bird populations by changing plant communities. Because of their toxic seed coat, māmane seeds do not seem to be a preferred food of mice (Banko et al. 2002).

Predators such as feral cats and rats may be more abundant in developed areas such as around Hale Pōhaku because of increased availability of food and water (in refuse, landscaping, etc). A large number of visitors come through the Visitor Information Station and many of them eat lunch there. Any food left out or improperly disposed of (left in the open) will no doubt be consumed by rats, cats, and non-native birds.

Invasive Birds

Non-native birds can compete directly with native birds for resources such as food. Japanese White-eyes are likely to compete directly with insectivorous and nectarivorous honeycreepers for limited resources in māmane woodlands. Non-native birds also can act as a food base for predators, which will take native birds as prey in addition to the non-natives.

2.2.3.3.3 Human Use

There are several human uses at Mauna Kea that impact native bird species. Introduction and maintenance of populations of non-native mammals for hunting and ranching activities impact native bird species that utilize māmane forest (such as the Palila) through habitat degradation by grazing feral and domestic ungulates. Sheep, cattle, and goats damage māmane trees and prevent regeneration of the forest, while at the same time enhancing the spread and establishment of non-native plant species. Hunting and ranching do not occur at Hale Pōhaku, proper, but both occur close by. Because Hale Pōhaku is not fenced, feral ungulates may still use the site. Access to hunting and hiking areas via trails and roads passing through Hale Pōhaku by both vehicles and hikers can also lead to introduction of invasive species and erosion. Other human uses, such as tourism and scientific research also have impacts, such as introduction of invasive plants and animals, providing food sources to invasive arthropods, mammals and birds, and (limited) trampling of forest habitat. Improperly disposed food items and water used in landscaping and cleaning activities may help sustain larger populations of invasive species than would otherwise occur in the subalpine environment.

Because birds do not occupy the summit regions, human uses in the astronomy district will not directly impact bird populations. However, astronomy support facilities at mid-elevation areas do impact bird habitat through habitat loss, limited contamination (small spills associated with such activities as vehicle maintenance), unintentional provision of food and water for invasive species, and general wear and tear. At Hale Pōhaku these impacts are present, but they are generally limited in scope due to the small size of the developed area.

Human uses of all kinds also increase the risk of accidental fires. Sparks from catalytic converters, improperly discarded cigarettes and matches, camping fires, military exercises, and other activities can all cause wildfires. Fires are further discussed in Section 2.2.1.3.2.

2.2.3.3.4 Climate Change

Climate change could impact bird populations in several ways. If climate change affects plant communities then it could change availability of food and habitat to the native birds that utilize the māmane woodlands. Depending on the change, this could have both negative and positive effects on the bird community. A change in the plant community (especially an increase in density of fruiting plants) in response to increased rainfall, as predicted by some climate models (Hamilton 2007), could lead to an increase in abundance of non-native vertebrates and invertebrates, which may negatively effect native bird populations. On the other hand, an increased availability of insects, nectar, and fruit (seed pods) due to increased rainfall may also have a positive benefit for species such as the ʻIʻiwi, ʻAmakihi, ʻApapane, and Palila. However, if climate change leads to increased drought conditions in the subalpine environment of Mauna Kea, as predicted by other climate researchers (Cao 2007; Cao et al. 2007; Giambelluca and Luke 2007; Giambelluca 2008), this will no doubt have a negative impact on most of the native bird species that utilize māmane woodlands. Palila populations have been observed to decline during periods of dry weather (such as El Niño events), when food resources were limited (Gray et al. 1999). See Section 2.2.1.3.6 for more information on potential effects of climate change on plant communities.

Warming temperatures may also allow invasive species, including disease vectors, to move to higher elevations on the mountain. This would have a devastating effect on native birds, many of which are currently surviving only in areas free of malaria and its vector, the mosquito.

2.2.3.4 Bird Community Information Gaps

There have been relatively few bird surveys conducted in Hale Pōhaku and the MKSR. The following information gaps regarding the condition of the subalpine and alpine bird communities at Hale Pōhaku and the MKSR have been identified through review of the literature and consultation with local experts:

1. Quantitative bird surveys
   a) Hale Pōhaku: No quantitative studies documenting bird community composition, population sizes, or distribution of native and non-native species have been conducted at Hale Pōhaku. Two brief qualitative studies were conducted in 1979 and 1985. These provide a good baseline for species lists, but do not provide information on abundance and distribution of birds.
   d) Summit Access Road and Mauna Kea Science Reserve: No bird surveys have been conducted recently along the Summit Access Road or in the MKSR. Limited survey work was conducted in 1988, at the VLBA proposed sites. The need for bird surveys in this area is not as great as in the subalpine area. Researchers could take note of any suspected Hawaiian petrel burrows while conducting other survey work (such as archaeological, invertebrate, or vegetation studies) in this area. If any suspected burrows are observed, then a more thorough bird survey could be conducted.

2. Status of invasive species
No information is available regarding density, distribution, and effects of established invasive bird species on the properties. There is a need for a comprehensive survey of invasive bird species at Hale Pōhaku and identification of their impacts on the native plant and animal communities (positive and negative).

3. Protected species and Species of Concern
Several protected species and Species of Concern are known to inhabit the subalpine region of Mauna Kea. A great deal of research has been conducted on the Palila, and to a lesser extent, on the other honeycreepers that inhabit māmane forests, in other areas of Mauna Kea. However, surveys at Hale Pōhaku have been limited in scope and scale. This may be due in part to the degraded nature of the māmane forests at Hale Pōhaku. At minimum, a current baseline study of native bird populations in the area is warranted.

2.2.4 Mammals

Hawai'i has very few native species of mammals. Most of the native mammals found in the Hawaiian Islands are marine mammals. The only native land mammal in Hawai'i is the 'Ope'ape'a, or Hawaiian hoary bat (*Lasiurus cinereus semotus*). Conversely, Hawai'i has many non-native species of animals that were brought to the islands by humans, beginning with the arrival of the first Polynesians. Some of these were accidental introductions, but most were purposeful, either for food, pets, or biological control.

2.2.4.1 Subalpine Mammal Communities (Hale Pōhaku and Lower Summit Access Road)

Mammals found in the subalpine zone on Mauna Kea include the Hawaiian hoary bat (*Lasiurus cinereus semotus*), feral cats (*Felis catus*), black rats (*Rattus rattus*), mice (*Mus musculus* and *Mus domesticus*), domesticated sheep (*Ovis aries*), mouflon sheep (*Ovis musimon*), feral sheep/mouflon sheep hybrids, goats (*Capra hircus*), cattle (*Bos taurus*), feral pigs (*Sus scrofa*), and mongoose (*Herpestes auropunctatus*). The bat is discussed in Section 2.2.4.1.1, and the remainder are discussed in Section 2.2.4.1.2. Table 2.2-8 lists mammal species known to occur in subalpine and alpine habitats on Mauna

Kea, including Hale Pōhaku and the MKSR. Figure 2.2-24 presents photos of mammal species found in high elevation areas on Mauna Kea.

2.2.4.1.1 Threatened and Endangered Species, Candidate Species and Species of Concern

The federally listed Endangered ʻOpeʻapeʻa (*Lasiurus cinereus semotus*) was once found on all the main Hawaiian Islands, but now is thought to be limited to Hawaiʻi, Kauaʻi, and Maui. It was listed as a federally Endangered Species in 1970. ʻOpeʻapeʻa have been observed up to 13,500 ft (4,115 m) on Mauna Loa, and use a variety of both native and non-native vegetation types (Frasher et al. 2007). While the Hawaiian hoary bat typically roosts alone in foliage (as opposed to roosting in large colonies as many bats do), it has also been observed in lava tubes, man made structures, and rock crevices (Frasher et al. 2007). ʻOpeʻapeʻa are known to migrate, and their densities in high elevation areas are thought to be highest during the winter months (December through March) (Menard 2001; Bonaccorso 2008; Menard 2008). ʻOpeʻapeʻa have been observed in the māmane woodlands on Mauna Kea (NASA 2005), but the status of the bat at Hale Pōhaku and environs is unknown.

2.2.4.1.2 Invasive Species

Non-native mammals found at Hale Pōhaku include feral cats (*Felis catus*), black rats (*Rattus rattus*), mice (*Mus musculus* and *Mus domesticus*), mongoose (*Herpestes auropunctatus*), domesticated sheep (*Ovis aries*), mouflon sheep (*Ovis musimon*), goats (*Capra hircus*), cattle (*Bos taurus*), and feral pigs (*Sus scrofa*). Each of these has had a role in the degradation of māmane woodlands and/or their associated animal communities on Mauna Kea.

Invasive mammals have had a serious impact on native Hawaiian species, as predators, competitors, and agents of change in the structure and composition of plant communities. Invasive mammalian predators include cats, dogs, rats, mongoose, feral pigs, and mice. Cats, rats, and mongooses all prey on bird species found in the māmane woodlands. See Section 2.2.3.3.2 for more information on predation of native birds. Rats and mice eat insects, and may especially impact flightless species (of which there are several in the subalpine and alpine zones on Mauna Kea). Several species of flightless insects no longer occur on the main Hawaiian Islands where rats are common (Gagne and Christensen 1985). We may never know what impact mammalian predators have had in native invertebrates in the subalpine zone, as arthropod communities in these areas were not well documented historically.

Feral pigs, goats, sheep, mouflon, cattle, and even horses have impacted plant communities throughout the islands, and the māmane woodlands are one of the hardest hit areas. The damaging effects of grazing animals on native forests have been known for some time. In 1909, Augustus Knudson of Kauaʻi wrote in the *Hawaiian Forester and Agriculturalist* that "Cattle and goats are really the only enemy that Hawaiian forests have. Kill them off and prevent their return, and in ten years you cannot recognize the region again; in twenty years the forest is practically restored, though young." (Berger 1975).

Non-native ungulates have been present on Mauna Kea for some time. Scowcroft and Conrad (1992) summarized the history of introduction of grazing animals to Mauna Kea as follows (Scowcroft and Conrad 1992):

> Domestic livestock were introduced to the Hawaiian Islands late in the 18th century (Kramer 1971). Feral populations of cattle, sheep, and goats (*Bos taurus, Ovis aries, Capra hircus*) soon became established in forests. By 1825, feral sheep had established in Mauna Kea's subalpine woodland. Lacking natural predators except for wild dogs (*Canis domesticus*), the sheep population reached about

40,000 animals by the early 1930s, one for every 5 a (2 ha) of habitat (Bryan 1937b). Sheep suppressed māmane and other tree reproduction over large areas, stripped bark from tree stems, and consumed herbaceous vegetation, thereby leaving the soil exposed to accelerated erosion (Warner 1960). Because damage to the ecosystem was severe and because feral sheep competed with commercial flocks (Judd 1936), Hawai'i Territorial foresters built a stock-proof fence around the Mauna Kea Forest Reserve (Bryan 1937a) and reduced the population through sheep drives and hunter-guide programs. Fewer than 500 feral sheep were left by 1950 (Bryan 1950). Control efforts were then relaxed, and populations increased.

Sustained yield management for public hunting was started in 1955, with the population kept below 5,000 animals. During the 1970s, the population averaged 1,500 animals. Even at this relatively low level, vegetation continued to deteriorate where sheep concentrated, especially at tree line (Scowcroft 1983; Scowcroft and Giffin 1983; Scowcroft and Sakai 1983).

Ecosystem damage has also been caused by mouflon sheep (*Ovis musimon*), which were released in the Mauna Kea Forest Reserve starting in 1962 (Giffin 1982). Food preferences, grazing and browsing behavior, and herding habits are similar to those of feral sheep, and native plants are particularly susceptible to damage by mouflon. In 1986, the largest concentrations of mouflon were on the southeastern and northwestern flanks of the mountain, and animals were moving into areas formerly occupied by feral sheep. The mouflon population was estimated at 500 animals (R.E. Bachman, pers. comm. 1986).

Continued degradation of the māmane woodland in the late 1970s posed a significant threat to the Palila (*Loxioides bailleui*), an endangered endemic Hawaiian bird now found only in the subalpine woodland of Mauna Kea (Berger 1972; van Riper et al. 1978; Scott et al. 1984). Palila depend on māmane and, to a lesser extent, on naio trees for food and nest sites (van Riper 1980a). Critical habitat for Palila was designated in 1977 and included almost all State-owned māmane and naio-māmane woodlands on Mauna Kea (USFWS 1977).

Because of continued habitat degradation and the attendant threat to the Palila, a suit on behalf of the Palila was brought by conservationists against the state of Hawai'i. Noncompliance with the U.S. Endangered Species Act of 1973 was charged. A detailed account of the initial Palila lawsuit and events that proceeded was given by Juvik and Juvik (1984). The suit was decided in favor of the bird, and the State was ordered to remove feral sheep and feral goats completely and permanently from those portions of the māmane forest designated as critical Palila habitat. The status of mouflon sheep was not affected by the court order.

The feral sheep and goat "eradication" effort was completed in 1981. Five years later, it was evident that a few feral sheep had escaped death, as expected. The authors have seen a flock of 20 feral sheep at tree line on the western side of Mauna Kea. Sheep tracks and signs of recent browsing were common in the vicinity of that sighting.

To date there are still feral ungulates roaming the subalpine and alpine zone on Mauna Kea, and they continue to negatively impact native plant communities there. Between 200-500 feral ungulates are shot each year as part of control efforts conducted in the Mauna Kea Forest Reserve. Feral sheep and mouflon are the most abundant ungulates, as feral goats have been greatly reduced through hunting efforts. Only 26 feral goats have been observed (and shot) during semi-annual helicopter hunting efforts conducted by DOFAW over the last ten years (Fretz 2008). Although a fence was built around Mauna Kea to protect the forest reserve, funds for upkeep are not sufficient, and the fence has many holes that allow feral animals to continue to move across the fenceline, into and out of Mauna Kea Forest Reserve (Fretz 2008). DLNR is seeking funding to build and maintain a perimeter fence to protect the Mauna Kea Forest Reserve. If this funding is granted, the presence of the new (or repaired) fence, combined with funds for proper upkeep, will help prevent migration of feral ungulates from lower elevations, and allow for more successful control, and eventually, eradication of feral ungulates found in the upper elevations of Mauna

Kea (provided that sufficient effort is made to eradicate the animals). Currently efforts are being made to fence important areas of Palila habitat, rather than the entire Forest Reserve.

Non-native mammals can also negatively impact native subalpine communities through dispersal of invasive plant seeds, and in some cases through direct predation of native seeds and seedlings (Bruegmann 1996; Cabin et al. 2000). Rodents often eat native plant seeds. Rodent predation of native plant seeds is implicated in failure of native forest regeneration lowland dry forests (Cabin et al. 2000; Chimera 2004). Although rodents are not known to forage on māmane seeds (Cabin et al. 2000), they are likely to impact regeneration of other native species in the māmane woodlands on Mauna Kea.

2.2.4.1.3 Mammal Surveys at Hale Pōhaku

There have been no surveys conducted specifically for mammals at Hale Pōhaku. During her 1979 bird survey, Stemmerman observed mice in the woodlands and developed areas at Hale Pōhaku, and feral goats less than ¼ mile down slope of Hale Pōhaku (Stemmerman 1979). DLNR-DOFAW conducts semi-annual helicopter shoots of all feral sheep, goats, and mouflon on Mauna Kea within the forest reserve and up to the summit. Therefore data exists on numbers shot each year, which can be used to track changes in relative abundances in feral ungulate numbers over time (Fretz 2008).

2.2.4.2 Alpine Mammal Communities (MKSR and Upper Summit Access Road)

The density of mammals in the alpine zone on Mauna Kea is low due to limited food resources. Sheep, goats, cattle, cats and mice have all been recorded in the alpine zone of Mauna Kea (Hartt and Neal 1940; Juvik and Juvik 1984; Forsyth 2002; Conant et al. 2004).

2.2.4.2.1 Threatened and Endangered Species, Candidate Species and Species of Concern

No Endangered, Threatened, or Candidate Species, or Species of Concern are known to reside in the alpine zone on Mauna Kea. It is possible that the federally listed Endangered ʻOpeʻapeʻa (*Lasiurus cinereus semotus*) may occasionally use the area, although no records regarding this are available. It seems unlikely that this species would roost here given the cold climate and lack of trees.

2.2.4.2.2 Invasive Species

Sheep, goats and cattle have been documented all the way up to the summit of Mauna Kea. Grazing ungulates will feed on almost any palatable plant not protected by rocky crevices or impassable topography on the summit (Conant et al. 2004). Prior to ungulate control efforts, feral ungulates decimated the once thriving silversword population in the subalpine and alpine zones on Mauna Kea and no doubt reduced abundances of other palatable native species (Hess et al. 1999). A flock of 60 feral sheep was recently (Feb. 2008) observed in Pohakuloa Gulch and scat was observed at Lake Waiau in the Ice Age Natural Areas Reserve (Hadway 2008). Feral goats are likely to be rare or absent from MKSR, but feral sheep and mouflon are expected to occur there (Fretz 2008).

Although densities of feral ungulates in the alpine zone on Mauna Kea are currently low, even a few animals can exert serious grazing pressure on the plants found in this community, and feral ungulates continue to threaten native plant communities. For example, a recently discovered, isolated population of Mauna Kea silversword (*Argyroxiphium sandwicense sandwicense*) at approximately 12,200 ft (3,700 m) elevation in MKSR showed signs of grazing by feral ungulates (Nagata 2007; Tomlinson 2007). Other impacts of feral ungulates on the alpine zone include soil/cinder compaction, addition of nutrients to nutrient poor soils, and seed dispersal. These issues have not been examined on Mauna Kea (Aldrich 2005).

Feral cats and rats may be present in the lower reaches of the alpine zone, at very low densities. If Hawaiian petrels utilize the alpine areas on Mauna Kea, mammalian predators may prey on eggs, nestlings and adult petrel. Mice have been observed within the observatories and along the road above 12,000 ft (3,660 m) (Conant et al. 2004). Mice are known to eat arthropods and seeds and could have a negative impact on native arthropod communities at the summit, especially around the developed areas. However, their overall impact on the alpine community is unknown.

2.2.4.2.3 Mammal Surveys at MKSR

In 1988, Maile Kjargaard conducted a vertebrate (bird and mammal) survey at two proposed sites for the VLBA antennae, located between 11,800 and 12,400 ft (3,600 and 3,780 m) (Kjargaard 1988). The primary goal of the survey was to look for signs of Hawaiian petrels. Evidence of use of the sites by sheep was present in the forms of droppings, and sheep remains. Because of the lack of food in the area, Kjargaard suggested that these sites were mainly used as refuges from hunting pressure at lower elevations.

No other records of mammal surveys conducted in the MKSR are available. No formal surveys for mammals have been conducted at the Ice Age NAR, but opportunistic sightings of mammals (or sign of mammal damage to vegetation) are recorded in the DNLR GIS (Hadway 2008). Records from semi-annual helicoptor shoots conducted in MKSR by DLNR provide a record of changes in relative abundance of feral ungulates over time (Fretz 2008).

2.2.4.3 Threats to Mammal Communities on Mauna Kea

Habitat loss and pesticide use to control insects are believed to be the primary threats to Hawaiian hoary bat (*Lasiurus cinereus semotus*) (USFWS 1998b). Not enough information is available about the bat's use of subalpine habitats to speculate about what factors might affect its populations in high elevation areas of Mauna Kea. Although they have been observed at high elevation areas on Mauna Loa, their use of high elevation habitats on Mauna Kea is not well documented (Bonaccorso 2008; Menard 2008).

2.2.4.4 Mammal Community Information Gaps

There have been no mammal-specific surveys conducted in Hale Pōhaku and the MKSR, although Maile Stemmerman Kjargaard did look for signs of mammals during her bird surveys at Hale Pōhaku and MKSR. The following information gaps regarding the condition of the subalpine and alpine mammal communities at Hale Pōhaku and the MKSR have been identified through review of the literature and consultation with local experts:

1. Quantitative mammal surveys
    a) Hale Pōhaku: No quantitative studies documenting the composition of the mammal community, population sizes, or distribution of native and non-native species have been conducted at Hale Pōhaku. A brief (qualitative) inspection for mammals was conducted by Stemmerman in connection with her 1979 bird survey. DOFAW collects data on the number of sheep and mouflon shot during helicoptor shoots conducted twice a year. Although these

numbers do not provide an estimate of population size, they can be used to track changes in relative abundance of sheep and mouflon on the mountain over time.

b) Summit Access Road and Mauna Kea Science Reserve: No mammal surveys have been conducted along the Summit Access Road or in the MKSR. Kjargaard conducted a brief inspection for mammals in 1988 at the VLBA proposed sites.

2. Status of Invasive Species

No information is available regarding density, distribution, and effects of established invasive mammal species on the properties. There is a need for a comprehensive survey of invasive mammal species at Hale Pōhaku and identification of environmental problems they may be causing.

3. Protected species/Species of concern

No surveys for the Hawaiian hoary bat have been conducted at Hale Pōhaku or in MKSR.

Figure 2.2-1: Mauna Kea high elevation ecosystems

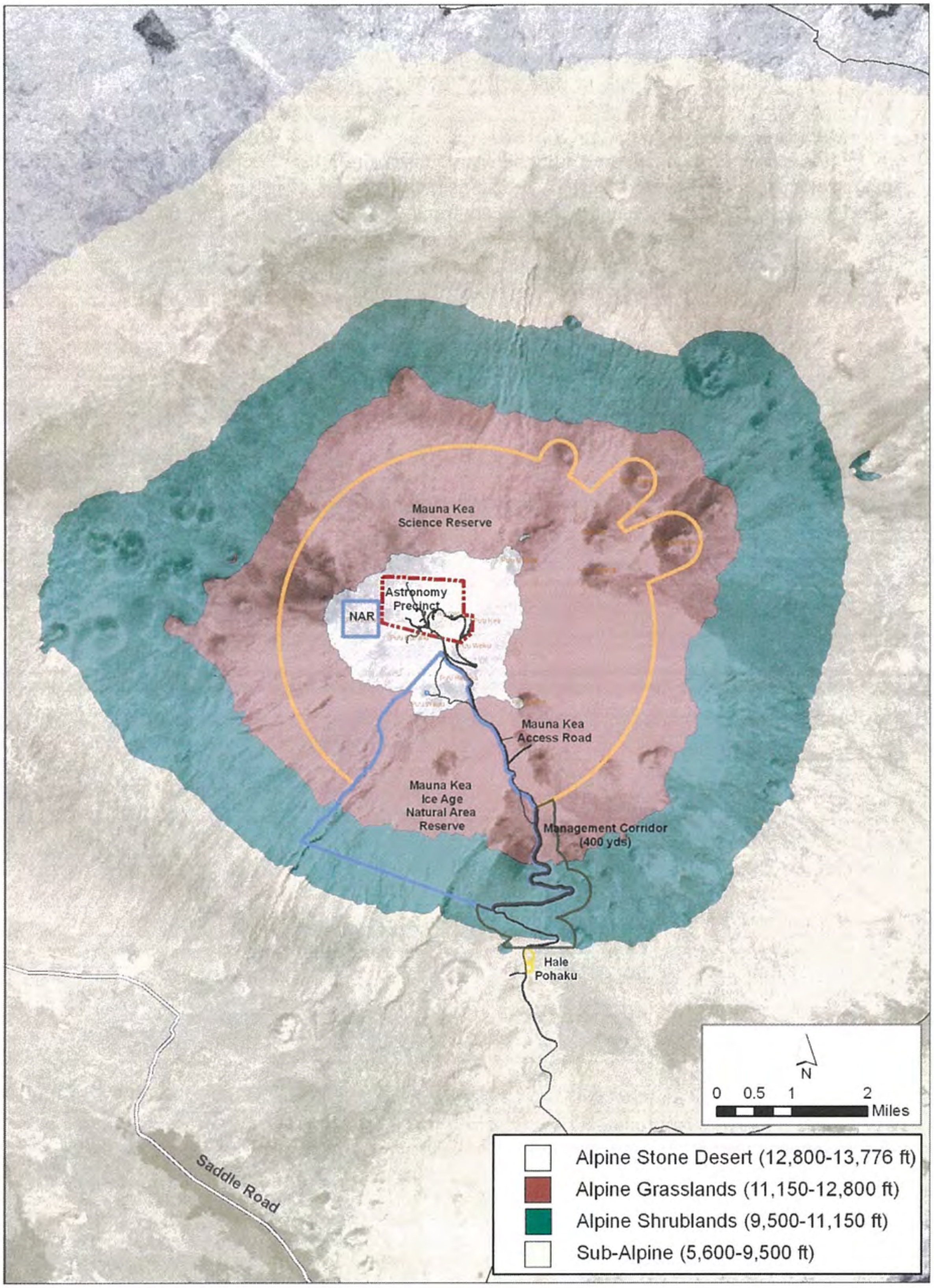


Figure 2.2-2: Photos of common native plants

Māmane (*Sophora chrysophylla*)
Photo by Jennifer Garrison

Pūkiawe (*Leptecophylla tameiameiae*)
Photo by Forest and Kim Starr

'Ohelo (*Vaccinium reticulatum*)
Photo by Jennifer Garrison

'Āheahea (*Chenopodium oahuense*)
Photo by Forest and Kim Starr

Littleleaf Stenogyne (*Stenogyne microphylla*)
Photo by Forest and Kim Starr

Mā'ohi'ohi (*Stenogyne rogosa*)
Photo by Forest and Kim Starr

Pāwale (*Rumex giganteus*)
Photo by Forest and Kim Starr

'A'ali'i (*Dodonaea viscosa*)
Photo by Forest and Kim Starr

Alpine mirror plant (*Coprosma montana)*
Photo by Forest and Kim Starr

'Aiakenēnē (*Coprosma ernodeoides*)
Photo by Forest and Kim Starr

'Ulei (*Osteomeles anthyllidifolia*)
Photo by Forest and Kim Starr

Alpine catchfly (*Silene struthioloides*)
Photo by Forest and Kim Starr

Alpine hairgrass (*Deschampsia nubigena*)
Photo by Forest and Kim Starr

Kalamoho (*Pellaea ternifolia)*
Photo by Forest and Kim Starr

Hawai'i bentgrass (*Agrostis sandwicensis*)
Photo by Forest and Kim Starr

Pili uka (*Trisetum glomeratum*)
Photo by Forest and Kim Starr

ʻIwaʻiwa *(Asplenium adiantum-nigrum)*
Photo by Forest and Kim Starr

Olaliʻi *(Asplenium trichomanes)*
Photo by Forest and Kim Starr

Figure 2.2-3: Photos of rare native plants

Mauna Kea silversword (*Argyroxiphium sandwicense sandwicense*).
Photo by Jennifer Garrison

Hawai'i catchfly (*Silene hawaiiensis)*.
Photo © Warren L. Wagner & Smithsonian Institution Department of Botany

'Ākala (*Rubus hawaiensis*)
Photos by Forest & Kim Starr

'Akoko (*Chamaesyce olowaluana*)
Photo by Forest & Kim Starr

Na'ena'e (*Dubautia scabra*)
Photo by Forest & Kim Starr

Mauna Kea dubautia (*Dubautia arborea*)
Photo by Forest & Kim Starr. Inset photo © Gerald Carr & Smithsonian Institution Department of Botany

Lava dubautia (*Dubautia ciliolata* ssp. *ciliolata*).
Photo © Warren L. Wagner & Smithsonian Institution Department of Botany

Hawaii black snakeroot (*Sanicula sandwicensis*).
Photo © Derral Herbst & Smithsonian Institution Department of Botany

Hawaiian vetch (*Vicia menziesii*).
Photo © Charles Lamoureux & Smithsonian Institution Department of Botany

Alpine tetramolopium (*Tetramolopium humile* ssp. *humile* var. *humile*). Photo by Forest & Kim Starr

'Ena 'ena (*Pseudognaphalium sanwicensium*).[1]
Photo by Forest & Kim Starr

'Ohelo papa (Hawaiian strawberry, *Fragraria chiloensis*). Photo by Forest & Kim Starr

[1] Called *Gnaphalium sandwicensium* in some references.

Figure 2.2-4: Photos of common invasive plants

Needlegrass (*Nassella cernua*)
Photo by Sally and Andy Wasowski

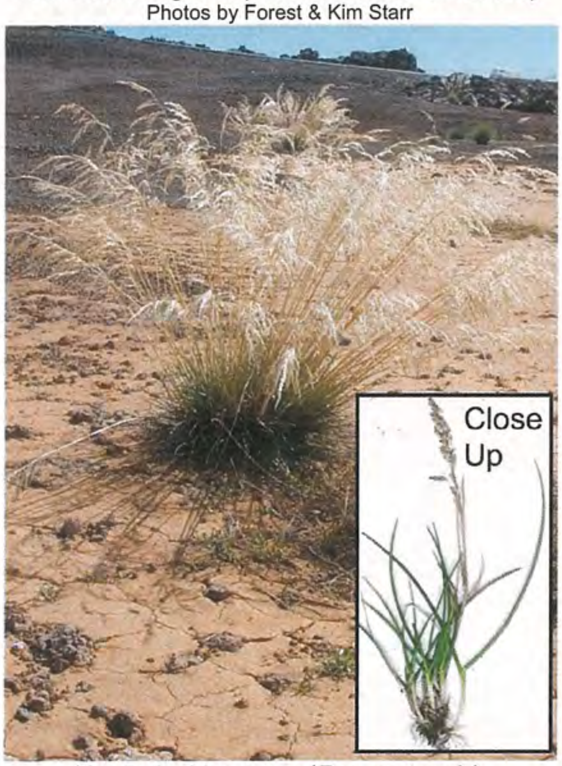
Velvet grass (*Holcus lanatus*)
Photos by Forest & Kim Starr

Ripgut brome (*Bromus diandrus*)
Photos by Forest & Kim Starr

Orchardgrass (*Dactylis glomerata*)
Photos by Forest & Kim Starr

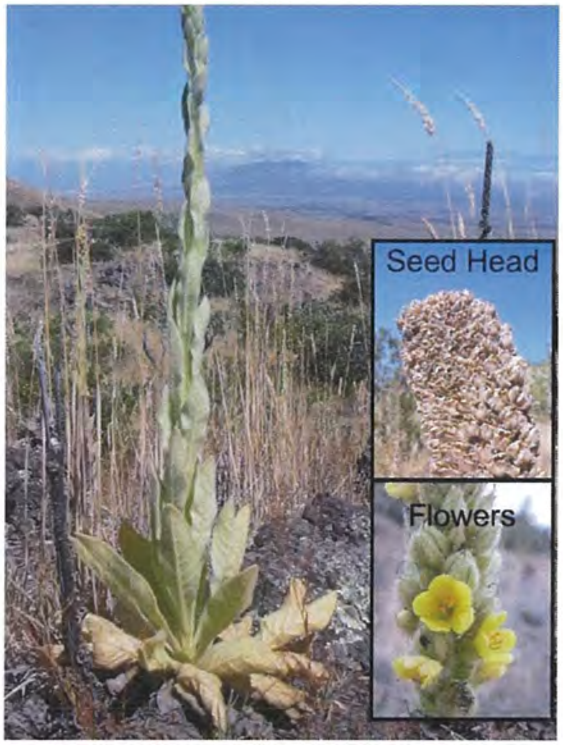
Sweet vernalgrass (*Anthoxanthum odoratum*)
Photos by Forest & Kim Starr

Fountain grass (*Pennisetum setaceum*)
Photos by Forest & Kim Starr

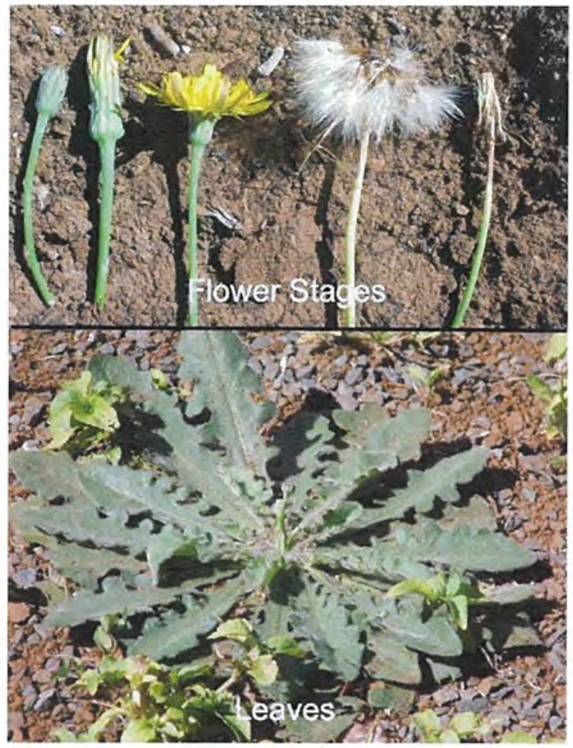


Kentucky bluegrass (*Poa pratensis*)
Photos by Forest & Kim Starr

Rye grass (*Lolium* sp.)
Photo by Forest & Kim Starr. Inset photo by Dan Tenaglia.



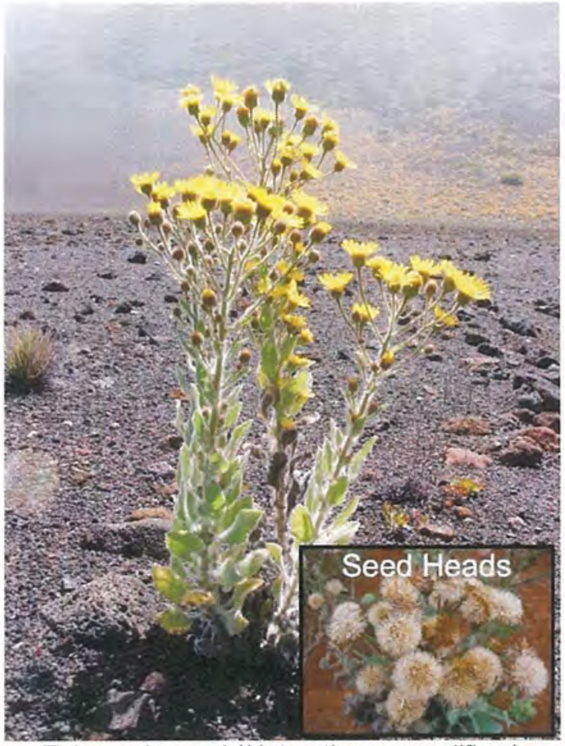
Common mullein (*Verbascum thapsus*)
Photos by Forest & Kim Starr



Hairy cats-ear (*Hypochoeris radicata*)
Photos by Forest & Kim Starr

Fireweed (*Senecio madagascariensis*)
Photos by Forest & Kim Starr

Common dandelion (*Taraxacum officinale*)
Photos by Forest & Kim Starr



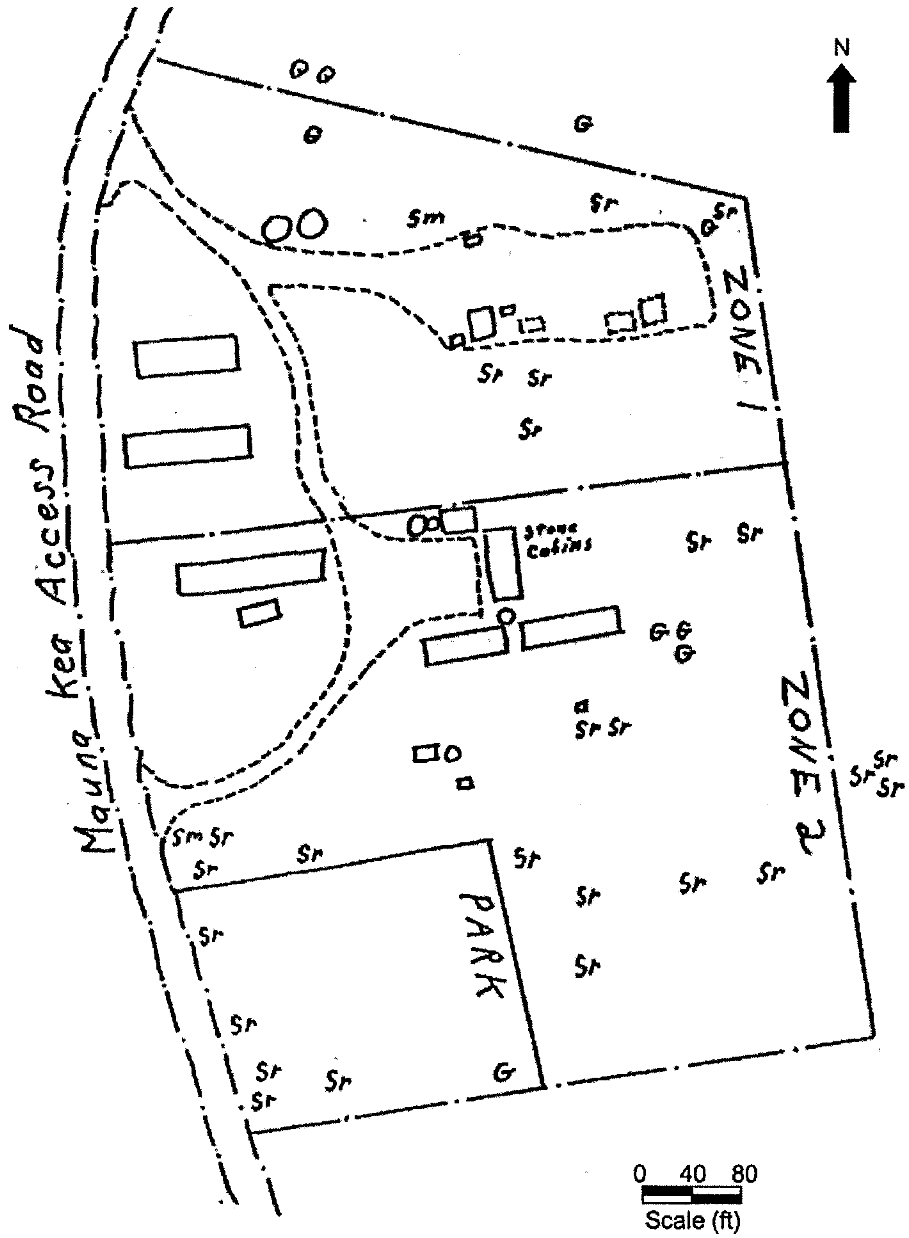
Telegraph weed (*Heterotheca grandiflora*)
Photos by Forest & Kim Starr

Alfilaria or pin clover (*Erodium cicutarium*)
Photos by Forest & Kim Starr

Sheep sorrel (*Rumex acetosella*)
Photos by Forest & Kim Starr

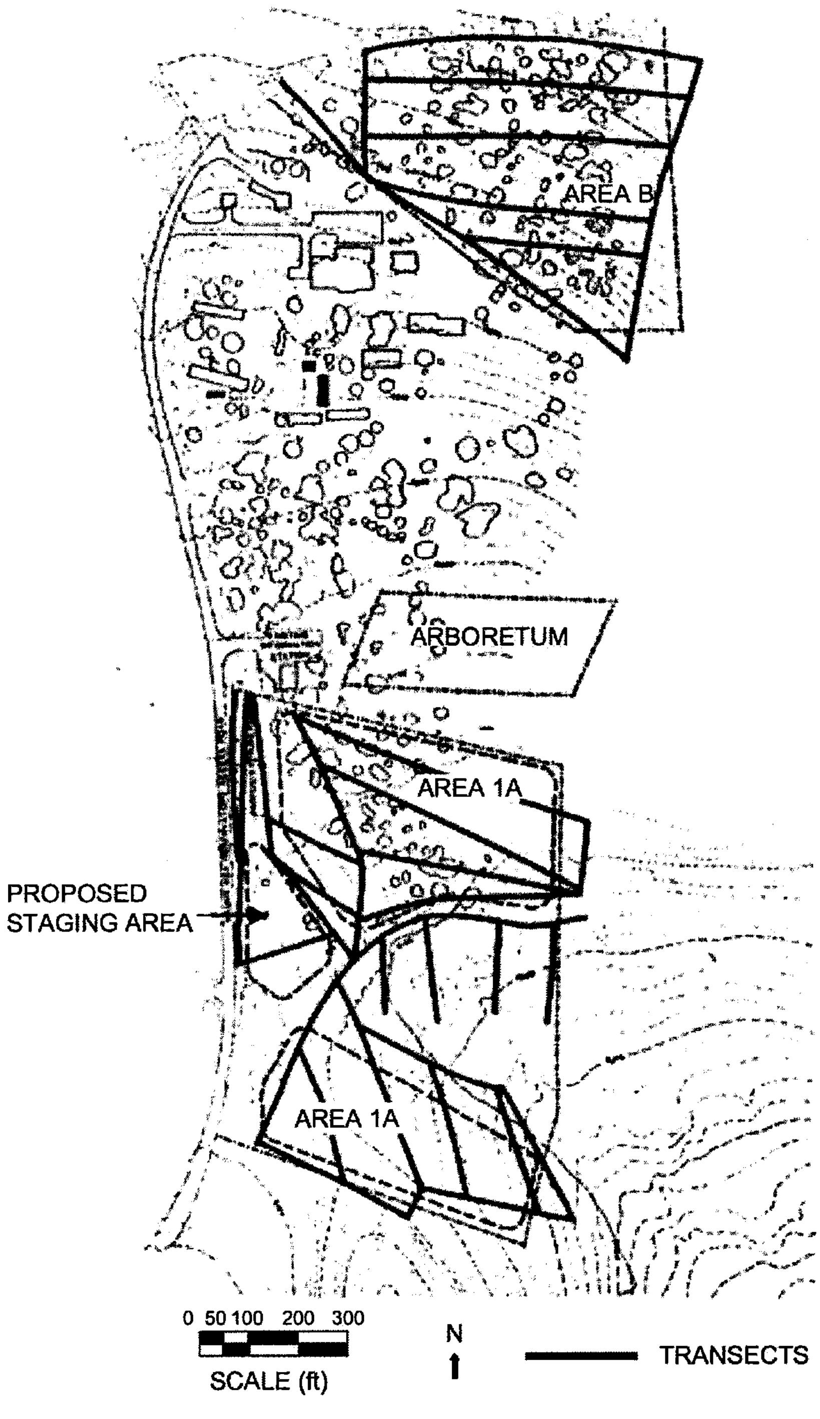
Common groundsel (*Senecio vulgaris*)
Photos by Dan Tenaglia

Figure 2.2-5: Gerrish 1979 survey area at Hale Pōhaku



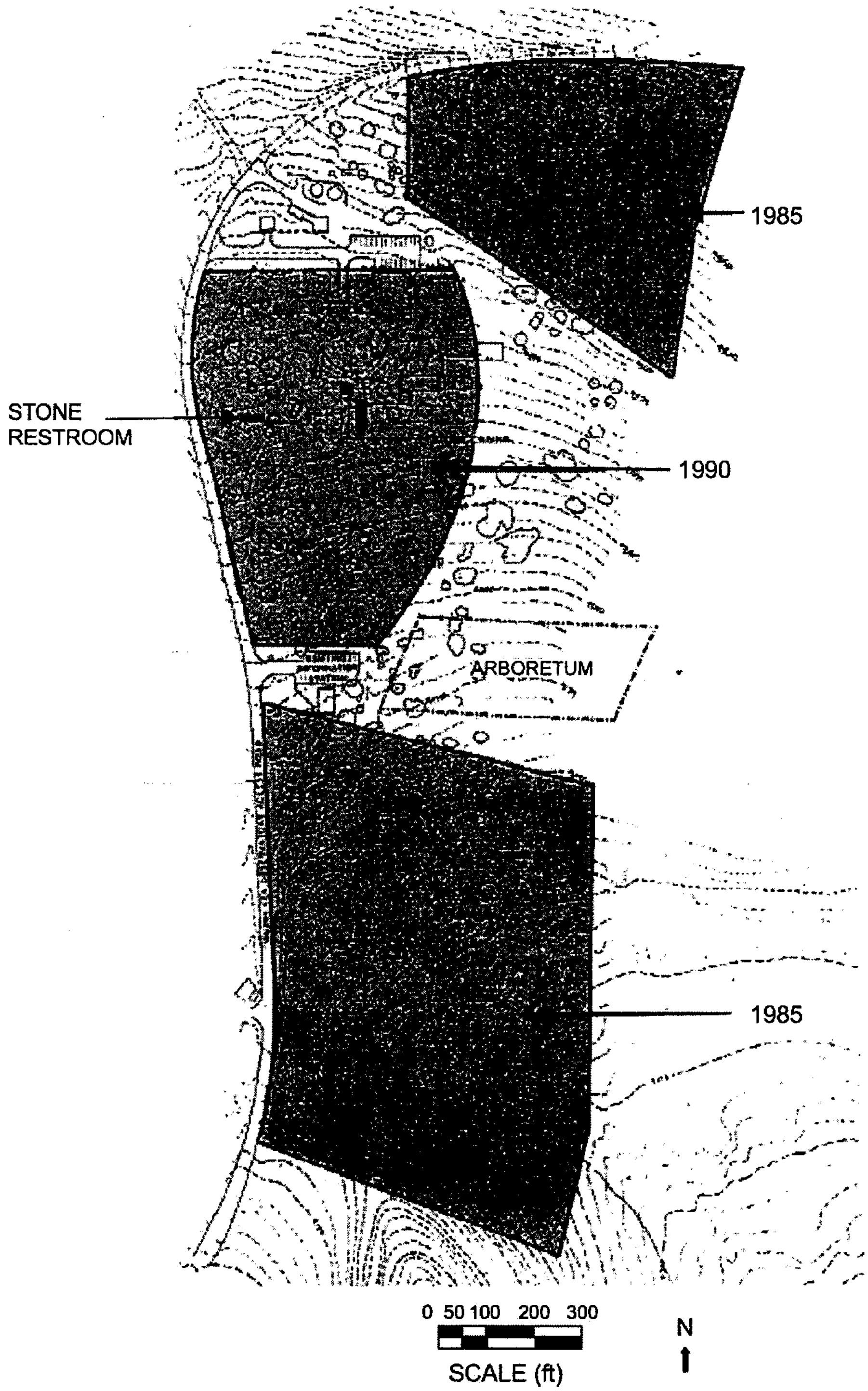
Notes: Map shows layout of Hale Pōhaku as it occurred in 1979, and does not include current buildings. Locations of three native plant species are indicated by letters on the figure. G = *Geranium cuneatum*, Sr = *Stenogyne rugosa*, Sm = *Stenogyne microphylla.* Reproduced from Gerrish, G. 1979. Vegetation Survey. Appendix B in: Group 70. 1980. Revised environmental impact statement for Hale Pohaku: mid-elevation facilities master plan, Hamakua, Mauna Kea, Hawaii. Prepared for Group 70, Honolulu, HI. 24 p.

Figure 2.2-6: Char 1985 survey area at Hale Pōhaku



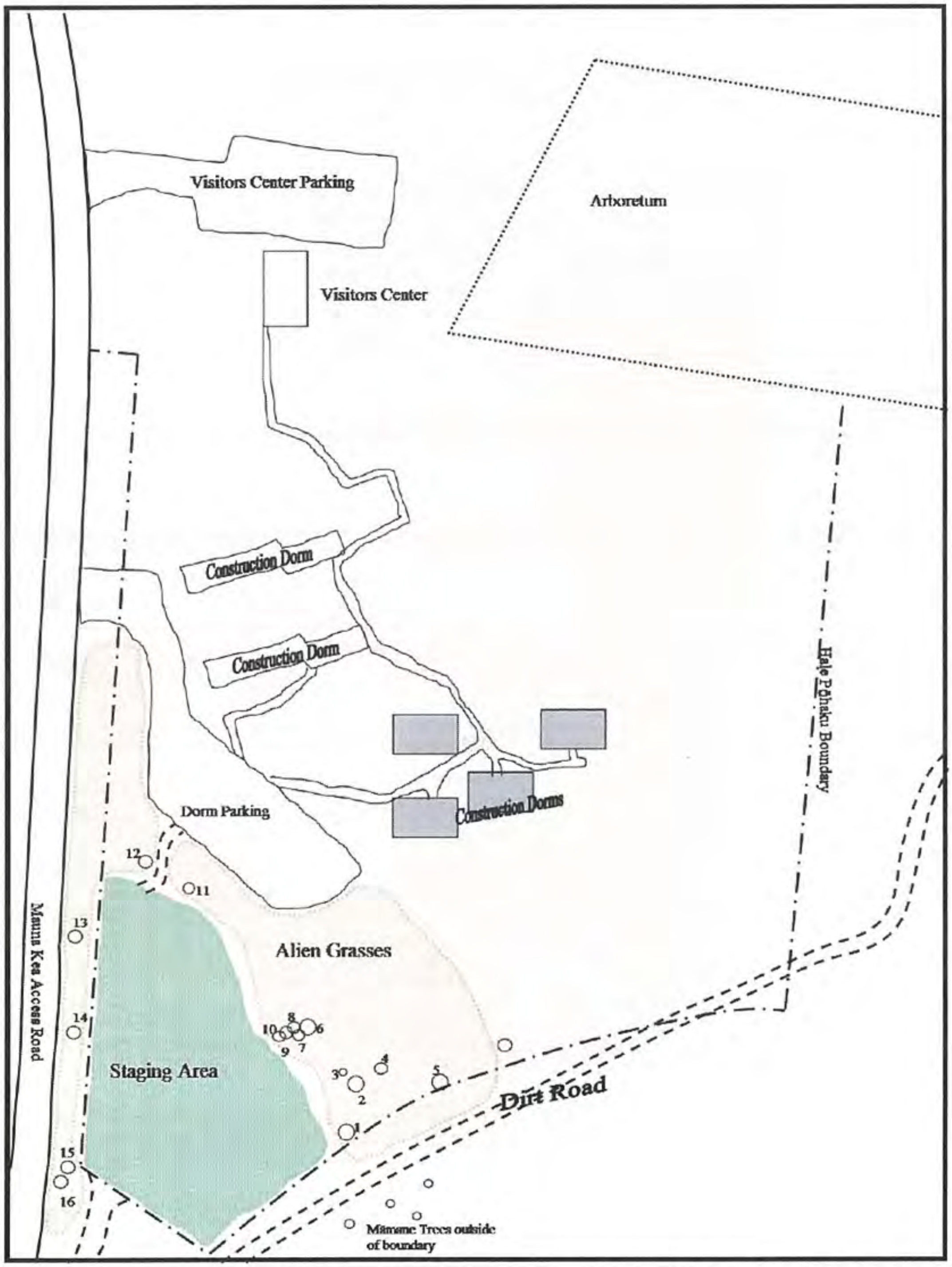
Reproduced from Char, W. P. 1985. Botanical survey for the proposed temporary construction camp housing at Hale Pohaku, Mauna Kea, Island of Hawaii. Appendix A in: MCM Planning and University of Hawaii. 1985. Final supplemental environmental impact statement for construction camp housing, amendment to the Mauna Kea Science Reserve Complex Development Plan. Hale Pohaku, Hamakua, Mauna Kea, Hawaii. Prepared for MCM Planning, Honolulu, HI. 10 p.

Figure 2.2-7: Char 1990 survey area at Hale Pōhaku



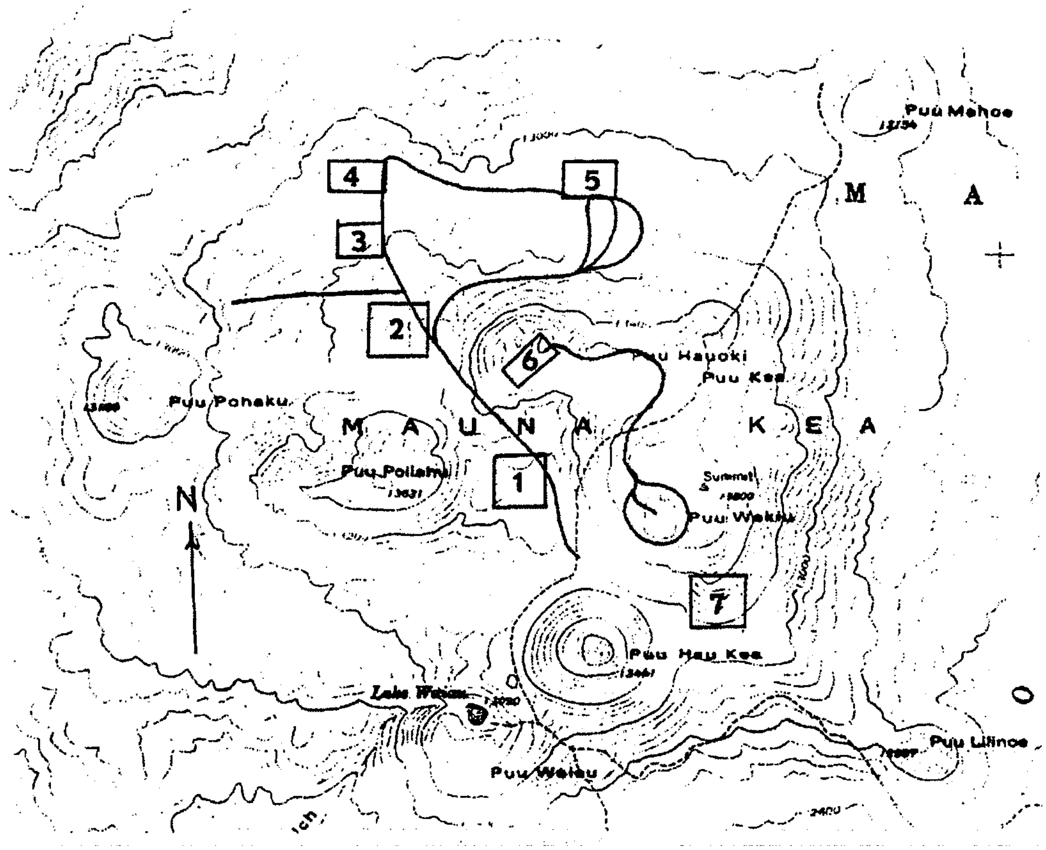
Reproduced from Char, W. P. 1990. Botanical Survey, JNLT and Associated Facilities for the Proposed Japanese National Large Telescope, Mauna Kea, Hawai'i. Prepared for MCM Planning, Honolulu, HI. 16 pp.

Figure 2.2-8: Pacific Analytics 2004 survey area at Hale Pōhaku



Notes: Surveyed areas indicated in green and tan. Individual māmane trees are indicated by numbered circles. Scale bar not included in original figure. Reproduced from: Pacific Analytics. 2004. Botanical survey of the Hale Pohaku mid-elevation facilities construction staging area. Prepared for The Outrigger Telescopes Project, National Aeronautics and Space Administration by Pacific Analytics LLC, Albany, OR. 19 p.

Figure 2.2-9: Smith et al. 1982 summit area vegetation survey locations



Notes: Numbered squares indicate intensively surveyed areas. Heavy lines indicate reconnaissance areas. Reproduced from: Smith, C. W., W. J. Hoe and P. J. O'Conner. 1982. Botanical Survey of the Mauna Kea summit above 13,000 feet. Prepared for Group 70. October 1982.

Figure 2.2-10: Photos of selected native invertebrate species occurring in subalpine and alpine habitat on Mauna Kea

Wēkiu bug (*Nysius wekiuicola*)
Photo by Jesse Eiben

Lycosid spider (*Lycosa sp.*)
Photo by Peter Oboyski

Summit Agrotis moth (*Agrotis or Peridroma sp.*)
Photo by Jesse Eiben

Tephritid fly (*Trupanea arboreae*)
Photos by Idelle Cooper

Koa bug (*Coleotichus blackburniae*)
Photo by Forest & Kim Starr

Kamehameha butterfly (*Vanessa tameamea*)
Photos by Forest & Kim Starr

Cydia moth (*Cydia plicata*)
Photo by Peter Oboyski

Agrotis noctuid moth (*Agrotis melanoneura*)
Photo by Jesse Eiben

Thyrocopa moth (*Thyrocopa kikaeleaka*)
Photos by MJ Medeiros, courtesy of the British Museum of Natural History

Thyrocopa moth (*Thyrocopa adumbrata*)
Photos by MJ Medeiros, courtesy of the British Museum of Natural History

Yellow-faced bee (*Hylaeus flavipes*)
Photos by Jesse Eiben

Hawaii mamane long-horned beetle (*Plagithmysus blackburni*)
Photos by Forest and Kim Starr

Notes: Images by Forest and Kim Starr available at: http://www.hear.org/starr/hiinsects/images/index.html. Images from Peter Oboyski available at: http://nature.berkeley.edu/~poboyski/hawaii/insects.htm.

Figure 2.2-11: Photos of common invasive invertebrate species

Yellowjacket (*Vespula pensylvanica*)
Photo by David Foote, USGS

Honeybees (*Apis mellifera*)
Photo courtesy of USDA

Convergent ladybeetle *(Hippodamia convergens)*
Photo by Walter Siegmund[1]

Argentine ant (*Linepithema humile*)
Photo by Peter Oboyski

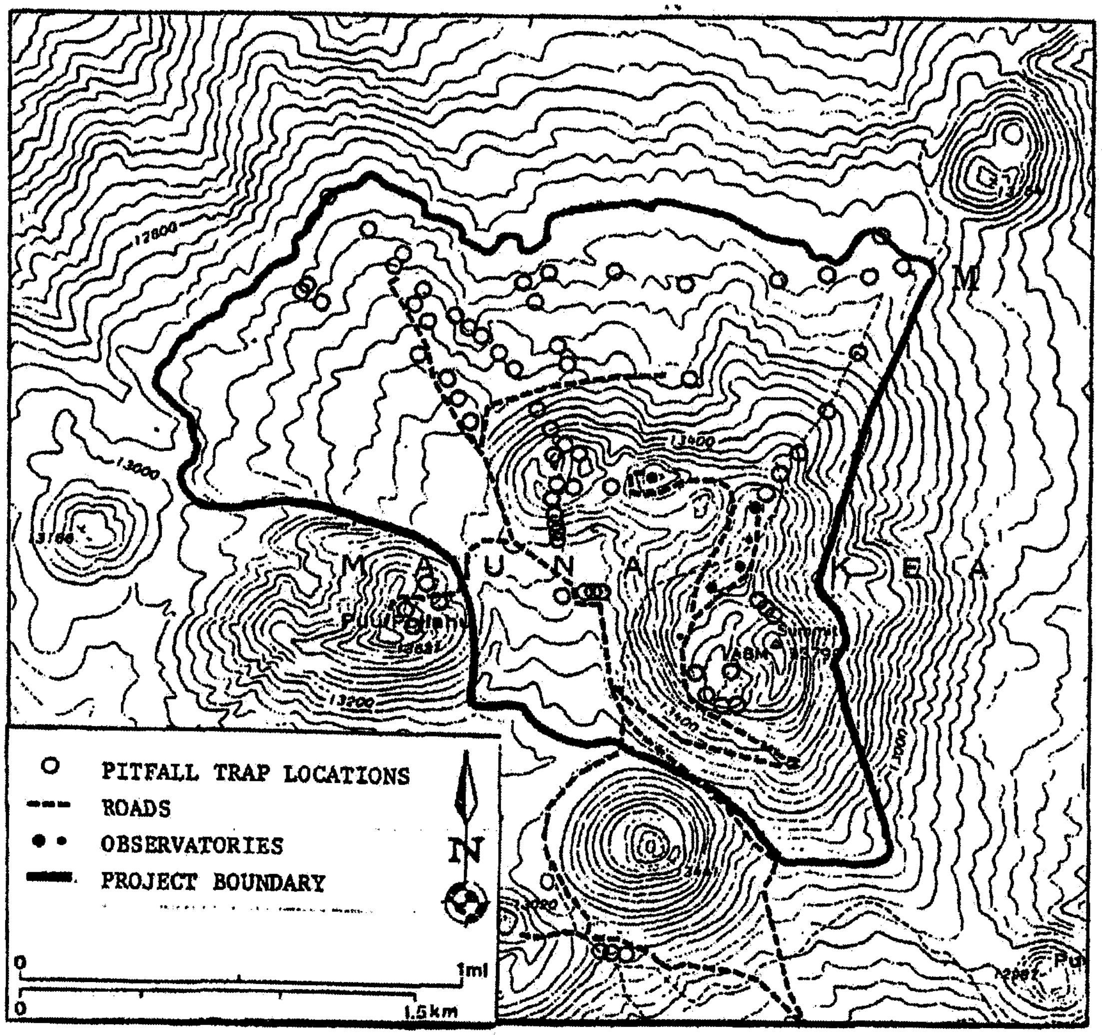
[1] Ladybeetle photo from: *http://commons.wikimedia.org/wiki/Image:Hippodamia_convergens_08084.JPG*

Monomorium pharaonis &
Tetramorium bicarinatum
Photos from antweb.org[2]

Cardiocondyla venustula &
Pheidol megacephala
Photos from antweb.org

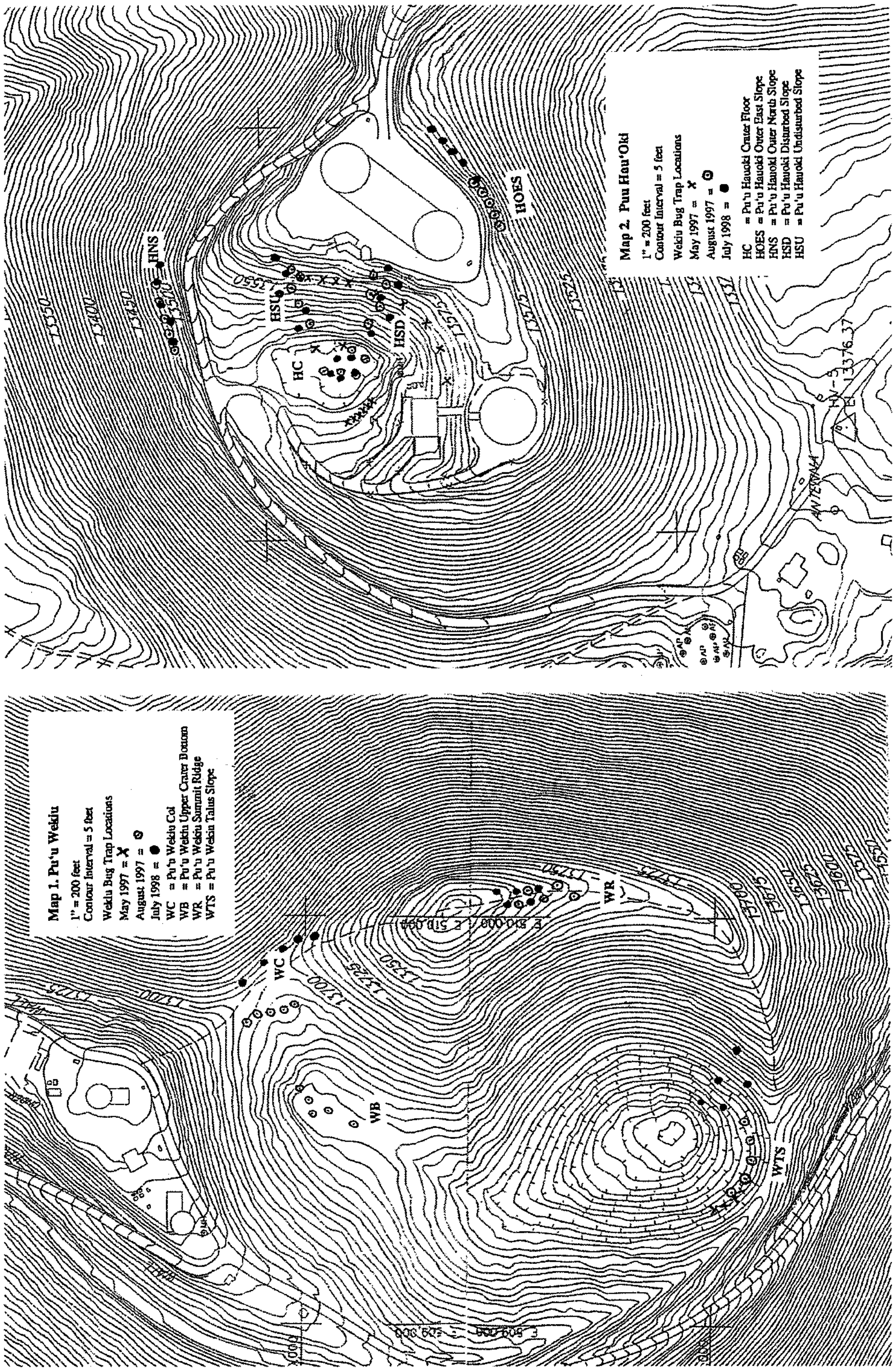
[2] Photos credited to antweb.org are from the "Antweb field guide to ant species of Hawaii," available online at http://www.antweb.org/hawaii/species.pdf

Figure 2.2-12: Howarth and Stone 1982 arthropod survey locations



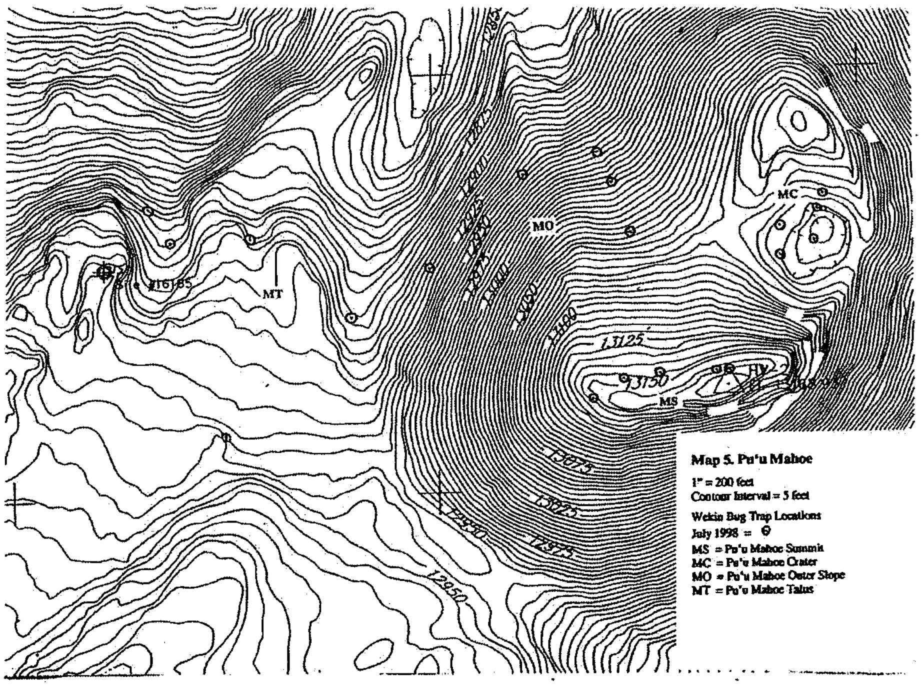
Notes: Reproduced from: Howarth, F. G. and F. D. Stone. 1982. An assessment of the arthropod fauna and aeolian ecosystem near the summit of Mauna Kea, Hawaii. Submitted to Group 70. Bernice P. Bishop Museum, Honolulu. 18.

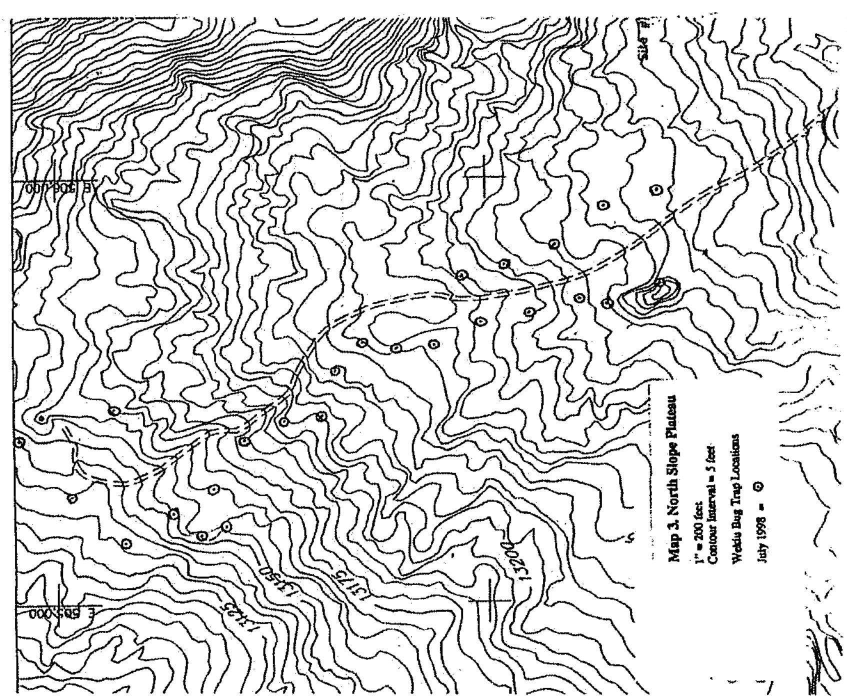
Figure 2.2-13: Howarth et al. 1997-8 arthropod survey locations: Pu'u Wēkiu and Pu'u Hau'Oki.



Notes: Reproduced from: Howarth, F. G., G. J. Brenner and D. J. Preston. 1999. An arthropod assessment within selected areas of the Mauna Kea Science Reserve. Final Report. Prepared for the University of Hawaii Institute of Astronomy. Appendix J in Group 70. 2000. Mauna Kea Science Reserve Master Plan. Bishop Museum and Pacific Analytics, Honolulu. 65 p.

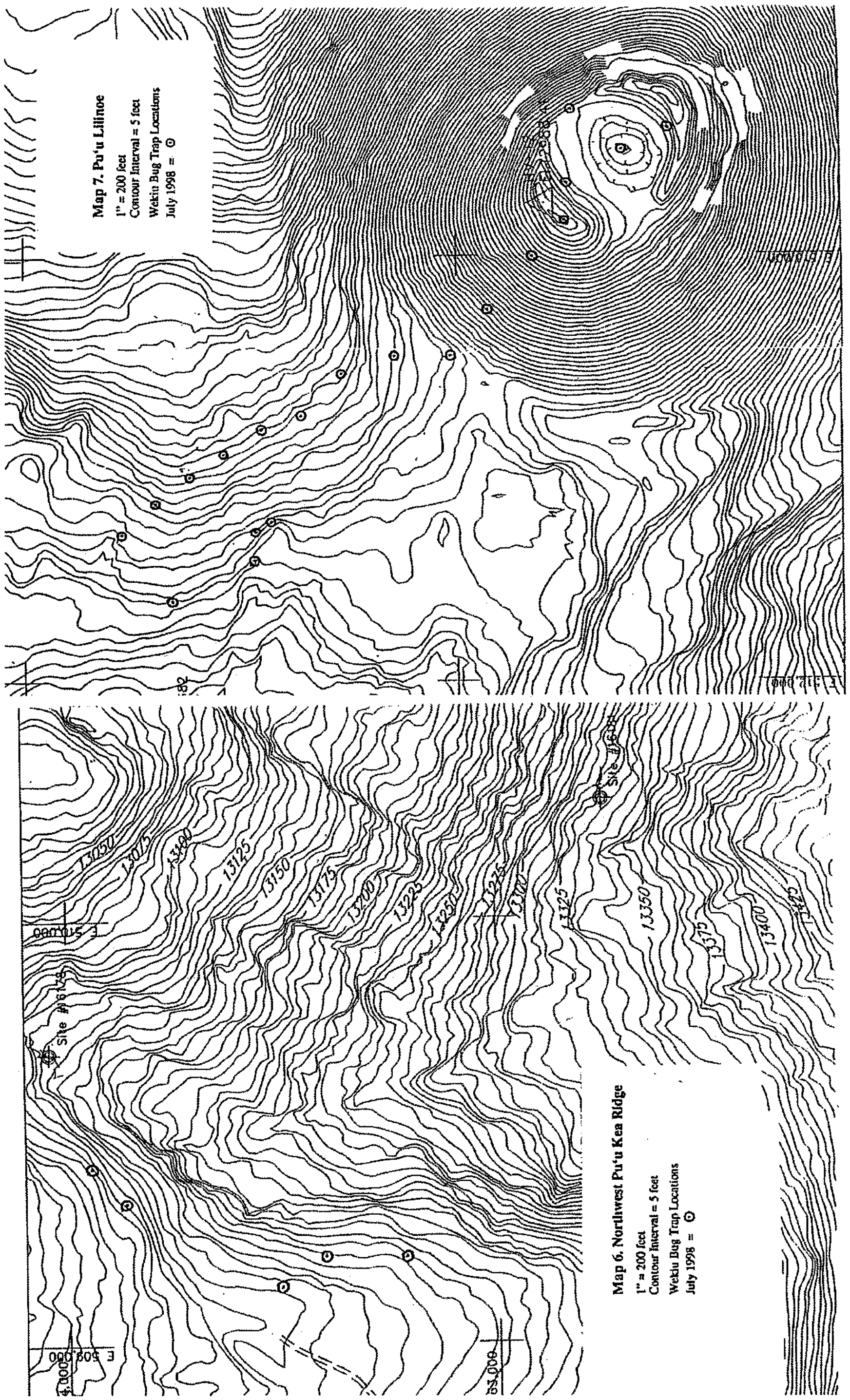
Figure 2.2-14: Howarth et al. 1997-8 arthropod survey locations: North Slope Plateau and Pu'u Mahoe.





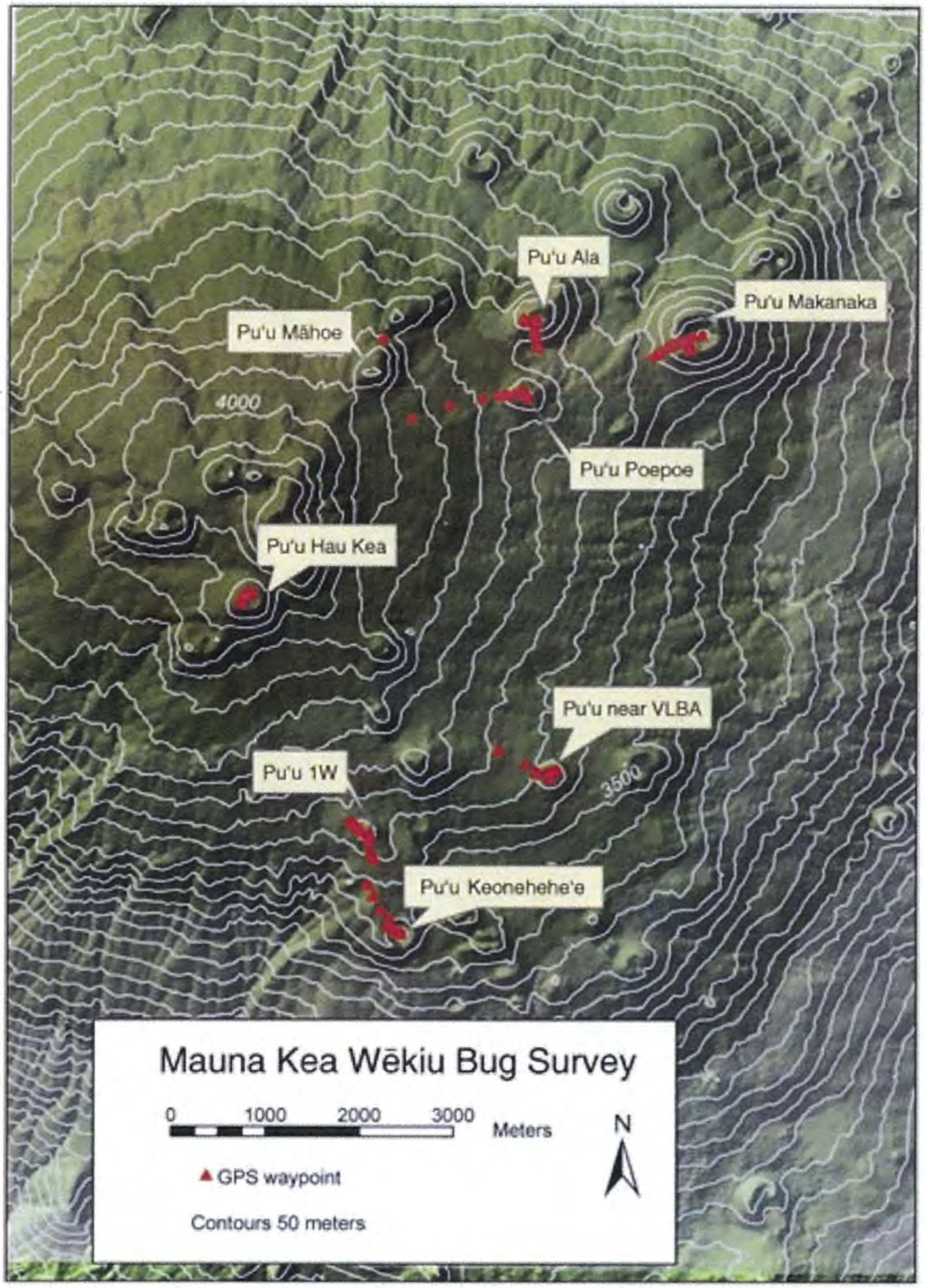
Notes: Reproduced from: Howarth, F. G., G. J. Brenner and D. J. Preston. 1999. An arthropod assessment within selected areas of the Mauna Kea Science Reserve. Final Report. Prepared for the University of Hawaii Institute of Astronomy. Appendix J in Group 70. 2000. Mauna Kea Science Reserve Master Plan. Bishop Museum and Pacific Analytics, Honolulu. 65 p.

Figure 2.2-15: Howarth et al. 1997-8 arthropod survey locations: Northwest Pu'u Kea Ridge and Pu'u Lilinoe



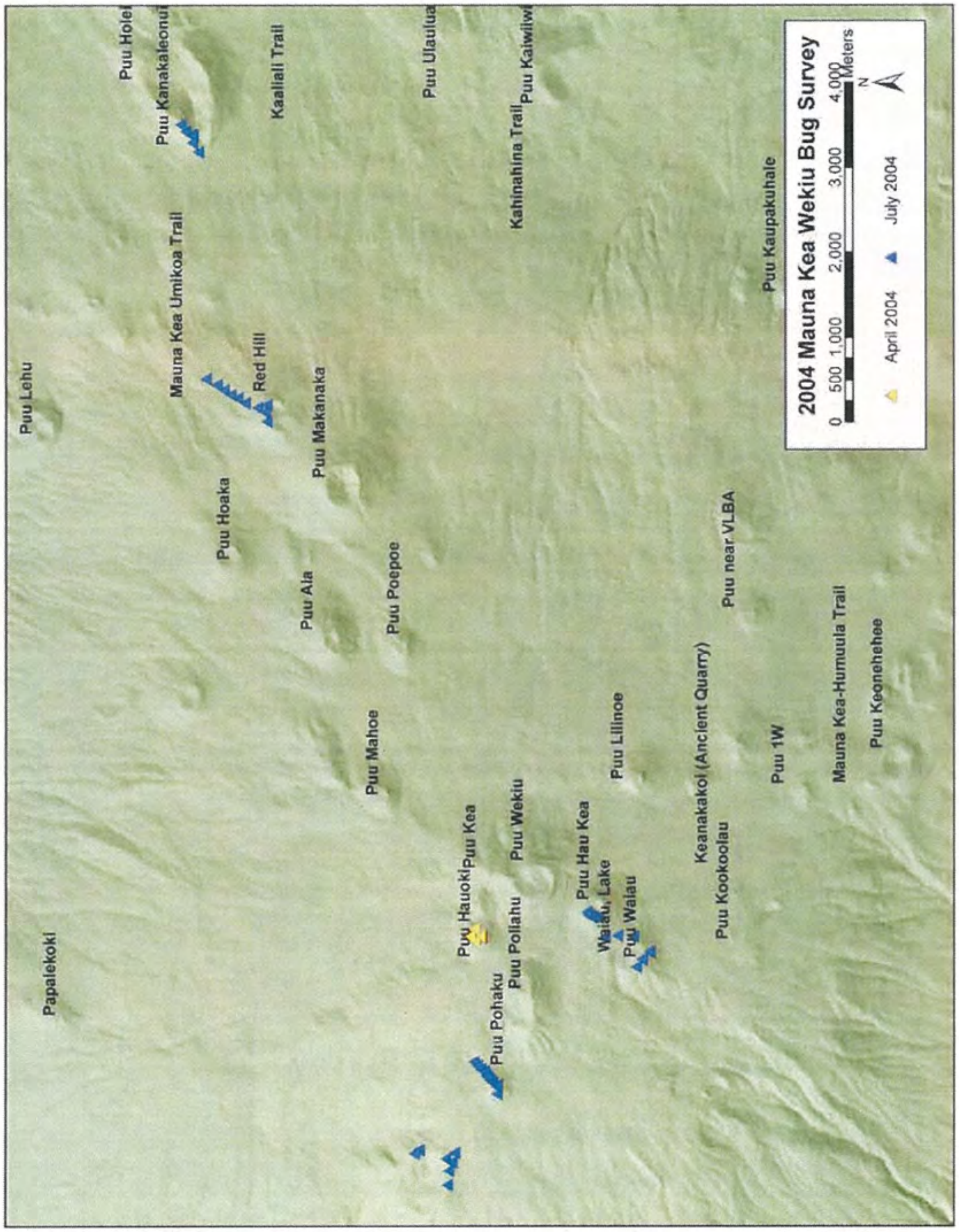
Notes: Reproduced from: Howarth, F. G., G. J. Brenner and D. J. Preston. 1999. An arthropod assessment within selected areas of the Mauna Kea Science Reserve. Final Report. Prepared for the University of Hawaii Institute of Astronomy. Appendix J in Group 70. 2000. Mauna Kea Science Reserve Master Plan. Bishop Museum and Pacific Analytics, Honolulu. 65 p.

Figure 2.2-16: 2001 Wēkiu bug survey locations (Englund et al. 2002)



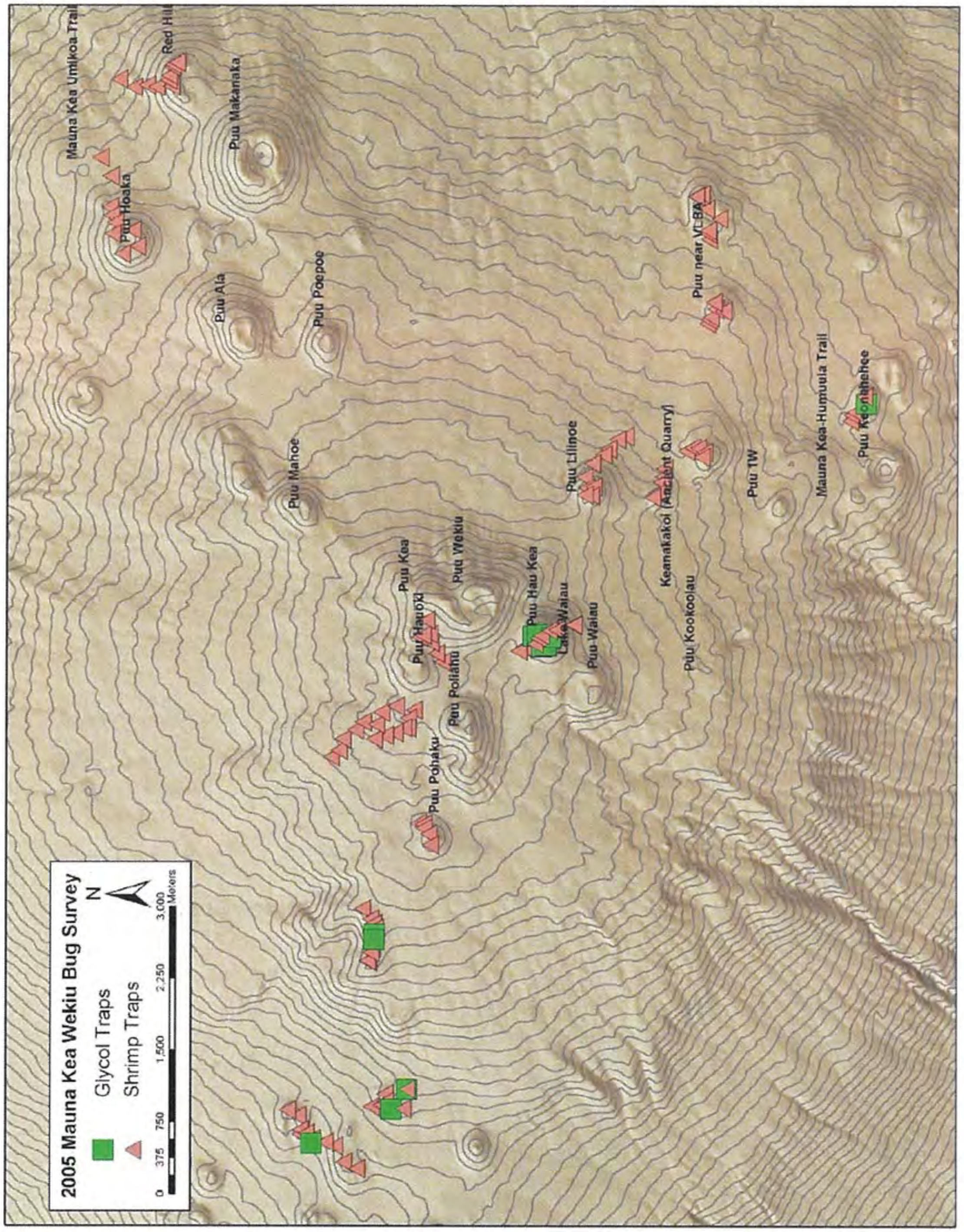
Notes: Reproduced from: Englund, R. A., D. A. Polhemus, F. G. Howarth and S. L. Montgomery. 2002. Range, habitat, and ecology of the Wēkiu bug (*Nysius wekiuicola*), a rare insect species unique to Mauna Kea, Hawai'i Island. Final report. Prepared for Office of Mauna Kea Management, University of Hawaii. Hawaii Biological Survey Report 2002-023. Bishop Museum, Honolulu. 49 p.

Figure 2.2-17: 2004 Wēkiu bug survey locations (Englund et al. 2005)



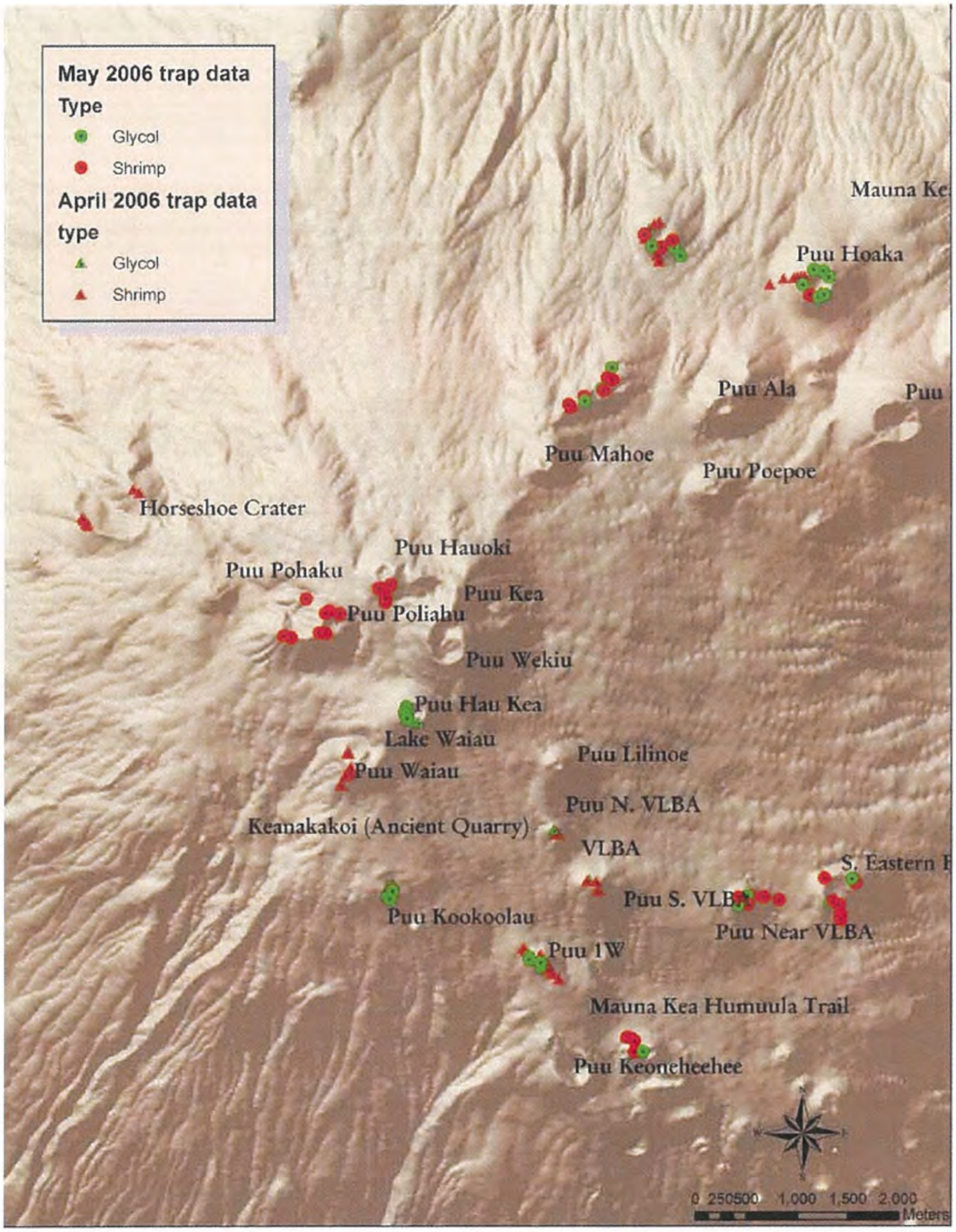
Notes: Reproduced from: Englund, R. A., A. Ramsdale, M. McShane, D. J. Preston, S. Miller and S. L. Montgomery. 2005. Results of 2004 Wēkiu Bug (*Nysius wekiuicola*) Surveys on Mauna Kea, Hawai'i Island. Final Report. Prepared for Office of Mauna Kea Management. Hawaii Biological Survey, Bishop Museum, Honolulu, HI. 37 p

Figure 2.2-18: 2005 Wēkiu bug survey locations (Englund et al. 2006)



Notes: Reproduced from: Englund, R. A., A. E. Vorsino, H. M. Laederich, A. Ramsdale and M. McShane. 2006. Results of 2005 Wēkiu Bug (*Nysius wekiuicola*) Surveys on Mauna Kea, Hawai'i Island. Final Report. Prepared for Office of Mauna Kea Management. Hawaii Biological Survey Report 2006-010. Hawaii Biological Survey, Bishop Museum, Honolulu, HI. 63 p.

Figure 2.2-19: 2006 Wēkiu bug survey locations (Englund et al. 2007)



Notes: Reproduced from: Englund, R. A., A. E. Vorsino and H. M. Laederich. 2007. Results of the 2006 Wēkiu Bug (*Nysius wekiuicola*) Surveys on Mauna Kea, Hawai'i Island. Final Report. Prepared for Office of Mauna Kea Management. Hawaii Biological Survey Report 2007-003. Hawaii Biological Survey, Bishop Museum, Honolulu, HI. 66 p.

Figure 2.2-20: Wēkiu bug potential habitat

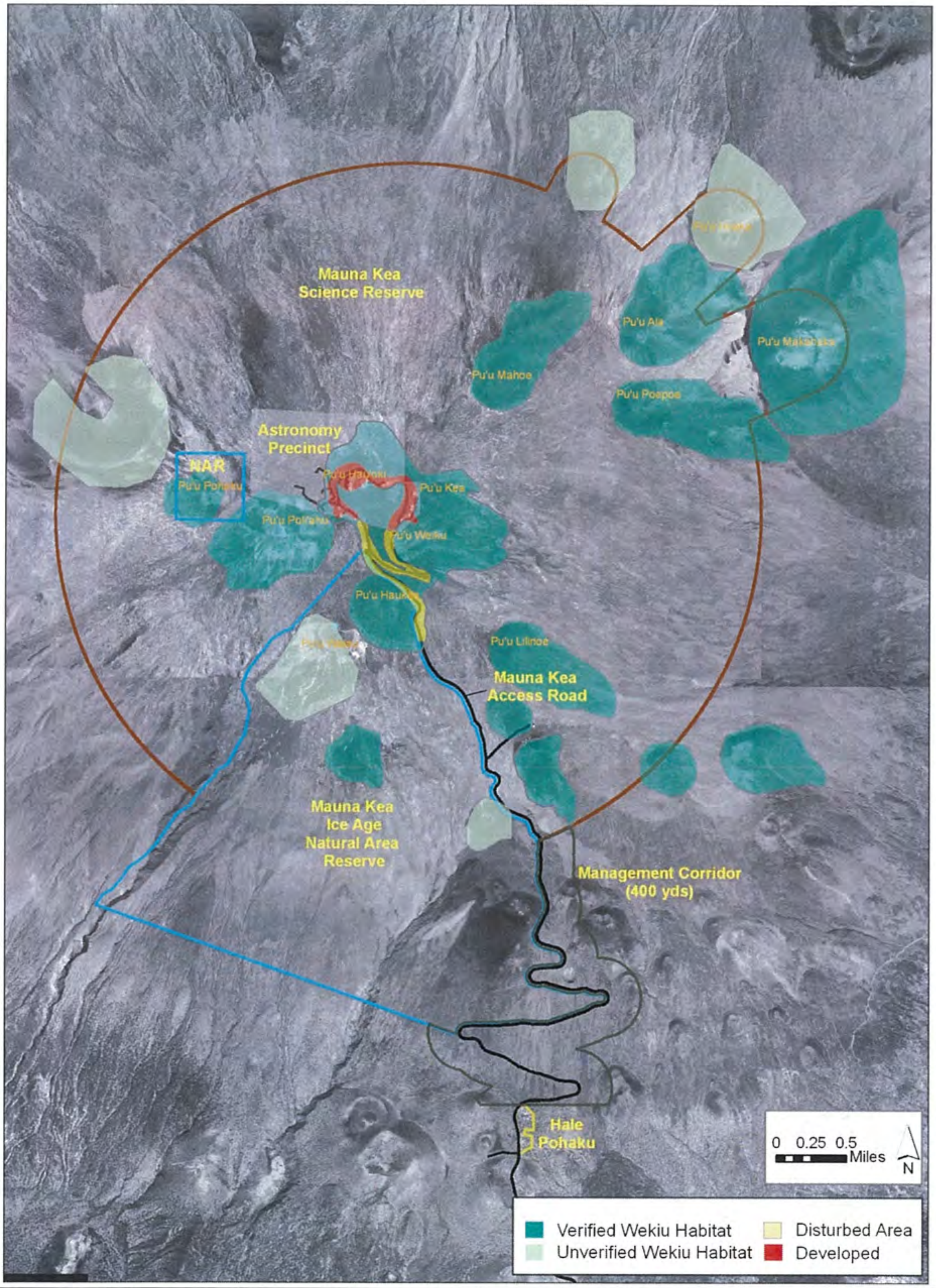


Figure 2.2-21: Photos of native bird species occurring in subalpine habitat on Mauna Kea

Palila (*Loxioides bailleui*)
Photo by Jack Jeffrey

'Apapane (*Himatione sanquinea*)
Photo by Jack Jeffrey

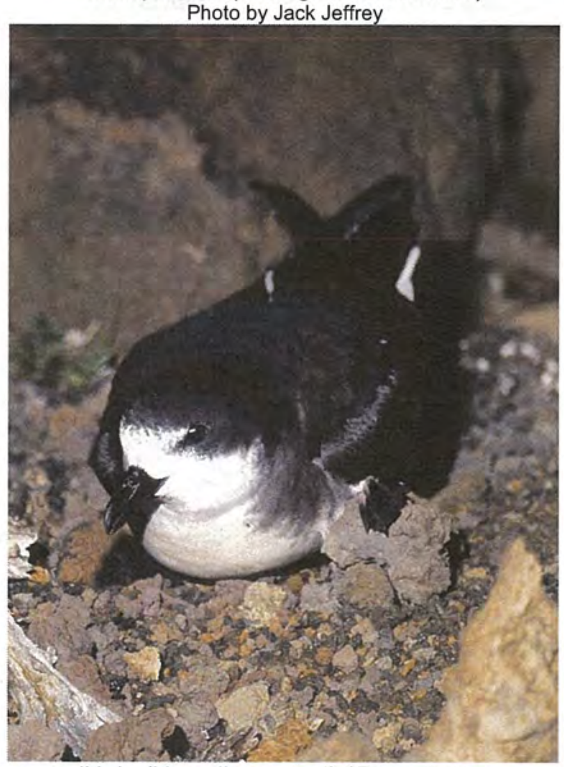
'Amakihi (*Hemignathus virens virens*)
Photo by Jack Jeffrey

Hawai'i 'Elepaio (*Chasiempis sandwichensis*)
Photo by Jack Jeffrey

'I'iwi (*Vestiaria coccinea*)
Photo by Jack Jeffrey

'Akiapola'au (*Hemignathus munroi*)
Photo by Jack Jeffrey

Pueo (*Asio flammeus sandwichensis*)
Photo by Jack Jeffrey



'Ua'u (Hawaiian petrel) (*Pterodroma sandwichensis*)
Photo by Jack Jeffrey

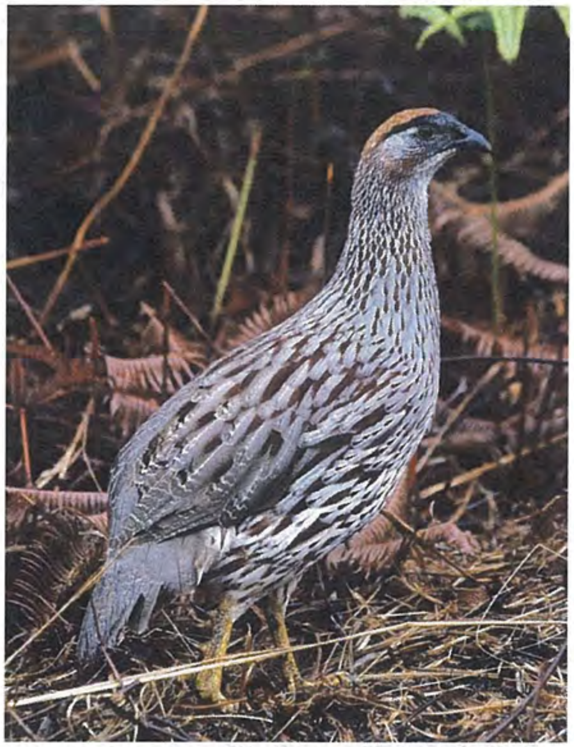
Kolea (Pacific golden plover) (*Pluvialis fulva*)
Photo by Jack Jeffrey

'Io (*Buteo solitarius*)
Photo by Jack Jeffrey

Nene (*Branta sandvicensis*)
Photo by Jack Jeffrey

Notes: All bird photos provided by Jack Jeffrey Photography (jackjeffreyphoto.com).

Figure 2.2-22: Photos of common non-native bird species occurring in subalpine habitat on Mauna Kea



Erckel's Francolin (*Francolinus erckelii*)
Photo by Jack Jeffrey

Chukar (*Alectoris chukar*)
Photo by Jack Jeffrey

California Quail (*Callipepla californica*)
Photo by Jack Jeffrey

Eurasian Skylarks (*Alauda arvensis*)
Photo by Jack Jeffrey

Japanese White-eyes (*Zosterops japonicus*)
Photo by Jack Jeffrey

Red-billed Leiothrix (*Leiothrix lutea*)
Photo by Jack Jeffrey

House Finches (*Carpodacus mexicanus*)
Photo by Jack Jeffrey

House Sparrows (*Passer domesticus*)
Photo by Jack Jeffrey

Notes: All bird photos provided by Jack Jeffrey Photography (jackjeffreyphoto.com).

Figure 2.2-23: Palila critical habitat

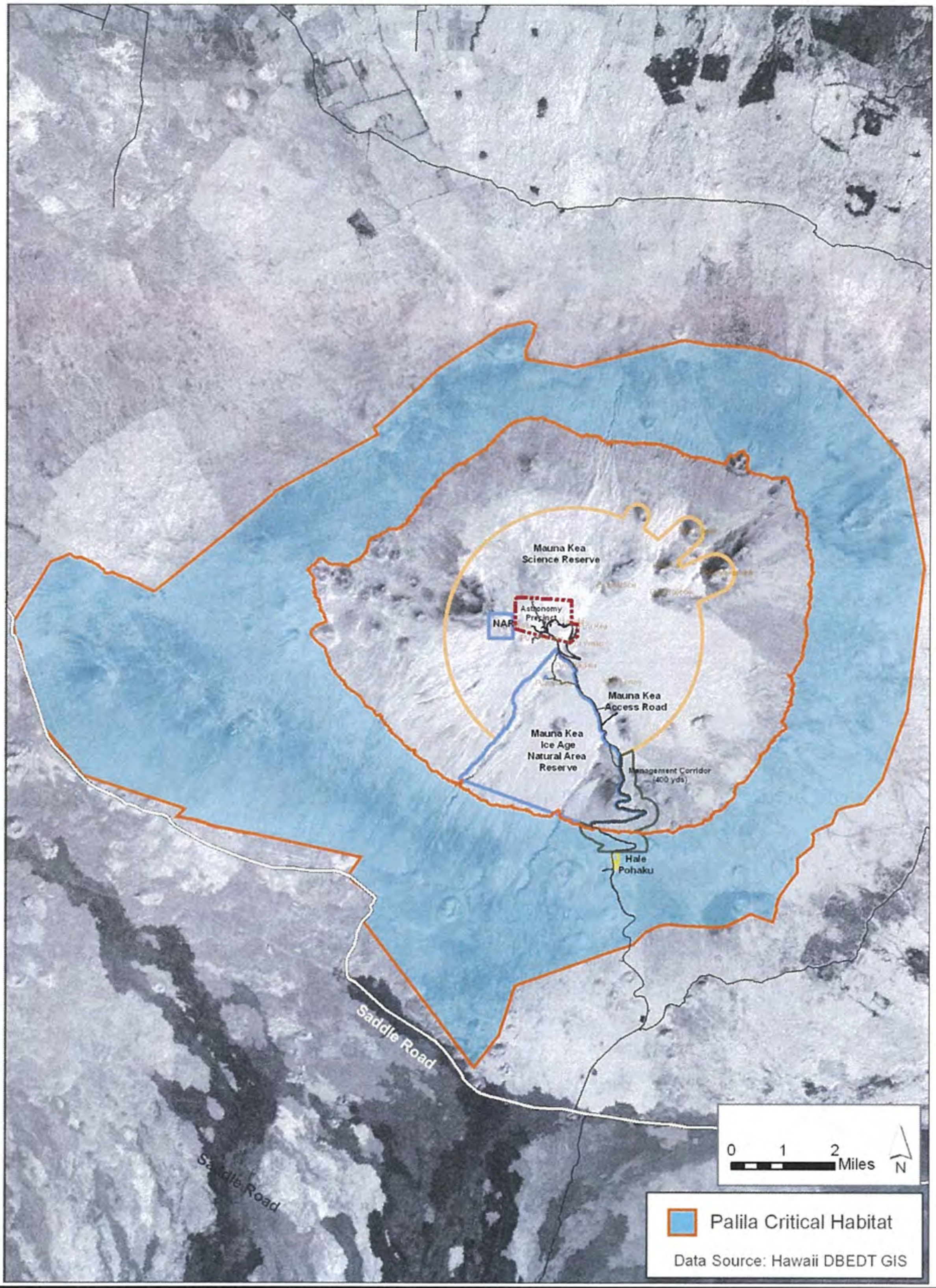
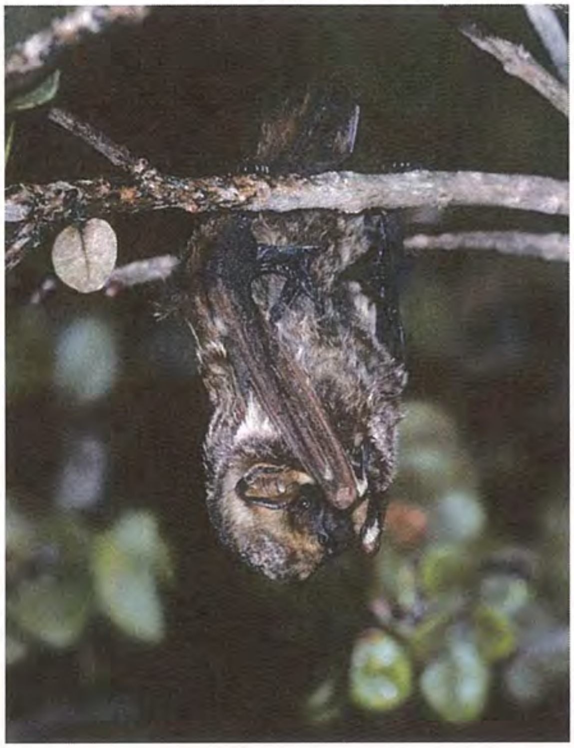


Figure 2.2-24: Photos of native and non-native mammal species



Hawaiian hoary bat (*Lasiurus cinereus semotus*)
Photo by Jack Jeffrey

Feral cats (*Felis catus*)
Photo http://commons.wikimedia.org/wiki/File:Feral_cat_1.JPG

Mongoose (*Herpestes auropunctatus*)
Photo by J.M. Garg

Goats (*Capra hircus*)
Photo courtesy of USDA

Rats (*Rattus norvegicus)*
Photo courtesy of National Institute of Health

Mice (*Mus musculus*)
Photo courtesy of Utah Division of Wildlife Resources

Mouflon sheep (*Ovis musimon*)
Photo by Jessica Dennett

Domesticated sheep (*Ovis aries*)
Photo courtesy of Copyrightfreephotos.com

Table 2.2-3. Vascular plant species found on Mauna Kea above 9,000 ft

Community	Elevation (m)	Scientific Name	Common name	Type	Origin[1]	Legal Status[2]	Location/ Abundance[3] MKSR	Rd	HP	Refs	Notes
		Ferns									
Subalpine & Alpine	1800-4205	*Asplenium adiantum-nigrum* L.	'iwa 'iwa, Bird's nest fern	Fern	I	--	U	√	√	1,2,3, 5,7,9, 10	
Subalpine	1800-2900	*Asplenium fragile* K. Presl var. *insulare* Morton	diamond spleenwort	Fern	E	FE, SE	--	H	H	3	*Asplenium rhomboideum* in ref 3
Subalpine	1800-2900	*Asplenium trichomanes* L.	'olali'i, 'owali'i	Fern	I	--	--	√	√	2,3,5, 7,10	
Subalpine & Alpine	1800-4205	*Cystopteris douglasii* Hooker	Douglas' bladderfern	Fern	E	SSOC	R	√	√	1,7,9	
Subalpine	1800-2900	*Dryopteris wallichiana* (Spreng.) Hyl.	alpine woodfern	Fern	I	--	--	H	H	3	*Dryopteris paleacea* in ref 3
Subalpine	1800-2900	*Pellaea ternifolia* (Cav.) Link	kalamoho, lau-kahi	Fern	I	--	--	√	√	2,3,5, 7,10, 11	
Subalpine	1800-2900	*Microlepia strigosa* (Thunb.) C. Presi	palai, palapalai	Fern	I	--	--	√	√	8	
		Monocots									
Subalpine	**1800-2900**	***Agrostis avenacea* J.G. Gmel.**	**he'upueo, Pacific bentgrass**	Grass	I	--	--	H	H	**3**	***Agrostis retrofracta* in ref. 3**
Subalpine & Alpine	**1800-4205**	***Agrostis sandwicensis* Hillebr.**	**Hawaii bentgrass**	Grass	E	--	C	√	√	**1,2,5, 7,9, 10**	
Subalpine	1800-2900	*Aloe vera*	aloe	Herb	X	--	--	√?	√	2,7,11	
Subalpine	1800-2900	*Anthoxanthum odoratum* L.	sweet vernalgrass	Grass	XX	--	H	√	√	2,3,6, 7,8,10 11,14	
Subalpine	1800-2900	*Bromus catharticus* Vahl	rescue grass	Grass	X			√	√	7	*Bromus willdenowii* in ref. 7.
Subalpine	1800-2900	*Bromus diandrus* Roth	ripgut grass	Grass	X	--	--	√	√	2,7,8, 10,11	*B. rigidus* in ref. 7, 8, 11 & 14, and *B. rigida* in ref 10.

Community	Elevation (m)	Scientific Name	Common name	Type	Origin[1]	Legal Status[2]	Location/ Abundance[3] MKSR	Rd	HP	Refs	Notes
Subalpine	**1800-2900**	***Carex macloviana* spp *subfusca* Dum. D'Urv**	**St. Malo's sedge**	**Sedge**	**I**	**--**	**--**	**√**	**√**	**2,7,10 14**	
Subalpine	**1800-2900**	***Carex wahuensis* C.A. Mey.**	**Oahu sedge**	**Sedge**	**E**	**--**	**--**	**√**	**√**	**7**	
Subalpine	1800-2900	*Dactylis glomerata* L.	cocksfoot, orchardgrass	Grass	XX	--	--	√	√	2,6,7, 14	
Subalpine	**1800-2900**	***Deschampsia nubigena* Hillebr.**	**alpine hairgrass**	**Grass**	**E**	**--**	**--**	**√**	**√**	**2, 6,7,8, 10,11, 14**	***Deschampsia australis* in refs 10 & 11**
Subalpine	**1800-2900**	***Eragrostis* sp.**	**lovegrass**	**Grass**	**E**	**--**	**--**	**√**	**√**	**7**	
Subalpine & Alpine Shrubland	1800-3800	*Holcus lanatus* L.	velvet grass	Grass	XX	--	--	√	√	2,6,7, 11	
Subalpine	1800-2900	*Iris* sp.	iris	Herb	X	--	--	?	√	2,7, 14	
Subalpine	1800-2900	*Koeleria macrantha* (Ledeb.) J.A. Schultes	prairie Junegrass	Grass	X	--	--	√	√	7,8	*Koeleria nitida* in ref. 7.
Subalpine	1800-2900	*Lolium* sp.	ryegrass	Grass	X	--	--	√?	√	2,7,11	
Subalpine & Alpine Shrubland	**1800-3800**	***Luzula hawaiiensis* Buchen.**	**Hawai'i wood rush**	**Rush**	**E**	**--**	**?**	**√**	**√**	**3,7,8**	
Subalpine	1800-2900	*Nassella cernua* Stebb. & A. Love	needlegrass	Grass	X	--	--	√	√	2,7,8, 10,11, 14	*Stipa cernua* in all refs.
Subalpine	**1800-2900**	***Panicum pellitum* Trin.**	**kāi'oi'o**	**Grass**	**E**	**--**	**--**	**√**	**√**	**7**	
Subalpine	1800-2900	*Pennisetum clandestinum* Hochst. ex Chiov.	kikiyu grass	Grass	XX	FNW	--	√	√	7	
Subalpine	1800-2900	*Pennisetum setaceum*	fountain grass	Grass	XX	SNW	--	√?	√?	7	Found at 9000 ft at Pohakuloa. May be spreading.
Subalpine & Alpine	1800-4205	*Poa annua* L.	annual bluegrass	Grass	X	--	H	H	H	3,7	
Subalpine & Alpine	1800-4205	*Poa pratensis* L.	Kentucky bluegrass	Grass	XX	--	H	√	√	2,3,6, 7,8,10 11,14	
Subalpine	1800-2900	*Rytidosperma pilosum* (R. Br.) Connor & Edgar	hairy oatgrass	Grass	X	--	--	√	√	2,7.14	*Danthonia pilosa* in ref 7,14

Community	Elevation (m)	Scientific Name	Common name	Type	Origin[1]	Legal Status[2]	Location/ Abundance[3] MKSR	Rd	HP	Refs	Notes
Subalpine	1800-2900	*Rytidosperma semiannulare* (Labill.) Connor & Edgar	wallaby grass	Grass	X	--	--	√	√	2,7,14	*Danthonia semiannularis* in ref 14.
Subalpine	**1800-2900**	***Sisyrinchium acre* H. Mann**	**mau'u lā'ili, mau'u hō'ula 'ili, Hawaii blue-eyed grass**	Grass	**E**	--	--	**H**	**H**	**3,5**	
Subalpine & Alpine	**1800-4205**	***Trisetum glomeratum* (Kunth) Trin.**	**pili uka, he'upueo, mountain pili**	Grass	**E**	--	**U**	√	√	**1,2,3, 5,7,8, 9, 10, 11, 14**	
Subalpine	1800-2900	*Vulpia bromoides* (L.) S.F. Gray	brome fescue	Grass	X	--	--	√	√	2,7,10 14	*Festuca dertonensis* in ref. 10.
Subalpine	1800-2900	*Vulpia myuros* (L.) C.C. Gmelin	rat tail fescue	Grass	X	--	--	√	√	2,7,10 14	*Festuca megalura* in ref. 10.
		Dicots									
Subalpine	1800-2900	*Achillea millefolium* L.	common yarrow, milfoil	Herb	X	--	--	√	√	2,7,8, 10	
Coastal to Subalpine	**0-1900**	***Argemone glauca* (Nutt. Ex Prain) Pope var. *decipiens* Ownbey**	**pua kala**	**Herb**	**E**	--	--	√	√	**7**	
Subalpine & Alpine Shrubland	**1800-3800**	***Argyroxiphium sandwicense* DC. ssp. *sandwicense***	**'āhinahina, Mauna Kea silversword**	**Shrub**	**E**	**FE, SE**	**H**	**H**	**H**	**3,5,7**	
Subalpine & Alpine	1800-4205	*Cerastium fontanum* Baumg. ssp. *vulgare* (Hartman) Greuter & Burdet	big chickweed	Herb	X	--	H	H	H	3	*Cerastium vulgatum* L. in ref. 3
Subalpine	**1800-2900**	***Chamaesyce olowaluana* (Sherff) Croizat & Deg.**	**'akoko**	**Tree**	**E**	**SSOC**	--	√	√	**7**	
Subalpine	1800-2900	*Chenopodium ambrosioides* L.	Mexican tea	Herb/ Shrub	X	--	--	√	√	8	
Subalpine	**1800-2900**	***Chenopodium oahuense* (Meyen) Aellen**	**'āheahea, 'āweoweo,**	**Shrub/ Tree**	**E**	--	--	√	√	**2,3,7, 8,10, 11, 14**	
Subalpine & Alpine	1800-4205	*Cirsium vulgare* (Savi) Ten.	bull thistle, pua kala	Herb	X	--	H	√	√	2,3,7, 10,11, 14	
Subalpine & Alpine	1800-4205	*Conyza bonariensis* (L.) Cronq.	hairy horseweed, ilioha	Herb	X	--	H	√	√	2,3,7, 11, 14	*Erigeron linifolius* Willd. In ref 3

Community	Elevation (m)	Scientific Name	Common name	Type	Origin[1]	Legal Status[2]	Location/ Abundance[3] MKSR	Rd	HP	Refs	Notes
Subalpine	1800-2900	*Conyza canadensis* (L.) Cronq.	Canadian horseweed	Herb	X	--	--	√	√	10	*Erigeron canadensis* L. in ref 10.
Subalpine	**1800-2900**	***Coprosma ernodeoides* A. Gray**	**'aiakanēnē, kūkaenēnē**	**Shrub**	**E**	**--**	**--**	**H**	**H**	**3,7**	
Subalpine	**1800-2900**	***Coprosma montana* Hillebr.**	**alpine mirror plant**	**Shrub/ Tree**	**E**	**--**	**--**	**H**	**H**	**5,7**	
Subalpine	1800-2900	*Cytisus palmensis* (Christ) Hutch.	tagasate, broom	Shrub	X	--	--	√	√	2,7,8, 11, 14	*Chamaecytisus palmensis* (Christ) Bisby & K. Nicholls [excluded] in USDA Plants website
Subalpine	**1800-2900**	***Dodonaea viscosa* Jacq.**	**'a'ali'i**	**Shrub/ Tree**	**I**	**--**	**--**	√	√	**7**	
Subalpine & Alpine Shrubland	**1800-3800**	***Dubautia arborea* (Gray) Keck**	**Mauna kea dubautia, na'ena'e**	**Shrub/ Tree**	**E**	**SSOC**	√	√	√	**4,5,7**	***Raillardia arborea* in ref 5.**
Subalpine & Alpine Shrubland	**1800-3800**	***Dubautia ciliolata* (DC) Keck subsp glutinosa**	**lava dubautia, na'ena'e**	**Shrub**	**E**	**--**	**H?**	√	√	**3,5,7**	**Listed as *Dubautia ciliolata* var *juniperoides* in ref. 3 and *Raillardia ciliolata* in ref 5.**
Subalpine	**1800-2900**	***Dubautia scabra* (DC) D. Keck**	**rough dubautia, na'ena'e**	**Shrub**	**E**	**--**	**--**	√	√	**7**	
Subalpine	**1800-2900**	***Dubautia struthioloides* (Gray) Keck**	**na'ena'e**	**Shrub**	**E**	**--**	**H**	**H**	**H**	**4**	**Currently thought to be a cross b/w *D. arborea* and *D. ciliolata***
Subalpine & Alpine Shrublands	1800-3800	*Epilobium billardierianum* ssp. *cinereum* (A. Rich.) Raven & Englhorn	willow herb	Herb	X	--	√	√	√	2,7,10 11, 14	*Epilobium cinereum* in ref. 10 & 11.
Subalpine	1800-2900	*Erodium cicutarium* (L.) L'Her ex Ait.	alfilaria, pin clover	Herb	X	--	--	√	√	2,7,10 11, 14	
Subalpine	1800-2900	*Eschscholzia californica* Cham.	California poppy	Herb	X	--	--	√	√	2,7,8, 10,11, 14	*Escholtzia californica* in ref 11.
Subalpine	1800-2900	*Eucalpytus saligna* Sm.	Sydney blue gum	Tree	X	--	--	√	√	7,8	
Subalpine	1800-2900	*Eucalyptus* spp.	eucalyptus, gum tree	Tree	X	--	--	√?	√	2,11, 14	

Community	Elevation (m)	Scientific Name	Common name	Type	Origin[1]	Legal Status[2]	Location/ Abundance[3] MKSR	Rd	HP	Refs	Notes
Subalpine	1800-2900	*Euchiton japonicus* (Thunb.) A. Anderb.	father-and-child plant	Herb	X	--	--	H	H	3	Listed as *Gnaphalium japonicaum* Thunb., in ref. 3
Subalpine	1800-2900	*Euchiton spaericus* (Wiild.) A.Anderb.	tropical creeping cudweed	Herb	X	--	--	√	√	7	
Subalpine and Alpine Shrubland	**1800-3070**	***Fragraria chiloensis***	**'ōhelo papa, strawberry**	**Herb**	**I**		**--**	**√**	**√**	**3**	
Subalpine	1800-2900	*Frangula californica* (Eschsch.) Gray ssp. *californica*	California buckthorn	Shrub/ Tree	X	--	--	√	√	8	*Rhamnus californica* Eschsch. In ref 8.
Subalpine & Alpine Shrubland	**1800-3800**	***Geranium cuneatum* spp. *hololeucum* (A. Gray) Carlq. & Bissing**	**nohoanu, hinahina**	**Shrub**	**E**	**--**	**H**	**√**	**√**	**2,3,7, 10,11**	
Subalpine	**1800-2900**	**Hesperocnide sandwicensis (Wedd.) Wedd.**	**Hawai'i stingingnettle**	**Herb**	**E**	**--**	**--**	**√**	**√**	**7**	
Subalpine	1800-2900	*Heteromeles arbutifolia* (Lindl.) M. Roemer	toyon	Tree	X	--	--	√	√	8	
Subalpine	1800-2900	*Heterotheca grandiflora* Nutt.	telegraph plant	Herb	X	--	--	√	√	2,7,8. 14	
Subalpine	1800-2900	*Hydrocotyle bowlesioides* Mathias & Constance	largeleaf marshpennywort	Herb	X	--	--	√	√	8	
Subalpine	1800-2900	*Hydrocotyle verticillata* Thunb.	whorled marshpennywort	Herb	X	--	--	√	√	8	
Subalpine & Alpine	1800-4205	*Hypochoeris radicata* L.	hairy cat's ear, gosmore	Herb	X	--	U	√	√	1, 2, 7, 9, 10, 11. 14	
Subalpine	1800-2900	*Ilex aquifolium* L.	English holly	Shrub/ Tree	X	--	--	√	√	8	
Subalpine	1800-2900	*Leontodon autumnalis* L.	fall dandelion	Herb	X	--	--	H	H	3	
Subalpine	1800-2900	*Lepidium africanum* (N.L. Burm.) DC	African pepperwort	Herb	X	--	--	√	√	2,7,8	
Subalpine	1800-2900	*Lepidium bonariense* L.	Argentine pepperweed	Herb	X	--	--	√	√	2, 7, 14	
Subalpine	1800-2900	*Lepidium hyssopifolium* Desv.	hyssopleaf pepperweed	Herb	X	--	--	√	√	14	

Community	Elevation (m)	Scientific Name	Common name	Type	Origin[1]	Legal Status[2]	Location/ Abundance[3] MKSR	Rd	HP	Refs	Notes
Subalpine	1800-2900	*Lepidium virginicum* L.	Virginia pepperweed	Herb	X	--	--	√	√	7, 10, 11	
Subalpine & Alpine Shrub Land	**1800-3800**	***Leptechophylla tameiameiae*** **(Chaam. & Schlechtend.) F.v. Muell.**	**pūkiawe**	**Shrub**	**I**	**--**	**√**	**√**	**√**	**2, 3, 7 10, 11, 14**	***Styphelia tameiameiae*** **in refs 2,3,10,11,&14**
Subalpine	1800-2900	*Ligustrum lucidum* Ait. f.	tree privet	Shrub/ Tree	X	--	--	√	√	8	
Subalpine	1800-2900	*Lupinus arboreus* Sims	yellow bush lupine	Shrub	X	--	--	√	√	8	
Subalpine	1800-2900	*Malva parviflora* L.	cheeseweed mallow	Herb	X	--	--	√	√	2,7,8, 10	
Subalpine	1800-2900	*Medicago sativa* L.	alfalfa, lucerne, 'alapapa	Herb	X	--	--	√	√	2,7,8. 14	
Subalpine	1800-2900	*Melilotus indica* (L.) All.	annual yellow sweetclover	Herb	X	--	--	√	√	2,7,8	
Subalpine	1800-2900	*Melilotus officinalis* (L.) Lam	white sweet clover	Herb	X	--	--	√	√	7,10	*Melilotus alba* Medik.
Subalpine	1800-2900	*Melilotus* sp.	sweetclover	Herb	X	--	--	√	√	2,10	
Subalpine	1800-2900	*Merrubium vulgare*	horehound	Herb/ Shrub	X	--	--	√	√	8	
Subalpine	**1800-2900**	***Metrosideros polymorpha***	**'ōhi'a, 'ōhi'a lehua**	**Tree**	**E**	**--**	**--**	**--**	**√**	**7,12**	
Subalpine	**1800-2900**	***Myoporum sandwicense*** **A. Gray**	**naio**	**Shrub/ Tree**	**I**	**--**	**--**	**√**	**√**	**3,7, 8**	
Subalpine	1800-2900	*Oenothera stricta* Ledeb. ex Link	Chilean evening primrose	Herb	X	--	--	√	√	7	
Subalpine	**1800-2900**	***Osteomeles anthyllidifolia*** **(Sm.) Lindl.**	**'ūlei**	**Shrub**	**I**	**--**	**--**	**√**	**√**	**7,8**	
Subalpine	1800-2900	*Pelargonium X hortorum* Bailey	zonal geranium	Herb/ Shrub	X	--	--	√	√	8	
Subalpine	**1800-2900**	***Phyllostegia racemosa*** **Benth. var racemosa**	**kiponapona**	**Vine**	**E**	**FE, SE**	**--**	**√**	**√**	**8**	
Subalpine	1800-2900	*Physocarpus* sp.	ninebark	Shrub	X	--	--	√	√	8	
Alpine Stone Desert	3900-4205	*Pinus contorta* Dougl. ex Loud.	lodgepole pine	Tree	X	--	H	--	--	3	
Subalpine	1800-2900	*Pinus radiata* D. Don	Monterey pine	Tree	X	--	--	√?	√	8	
Subalpine	1800-2900	*Pinus* sp.	pine	Tree	X	--	--	√?	√	2,7,11	
Subalpine	1800-2900	*Pisum sativum* L. var *macrocarpon* Seringe	garden pea	Vine	X	--	--	--	√	8	One plant seen

Community	Elevation (m)	Scientific Name	Common name	Type	Origin[1]	Legal Status[2]	MKSR	Location/ Abundance[3] Rd	HP	Refs	Notes
Subalpine	1800-2900	*Polycarpon tetraphyllum* (L.) L.	allseed, four leaf manyseed	Herb	X	--	--	√	√	2,7,8, 10	
Subalpine	**1800-2900**	***Pseudognaphalium sandwicensium* (Gaud.) A. Anderb.**	**'ena 'ena**	**Herb**	**E**	**--**	**--**	√	√	**2,3,7, 8,10, 11, 14**	**Listed as *Gnaphalium sandwicensium* Gaud in ref 3,10,11&14**
Subalpine	**1800-2900**	***Ranunculus hawaiensis* Gray**	**makou**	**Herb**	**E**	**FC, SC**	**--**	**H**	**H**	**3,5,7**	
Subalpine	**1800-2900**	***Rubus hawaiensis* A. Gray**	**'ākala**	**Shrub**	**E**	**--**	**--**	√	√	**8**	
Subalpine & Alpine	1800-4205	*Rumex acetosella* L.	sheep sorrel	Herb	X	--	H	√	√	2,3,7, 10,11, 14	
Subalpine	**1800-2900**	***Rumex giganteus* Ait.**	**pāwale**	**Shrub/ Liana**	**E**	**--**	**--**	√	√	**5,8**	
Subalpine	**1800-2900**	***Sanicula sandwicensis* A. Gray**	**Hawaii black snakeroot**	**Herb**	**E**	**SSOC**	**--**	√	√	**7,8**	
Subalpine	**1800-2900**	***Santalum ellipticum* Gaudich.**	**'iliahialo'e, coast sandalwood**	**Shrub/ Tree**	**E**	**--**	**--**	**?**	√	**8**	Usually grows lower elev.
Subalpine	**1800-2900**	***Santalum paniculatum* Hook. & Arnott**	**'iliahi**	**Shrub/ Tree**	**E**	**--**	**--**	√	√	**8**	
Subalpine	1800-2900	*Senecio madagascariensis* Poir.	fireweed	Herb	X	SNW	--	√	√	7	
Subalpine & Alpine Shrub Land	1800-3800	*Senecio sylvaticus* L.	woodland ragwort, woodland groundsel	Herb	X	--	?	H	H	3,7	
Subalpine	1800-2900	*Senecio vulgaris* L.	common groundsel	Herb	X	--	--	√	√	2,7,10 11, 14	
Subalpine	**1800-2900**	***Silene hawaiiensis* Sherff**	**Hawai'i catchfly**	**Shrub**	**E**	**FT, ST**	**--**	**?**	√	**10**	
Subalpine & Alpine	**1800-4205**	***Silene struthioloides* A. Gray**	**alpine catchfly**	**Shrub**	**E**	**--**	√	√	√	**2,3,5, 7**	
Subalpine	**1800-2900**	***Solanum americanum* Mill.**	**pōpolo, glossy night-shade**	**Herb**	**I?**	**--**	**--**	√	√	**2,7**	
Subalpine	1800-2900	*Solanum nigrum* L.	black nightshade	Herb	X	--	--	√	√	11	
Subalpine	1800-2900	*Sonchus oleraceus* L.	sowthistle, pualele	Herb	X	--	--	√	√	2,7,10 11, 14	
Subalpine	**1800-2900**	***Sophora chrysophylla* (Salisb.) Seem.**	**māmane, mamani**	**Tree**	**E**	**--**	**--**	√	√	**2,3,5, 7,8, 10, 11, 14**	

Community	Elevation (m)	Scientific Name	Common name	Type	Origin[1]	Legal Status[2]	Location/ Abundance[3] MKSR	Rd	HP	Refs	Notes
Alpine Stone Desert	3900-4205	*Stellaria media* (L.) Vill.	common chickweed	Herb	X	--	H	--	--	3,7	
Subalpine	**1800-2900**	***Stenogyne microphylla* Benth.**	**littleleaf stenogyne**	**Vine**	**E**	**--**	**--**	√	√	**2,7,10 11, 14**	
Subalpine	**1800-2900**	***Stenogyne rugosa* Benth.**	**mā'ohi'ohi**	**Vine**	**E**	**--**	**--**	√	√	**2,7,8, 10, 11, 14**	
Subalpine & Alpine	1800-4205	*Taraxacum officinale* Weber	common dandelion	Herb	X	--	U	H	H	1,3,9	
Subalpine & Alpine Shrublands	**1800-3800**	***Tetramolopium humile* (Gray) Hbd. ssp. *humile* var. *humile***	**alpine tetramolopium**	**Shrub**	**E**	**--**	**?**	**H**	**H**	**3,5,7**	***Tetramolopium humile* var *skottsbergii* in ref 3**
Subalpine	1800-2900	*Tragopogon porrifolius* L.	salsify, oyster plant	Herb	X	--	--	√	√	8	
Subalpine	1800-2900	*Trifolium arvense* L.	rabbit foot clover	Herb	X	--	--	√	√	2,7,14	
Subalpine & Alpine	**1800-4205**	***Vaccinium reticulatum* Sm.**	**'ōhelo, 'ōhelo 'ai**	**Shrub**	**E**	**--**	**H**	**H**	**H**	**3**	***V. peleanum* in ref. 3**
Subalpine	1800-2900	*Verbascum thapsus* L.	common mullein, woolly mullein,	Herb	X	SNW	--	√	√	2,7,10 11, 14	
Subalpine	1800-2900	*Verbascum virgatum* Stokes	virgate mullein, wand mullein	Herb	X	--	--	√	√	2,7,10 14	
Subalpine	**1800-2900**	***Vicia menziesii* Spreng.**	**Hawaiian vetch**	**Herb**	**E**	**FE, SE**	**--**	**H**	**H**	**5**	

Notes:

1. Origin: E = endemic, I = indigenous, X = introduced/alien, XX = highly invasive. Native species are also indicated with bold type.
2. Legal Status: FC = Federal Candidate for listing, FE = Federally Endangered, FT= Federally Threatened, SC = State Candidate for Listing, SE = State Endangered, SSOC = State Species of Concern, ST = State Threatened, NW = State Noxious Weed, FNW = Federal Noxious Weed
3. Location: MKSR = Mauna Kea Science Reserve (12,000+ ft), Road = Access Road, HP = Hale Pohau. Notes on Access road: If the plant species was recorded as present at both MKSR and HP then it is assumed to be found along access road. No botanical surveys have been specifically conducted on the Access Road. Abundance: A = abundant, C = common, H = Historical records only, L = Locally common, O = Occasional, P = Possibly present historically, R = Rare, S = Single plant found, U = Uncommon, √ = recorded as present but abundance not specified, √? = possibly present, ? = Unknown.

Section 2.2. Biotic Environment

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Table 2.2-4. Lichen species found on Mauna Kea

Community	Elevation (m)	Scientific Name	Form	Origin[1]	Location/Abundance[2] MKSR	Road	HP	Refs[3]
Alpine Stone Desert	3900-4205	*Acarospora depressa* Magn. apud Malme	Crustose	I	U	?	?	1,9
Alpine Stone Desert	3900-4205	*Acarospora pyrenuloides* Magn.	Crustose	E	R	?	?	1,9
Alpine Stone Desert	3900-4205	*Acarospora* sp.	Crustose	I?	S	?	?	1,9
Alpine Stone Desert	3900-4205	*Bacidia* sp.	Crustose	I?	S	?	?	1,9
Alpine Stone Desert	3900-4205	*Caloplaca lithophila* Magn.	Crustose	E	O	?	?	1,9
Alpine Stone Desert	3900-4205	*Candelariella insidiata* Magn.	Crustose	E	S	?	?	1,9
Alpine Stone Desert	3900-4205	*Candelariella vitellina* (Ehrh.) Muell. Arg.	Crustose	I	A	?	?	1,9
Alpine Stone Desert	3900-4205	*Lecanora muralis* (Schreb.) Rabh.	Crustose	I	A	?	?	1,9
Alpine Stone Desert	3900-4205	*Lecidea skottsbergii* Magn.	Crustose	E	C	?	?	1,9
Alpine Stone Desert	3900-4205	*Lecidea vulcanica* Zahlbr.	Crustose	E	U	?	?	1,9
Alpine Stone Desert	3900-4205	*Lepraria* sp. (white)	Crustose	I?	C	?	?	1,9
Alpine Stone Desert	3900-4205	*Lepraria* sp. (green)	Crustose	I?	C	?	?	1,9
Alpine Stone Desert	3900-4205	*Physcia dubia* (Hoffm.) Lett.	Foliose	I	C	?	?	1,9
Alpine Stone Desert	3900-4205	*Placopsis* sp.	Crustose	I	S	?	?	1,9
Alpine Stone Desert	3900-4205	*Pseudephebe pubescens* (L.) Choisn.	Fruticose	I	L	?	?	1,9
Alpine Stone Desert	3900-4205	*Rhizocarpon geographicum* var *hawaiiensis* Raes.	Crustose	E	L	?	?	1,9
Alpine Stone Desert	3900-4205	*Rinodina* cf. *cacuminum* (Th.fr.) Malme	Crustose	I	S	?	?	1,9
Alpine Stone Desert	3900-4205	*Rinodina interrupta* Magn.	Crustose	E	S	?	?	1,9
Alpine Stone Desert	3900-4205	*Umbilicaria hawaiiensis* Magn.	Foliose	E	C	?	?	1,9
Alpine Stone Desert	3900-4205	*Umbilicaria magnussonii* Llano	Foliose	E	C	?	?	1,9
Alpine Stone Desert	3900-4205	*Umbilicaria pacifica* Magn.	Foliose	E	U	?	?	1,9

Notes:

1. Origin: E = endemic, I = indigenous, X = introduced/alien, XX = highly invasive.
2. Location: MKSR = Mauna Kea Science Reserve (12,000+ ft), Road = Access Road, HP = Hale Pohau. Abundance: A = abundant, C = common, H = Historical records only, L = Locally common, O = Occasional, P = Possibly present historically, R = Rare, S = Single plant found, U = Uncommon, √ = Recorded as present but abundance not specified, √? = Possibly present, ? = Unknown.
3. List of references provided with Table 2.2-3.

Table 2.2-5. Moss species found on Mauna Kea

Community	Elevation (m)	Scientific Name[1]	Origin[2]	Location/Abundance[3] MKSR	Road	HP	Refs[4]	Notes
Alpine Stone Desert	3900-4205	*Amphidium tortuosum* (Hornsch.) Robins.	I	O	H	H	1,3,9	
Alpine Stone Desert	3900-4205	*Andreaea acutifolia* Hook.f. & Wils.	I	O	?	?	1,9	
Alpine Stone Desert	3900-4205	*Bryum caespiticum* Hedw.	I	U	?	?	1,9	
Alpine Stone Desert	3900-4205	*Bryum hawaiicum* Hoe	E	U	?	?	1,9	
Subalpine	1800-2900	*Ceratodon purpureus* (Hedw.) Brid. ssp. *purpureus*	I	?	H	H	3	*Ceratodon purpureus* in ref 3.
Alpine Stone Desert	3900-4205	*Grimmia apocarpa* var. *pulvinata* (Hedw.) Jones	I	O	?	?	1,9	
Alpine Stone Desert	3900-4205	*Grimmia* cf. *pilifera* P. Beauv.	I	U	?	?	1,9	
Alpine Stone Desert	3900-4205	*Grimmia* sp.	I?	O	?	?	1,9	
Subalpine	1800-2900	*Grimmia trichophylla* Grev.	E	?	H	H	3	
Subalpine	1800-2900	*Orthotrichum diaphanum* Brid.	I	--	?	√	13	
Subalpine	1800-2900	*Philonotis turneriana* (Schwaegr.) Mitt.	I	?	√	√	7,8	
Alpine Stone Desert	3900-4205	*Pohlia* cf. *mauiensis* (Broth. ex Bartr.) Schultze-Motel	E	U	?	?	1,9	
Alpine Stone Desert	3900-4205	*Pohlia cruda* (Hedw.) Lindb.	I	C	?	?	1,9	
Alpine Stone Desert	3900-4205	*Racomitrium lanuginosum* (Hedw.) Brid. var. *pruinosum* Wilson	I	?	H	H	3	*Rhacomitrium lanuginosum var. pruinosum* in ref. 3
Alpine Stone Desert	3900-4205	*Rosulabryum capillare* (Hedw.) J.R.Spence	I	H			3	*Bryum capillare* in ref 3
Subalpine	1800-2900	*Schizymenium nealiae* (E.B.Bartram) A.J.Shaw	E	?	H	H	3	*Mielichhoferia nealiae* in ref. 3
Subalpine & Alpine	1800-4205	*Schizymenium pulvinatum* (Müll.Hal.) A.J.Shaw	E	H	H	H	3	*Mielichhoferia pulvinata* in ref 3
Alpine Stone Desert	3900-4205	*Tortella humilis* (Hedw.) Jenn.	I	U	?	?	1,9	
Alpine Stone Desert	3900-4205	*Zygodon tetragonostomus* A. Br.	I	U	?	?	1,9	

Notes:

1. Moss scientific names from Hartt & Neal have been updated according to Staples et al 2004.
2. Origin: E = endemic, I = indigenous, X = introduced/alien, XX = highly invasive. Native species are also indicated with bold type.
3. Location: MKSR = Mauna Kea Science Reserve (12,000+ ft), Road = Access Road, HP = Hale Pohau. Notes on Access road: If the plant species was recorded as present at both MKSR and HP then it is assumed to be found along access road. No botanical surveys have been specifically conducted on the Access Road. Abundance: A = abundant, C = common, H = Historical records only, L = Locally common, O = Occasional, P = Possibly present historically, R = Rare, S = Single plant found, U = Uncommon, √ = recorded as present but abundance not specified, √? = possibly present, ? = Unknown.
4. List of references provided in notes from Table 2.2-3.

Table 2.2-6. Invertebrates found at Hale Pōhaku and MKSR

Community	Elevation (m)	Scientific Name	Common name	Type	Origin[1]	Legal Status[2]	Location[3] MKSR	HP	Refs.	Notes
Arthropods										
Subalpine Dry Forest	1800-2900	*Psocidae* - Unknown species		Barklouse	X?			√	18	
Subalpine Dry Forest	1800-2900	*Hylaeus flavipes*	Yellow-faced bee	Bee	N	FSOC, HSOC		√	1	Native bee that may pollinate silverswords
Subalpine Dry Forest	1800-2900	*Plagithmysus blackburni*	Hawaiian mamane long horned beetle	Beetle	N			√	1	
Subalpine Dry Forest	1800-2900	*Plagithmysus montgomeryi*	Hawaiian long-horned beetle	Beetle	E			√	1	
Subalpine Dry Forest	1800-2900	*Amphiareus constrictus*	Minute Pirate Bug	Bug	X			√	12	Associated with mamane trees
Subalpine Dry Forest	1800-2900	*Buchananiella continua*	Minute Pirate Bug	Bug	X			√	12	Associated with mamane trees
Subalpine Dry Forest	1800-2900	*Coleotichus blackburniae*	Koa bug	Bug	N	FSOC	A	√	1	Found on Acacia koa and Dodonaea viscosa
Subalpine Dry Forest	1800-2900	*Nabis kahavalu*	Damsel Bug	Bug	E			√	5	
Subalpine Dry Forest	1800-2900	*Neseis nitida comitans*	Seed Bug	Bug	?			√	1	
Subalpine Dry Forest	1800-2900	*Nesius (Icteronysius) ochriasis*	Seed Bug	Bug	N			√	5	
Subalpine Dry Forest	1800-2900	*Nysius terrestris*	Seed Bug	Bug	N			√	6	Found on Chamaesyce olowaluana & Chenopodium oahuense
Subalpine Dry Forest	1800-2900	*Orius tristicolor*	Minute Pirate Bug	Bug	X			√	12	Associated with mamane trees
Subalpine Dry Forest	1800-2900	*Orthotylus sophorae*	Plant Bug	Bug	E			√	5	

Community	Elevation (m)	Scientific Name	Common name	Type	Origin[1]	Legal Status[2]	Location[3] MKSR	HP	Refs.	Notes
Arthropods										
Subalpine Dry Forest	1800-2900	*Pseudococcus nudus*	Mealybug	Bug	E			?	4	Honeydew producer that may support yellow jackets
Subalpine Dry Forest	1800-2900	*Forficula forficularia*	European earwig	Earwig	X			√	18	
Subalpine Dry Forest	1800-2900	*Vanessa tameamea*	Kamehameha Butterflly	Butterfly	E			√	11	
Subalpine Dry Forest	1800-2900	*Calliphora vomitoria*	Blue bottle fly	Fly	X			√	1	
Subalpine Dry Forest	1800-2900	*Lonchoptera furcata*	Spearwinged fly	Fly	X		A	√	1,8	
Subalpine Dry Forest	1800-2900	*Phormia regina*	Black blowfly	Fly	X			√	1	
Subalpine Dry Forest	1800-2900	*Sepsis biflexuosa*	Black scavenger fly	Fly	X			√	1	
Subalpine Dry Forest	1800-2900	*Chaetogaedia moticola*	Tachinid fly	Fly, Parasitic	X			√	1, 3	Parasitize Scotorythra & Paridroma moth larvae. Introduced as biocontrol agent.
Subalpine Dry Forest	1800-2900	*Gonia longipulvilli*	Tachinid fly	Fly, Parasitic	X			√	1	Cutworm parasite
Subalpine Dry Forest	1800-2900	Tephritidae – Unknown species	Tephritid fly	Fly	X?			√	18	
Subalpine Dry Forest	1800-2900	*Micromus usingeri*	Flightless brown lacewing	Lacewing	E	FSOC		√	19	Collected on *Dubautia arborea* plants on Mauna Kea.
Subalpine Dry Forest	1800-2900	*Agrotis melanoneura*	Black-Veined Agrotis Noctuid Moth	Moth	N	FSOC, HSOC		√	1	Observed at Hale Pōhaku
Subalpine Dry Forest	1800-2900	*Cydia crassicornis*	Cydia moth	Moth	N			√	1	Larva feed on mamane
Subalpine Dry Forest	1800-2900	*Cydia falsifalcella*	Cydia moth	Moth	N			√	1	Larva feed on mamane
Subalpine Dry Forest	1800-2900	*Cydia latifemoris*	Cydia moth	Moth	N			√	1	Larva feed on mamane

Community	Elevation (m)	Scientific Name	Common name	Type	Origin[1]	Legal Status[2]	Location[3] MKSR	HP	Refs.	Notes
Arthropods										
Subalpine Dry Forest	1800-2900	*Cydia obliqua*	Cydia moth	Moth	N			√	1	Larva feed on mamane
Subalpine Dry Forest	1800-2900	*Cydia storeella*	Cydia moth	Moth	N			√	1	Larva feed on mamane
Subalpine Dry Forest	1800-2900	*Lantanophaga pusilidactyla*	Plume moth	Moth	X			√	18	Biocontrol agent for Lantana
Subalpine Dry Forest	1800-2900	*Mestolobes* species	Crambinid moth	Moth	E			√	13	
Subalpine Dry Forest	1800-2900	*Peridroma albiorbis*	Noctuid moth	Moth	N			√	1, 3	Larva feed on mamane
Subalpine Dry Forest	1800-2900	*Scotorythra sp*	Looper moth	Moth	N			√	1, 3	Larva feed on mamane
Subalpine Dry Forest	1800-2900	*Thyrocopa adumbrata*	Thyrocopid moth	Moth	E			√	13	
Subalpine Dry Forest	1800-2900	*Thyrocopa indecora*	Thyrocopid moth	Moth	E			√	13	
Subalpine Dry Forest	1800-2900	*Thyrocopa* new species	Thyrocopid moth	Moth	E			√	13	Appears to be endemic to Mauna Kea.
Subalpine Dry Forest	1800-2900	*Uresephita polygonalis virescens*		Moth	N			√	3	Rare. Larva feed on mamane
Subalpine Dry Forest	1800-2900	*Lycosa sp.*	Lycosid Spider	Spider	N			√	1	
Subalpine Dry Forest	1800-2900	*Urozeletes rusticus*		Spider	A			√	18	
Subalpine Dry Forest	1800-2900	*Ectemnius sp.*	Solitary wasp	Wasp	E			√	18	
Subalpine Dry Forest	1800-2900	*Polistes dominus*	European paper wasp	Wasp	X			√		
Subalpine Dry Forest	1800-2900	*Polistes olivacius*	Red-brown paper wasp	Wasp	X			√	18	
Subalpine Dry Forest	1800-2900	*Vespula pensylvanica*	Western yellow jacket	Wasp	X		A	√	1, 3,8	
Subalpine Dry Forest	1800-2900	*Anagyrus sp*	Mealybug parasite wasp	Wasp, parasitic	X			√	1	Biocontrol agent
Subalpine Dry Forest	1800-2900	*Brachyserphus hawaiiensis*	Serphid wasp	Wasp, parasitic	N			√	1	

Community	Elevation (m)	Scientific Name	Common name	Type	Origin[1]	Legal Status[2]	Location[3] MKSR	HP	Refs.	Notes
Arthropods										
Subalpine Dry Forest	1800-2900	*Brasema cushmani*	Pepper weevil parasitic wasp	Wasp, parasitic	X			√	1	Biocontrol agent
Subalpine Dry Forest	1800-2900	*Calliephialtes grapholithae*	Ichneumonid wasp	Wasp, parasitic	X			√	1,2	Parasitize Cydia moth larvae
Subalpine Dry Forest	1800-2900	*Chelonus blackburni*	Braconid wasp	Wasp, parasitic	?			√	1	
Subalpine Dry Forest	1800-2900	*Diadegma blackburni*	Ichneumonid wasp	Wasp, parasitic	X		A	√	1, 2, 3, 8	Parasitize Cydia, Scotorythra & Peridroma moth larvae
Subalpine Dry Forest	1800-2900	*Diplazon laetatorius*	Hover Fly Larvae Parasite Wasps	Wasp, parasitic	X			√	1	
Subalpine Dry Forest	1800-2900	*Echthromorpha agrestoria f uscator*	Ichneumonid wasp	Wasp, parasitic	N			√	1	
Subalpine Dry Forest	1800-2900	*Euderus metallicus*	Eulophid wasp	Wasp, parasitic	N			√	1, 2	Parasitize Cydia moth larvae
Subalpine Dry Forest	1800-2900	*Hyposoter exiguae*	Ichneumonid wasp	Wasp, parasitic	X			√	1, 3	Parasitize Scotorythra & Peridroma moth larvae
Subalpine Dry Forest	1800-2900	*Meteorus laphygmae*	Ichneumonid wasp	Wasp, parasitic	X			√	1, 3	Parasitize Scotorythra moth larvae. Introduced as biocontrol agent.
Subalpine Dry Forest	1800-2900	*Ontsira palliatus*	Braconid wasp	Wasp, parasitic	?			√	1	
Subalpine Dry Forest	1800-2900	*Pristomerus hawaiiensis*	Ichneumonid wasp	Wasp, parasitic	X			√	1, 2	Parasitize Cydia moth larvae
Subalpine Dry Forest	1800-2900	*Sierola sp*	Bethyline wasp	Wasp, parasitic	N?			√	1	
Subalpine and Alpine	1800-2900	*Apis millifera*	European honeybee	Bee	X		A	√	18	
Subalpine and Alpine	3900-4205	*Laemostenus complanatus*	Carabid beetle	Beetle	X		A	√	18	
Subalpine and Alpine	3900-4205	Aphidae – Unknown species	Aphid	Bug	X		A	√	18	

Community	Elevation (m)	Scientific Name	Common name	Type	Origin[1]	Legal Status[2]	Location[3] MKSR	HP	Refs.	Notes
Arthropods										
Subalpine and Alpine	3900-4205	*Cicadellidae: Undetermined species*	Leafhopper	Bug	X?		A	√	18	
Subalpine and Alpine	1800-3400	*Nysius coenosulus*	Seed Bug	Bug	N		R?	√	6	Found on Chamaesyce olowaluana, Chenopodium oahuense, uncommon on Geranium cuneatum
Subalpine and Alpine	1800-4205	*Nysius palor*	Seed Bug	Bug	N		A	√	6	Common on rocks and cinders, Gnaphalium sandwicensium, Sophora chrysophylla, Dubautia ciliolata, Geranium cuneatum, Hypochaeris radicata
Subalpine and Alpine	3900-4205	Psyllidae: Undetermined sp	Psyllid/jumping plant louse	Bug	?		A	√	1,8, 18	
Subalpine and Alpine	3900-4205	*Agromyzidae – Unknown species*	Leaf miner fly	Fly	X		A	√	18	
Subalpine and Alpine	3900-4205	*Atherigona orientalis*	Pepper fruit fly	Fly	X		A	√	1,8, 18	Spelled *Atherogona orientalis* in Ref. 18
Subalpine and Alpine	3900-4205	*Pollenia rudis*	Cluster Fly	Fly	X		A	√	9	
Subalpine and Alpine	3900-4205	*Sepsis thoracica*	Small Dung Flly	Fly	X		A	√	1,8, 18	
Subalpine and Alpine	1800-3400	*Trupanea arboreae*	Tephritid fly	Fly	N		R	√	1,14	Associated with dubautia and other members of silversword alliance.

Community	Elevation (m)	Scientific Name	Common name	Type	Origin[1]	Legal Status[2]	Location[3] MKSR	HP	Refs.	Notes
Arthropods										
Subalpine and Alpine	3900-4205	Thripidae – several species	Thrips	Thrips	E?		A	√	18	
Subalpine and Alpine	1800-2900	*Sphecidae unknown species*	Digger wasp	Wasp	X?		A	√	18	
Alpine Shrubland	3000-3100	*Nysius kinbergi*	Seed Bug	Bug	N		A		6	Found on Gnaphalium sandwicensium
Alpine Shrubland	3000-3100	*Nysius lichenicola*	Seed Bug	Bug	N		A		6	Found on Dubautia ciliolata
Alpine Shrubland and Alpine Stone Desert	3400-4205	*Geocoris pallens*	Big eyed bug	Bug	X		R		1,6,7, 8	Uncommon on Hypocaeris radicata, uncommon on rocks and cinders
Alpine Stone Desert	3900-4205	*Ectopsocus sp*	Bark louse	Bark lice	E		A		1,8	
Alpine Stone Desert	3900-4205	*Liposcelis divinatorius*	Book louse	Bark lice	X		R?		1,8	
Alpine Stone Desert	3900-4205	*Palistreptus inconstans*	Bark louse	Bark lice	E		R?		1,8	
Alpine Stone Desert	3900-4205	*Hylaeus difficilis*	Yellow-faced bee	Bee	N	HSOC	A		1	
Alpine Stone Desert	3900-4205	*Hylaeus pele*	Yellow-faced bee	Bee	N		A		1	
Alpine Stone Desert	3900-4205	*Megachile timberlakei*	Leaf-cutting bee	Bee	X?		A		18	
Alpine Stone Desert	3900-4205	*Aleochara verna*	Rove beetle	Beetle	X		R?		10, 17	New state record. Found at Pu'u Pohaku, Ice Age NAR
Alpine Stone Desert	3900-4205	*Altica torquata*	Grapevine flea beetle	Beetle	X		A		1,8	
Alpine Stone Desert	3900-4205	*Agonum* cf. *muelleri*	Carabid beetle	Beetle	X		R		18	New state record for 2008; only found at Lake Waiau
Alpine Stone Desert	3900-4205	*Coccinella septempunctata*	Ladybird Beetle	Beetle	X		A		1,8, 18	Found at Lake Waiau

Community	Elevation (m)	Scientific Name	Common name	Type	Origin[1]	Legal Status[2]	Location[3] MKSR	HP	Refs.	Notes
Arthropods										
Alpine Stone Desert	3900-4205	*Creophilus maxillosus*	Hairy rove beetle	Beetle	X		R?		10, 17	Found at Pu'u Pohaku, Ice Age NAR
Alpine Stone Desert	3900-4205	Curculionidae: 1 undetermined sp	Weevil	Beetle	X		A		1,8	
Alpine Stone Desert	3900-4205	*Dermestes frischii*	Hide beetle	Beetle	X		R?		10, 17	Found at Pu'u Pohaku, Ice Age NAR
Alpine Stone Desert	3900-4205	*Dermestes maculatus*	Hide beetle	Beetle	I		R?		7	
Alpine Stone Desert	3900-4205	*Harmonia conformis*	Ladybird Beetle	Beetle	X		A		1,8	
Alpine Stone Desert	3900-4205	*Hippodamia convergens*	Ladybird Beetle	Beetle	X		R?		1,8, 10,17	Found at Pu'u Pohaku, Ice Age NAR
Alpine Stone Desert	3900-4205	Hydrophilidae: 1 undetermined sp	Water scavenger beetle	Beetle	?		R?		8	Lake Waiau
Alpine Stone Desert	3900-4205	*Necrobia rufipes*	Red legged ham beetle	Beetle	X		A		1, 8, 10, 17	
Alpine Stone Desert	3900-4205	*Onthophagus nigriventris*	Dung beetle	Beetle	X		R?		10	Found at Pu'u Pohaku, Ice Age NAR
Alpine Stone Desert	3900-4205	*Rhantus pacificus*	Diving water beetle	Beetle	E		R?		1	Lake Waiau
Alpine Stone Desert	3900-4205	Scarabidae: 1 undetermined sp	Scarab beetle	Beetle	X		A		1,8	
Alpine Stone Desert	3900-4205	*Sphaeridium scarabaeoides*	Dung beetle	Beetle	X		R?		10	Found at Pu'u Pohaku, Ice Age NAR
Alpine Stone Desert	3900-4205	Staphylinidae: 1 undetermined sp	Rove beetle	Beetle	?		R?		1,7,8	
Alpine Stone Desert	3900-4205	*Tachyporus nitidulus*	Rove beetle	Beetle	X		R?		10, 17	Found at Pu'u Pohaku, Ice Age NAR
Alpine Stone Desert	3900-4205	*Aphis sp*	Aphid	Bug	X		A		1,8	

Community	Elevation (m)	Scientific Name	Common name	Type	Origin[1]	Legal Status[2]	Location[3] MKSR	HP	Refs.	Notes
Arthropods										
Alpine Stone Desert	3900-4205	Delphacidae: 1 undetermined sp	Planthopper	Bug	X		A		1,8	
Alpine Stone Desert	3900-4205	*Lasiochilus sp*	Minute pirate bug	Bug	X		A		1,8	
Alpine Stone Desert	3900-4205	*Nabis capsiformis*	Pale damsel bug	Bug	X		A		1,8	
Alpine Stone Desert	3900-4205	*Neacoryphus bicrucis*	Whitecrossed seed bug	Bug	X		A		1,8	
Alpine Stone Desert	3900-4205	*Nysius sp*	Seed Bug	Bug	N		A		1,8	
Alpine Stone Desert	3900-4205	*Nysius wekiucola*	Wēkiu bug	Bug	E	FC	R		1,7,8	
Alpine Stone Desert	3900-4205	*Psylla uncatoides*	Acacia psyllid/jumping plant louse	Bug	X		A		1	
Alpine Stone Desert	3900-4205	*Lithobius sp.*	Centipede	Centipede	E		R		1,7	
Alpine Stone Desert	3900-4205	*Allograpta sp*	Flower fly	Fly	X		A		1,8	
Alpine Stone Desert	3900-4205	*Calliphora vomitoria*	Blue bottle fly	Fly	X		R?		1,8	
Alpine Stone Desert	3900-4205	Calliphoridae: >3 undetermined sp	Blow fly	Fly	?		A		1,8	
Alpine Stone Desert	3900-4205	*Copromyza equina*	Small Dung Flly	Fly	X		A		1,8	
Alpine Stone Desert	3900-4205	*Drosophila sp*	Fruit fly	Fly	X		A		1,8	
Alpine Stone Desert	3900-4205	*Drosophila suzukii complex*	Fruit fly	Fly	X		A		1,8	
Alpine Stone Desert	3900-4205	*Eristalis tenax*	European hover fly	Fly	X		A		18	
Alpine Stone Desert	3900-4205	*Haematobia irritans*	Horn fly	Fly	X		A		1,8	
Alpine Stone Desert	3900-4205	*Hydrellia sp*	Leaf mining fly	Fly	N		A		1,8	
Alpine Stone Desert	3900-4205	*Hydrellia tritici*	Lawn fly	Fly	X		A		1,8	

Community	Elevation (m)	Scientific Name	Common name	Type	Origin[1]	Legal Status[2]	Location[3] MKSR	HP	Refs.	Notes
Arthropods										
Alpine Stone Desert	3900-4205	*Leptocera sp*	Small Dung Fly	Fly	?		A		1,8	
Alpine Stone Desert	3900-4205	*Lucilia cuprina*	Australian sheep blowfly	Fly	X		A		1,8	
Alpine Stone Desert	3900-4205	Muscoidea: 1 undetermined sp	House fly	Fly	?		A		1,8	
Alpine Stone Desert	3900-4205	Phoridae: >1 undetermined sp	Scuttle fly	Fly	?		R?		1,8	
Alpine Stone Desert	3900-4205	*Psychoda sp*	Moth flly	Fly	?		R?		1,8	
Alpine Stone Desert	3900-4205	Sarcophagidae: >1 undetermined sp	Flesh flly	Fly	X		A		1,8	
Alpine Stone Desert	3900-4205	*Sepsis sp1*	Small Dung Flly	Fly	X		A		1,8	
Alpine Stone Desert	3900-4205	*Sepsis sp2*	Small Dung Flly	Fly	X		A		1,8	
Alpine Stone Desert	3900-4205	Sphaeroceridae: >1 undetermined sp	Small Dung Flly	Fly	?		A		1,8	
Alpine Stone Desert	3900-4205	*Stomoxys calcitrans*	Stable fly	Fly	X		A		1,8	
Alpine Stone Desert	3900-4205	*Bradysia sp1*	Fungus gnat	Fly, Gnat	?		A		1,8	
Alpine Stone Desert	3900-4205	*Bradysia sp2*	Fungus gnat	Fly, Gnat	?		A		1,8	
Alpine Stone Desert	3900-4205	*Leia sp*	Fungus gnat	Fly, Gnat	X		A		1,8	
Alpine Stone Desert	3900-4205	*Sciara sp*	Fungus gnat	Fly, Gnat	?		R?		1,8	
Alpine Stone Desert	3900-4205	Chironomidae: 1 undetermined sp	Non-biting midge	Fly, Midge	?		A		1,8	
Alpine Stone Desert	3900-4205	*Forcipomyia sp*	Biting Midge	Fly, Midge	E		A		1,8	
Alpine Stone Desert	3900-4205	*Gonia pallens*	Tachinid fly	Fly, parasitic	X		A		1,8	
Alpine Stone Desert	3900-4205	*Phasioormia pallida*	Tachinid fly	Fly, parasitic	X		A		1,8	
Alpine Stone Desert	3900-4205	Acari: Undetermined species	Mite	Mite	?		R		7	

Community	Elevation (m)	Scientific Name	Common name	Type	Origin[1]	Legal Status[2]	Location[3] MKSR	HP	Refs.	Notes
Arthropods										
Alpine Stone Desert	3900-4205	Anystidae: Undetermined species	Mite	Mite	N		R		7	
Alpine Stone Desert	3900-4205	Bdellidae: Undetermined sp	Mite	Mite	?		R		1,8	
Alpine Stone Desert	3900-4205	Eupodidae: Undetermined species	Mite	Mite	N		R		7	
Alpine Stone Desert	3900-4205	Laelapidae: Undetermined species	Mite	Mite	?		R		7	
Alpine Stone Desert	3900-4205	Phytoseidae: Undetermined species	Mite	Mite	?		R		7	
Alpine Stone Desert	3900-4205	*Agonopterix ulicetella*	Gorse soft shoot moth	Moth	X		A		1,8	Gorse biocontrol agent
Alpine Stone Desert	3900-4205	*Agrotis sp*	Miller Moth	Moth	N		R		1,7,8	Originally identified as *Archanara* sp. in ref. 7.
Alpine Stone Desert	3900-4205	*Erigone* species A	Sheet web spider	Spider	N		R		7	
Alpine Stone Desert	3900-4205	*Erigone* species B	Sheet web spider	Spider	N		R		7	
Alpine Stone Desert	3900-4205	*Lepthyphantes tenuis*	Sheet web spider	Spider	X		R		1,8	
Alpine Stone Desert	3900-4205	Linyphiidae: Undescribed species	Sheet web spider	Spider	?		R		1,8	
Alpine Stone Desert	3900-4205	*Lycosa sp*	Wolf spider	Spider	N		R		1,7,8	
Alpine Stone Desert	3900-4205	*Meriola arcifera*	Sac spider	Spider	X		R		1,8	
Alpine Stone Desert	3900-4205	Salticidae: one undetermined sp	Jumping spider	Spider	X		R?		1,8	
Alpine Stone Desert	3900-4205	Collembola: 1 undetermined sp of unkonwn family	Springtail	Springtail	N		R		7	
Alpine Stone Desert	3900-4205	Entomobryidae: Undetermined sp 1	Slender springtail	Springtail	N		R		7,8	
Alpine Stone Desert	3900-4205	Entomobryidae: Undetermined sp 2	Slender springtail	Springtail	N		R		7,8	

Community	Elevation (m)	Scientific Name	Common name	Type	Origin[1]	Legal Status[2]	Location[3] MKSR	HP	Refs.	Notes
Arthropods										
Alpine Stone Desert	3900-4205	*Thrips sp*	Thrip	Thrip	E		A		1,8	
Alpine Stone Desert	3900-4205	Undetermined micro-Hymenoptera		Wasp	?		R?		1,8	
Alpine Stone Desert	3900-4205	*Anoplius toluca*	Spider wasp	Wasp, parasitic	X		A		1	
Alpine Stone Desert	3900-4205	*Apanteles sp*	Braconid wasp	Wasp, parasitic	X		A		1,8	Parasite of moth & butterfly larvae
Alpine Stone Desert	3900-4205	*Bracon sp*	Braconid wasp	Wasp, parasitic	X		A		18	
Alpine Stone Desert	3900-4205	Chalcidoidea: 1 undetermined sp	Chalcidoid wasp	Wasp, parasitic	X		A		1,8	
Alpine Stone Desert	3900-4205	*Ichneumon cupitus*	Ichneumonid wasp	Wasp, parasitic	X		A		1,8	
Alpine Stone Desert	3900-4205	Ichneumonidae: >1 undetermined sp	Ichneumonid wasp	Wasp, parasitic	?		R?		1,8	
Alpine Stone Desert	3900-4205	*Trathala flavoorbitalis*	Ichneumonid wasp	Wasp, parasitic	X		A		1,8	
Snails										
Subalpine Dry Forest	1800-2900	*Succinea konaensis*	Succineid snail	Snail	E	FSOC		?	15, 16	
Subalpine Dry Forest	1800-2900	*Vitrina tenella*	Zonitid snail	Snail	E	FSOC		?	15, 16	
Subalpine Dry Forest	1800-2900	*Oxychilus alliarius*	Zonitid snail	Snail	X			?	15, 16	
Subalpine Dry Forest	1800-2900	*Striatura sp.*	Zonitid snail	Snail	?			?	15, 16	

Notes:

1. Origin: E = endemic, I = indigenous, N = Native, X = introduced/alien.
2. Legal Status: FC = Federal Candidate for listing, FE = Federally Endangered, FT= Federally Threatened, SC = State Candidate for Listing, SE = State Endangered, HSOC = Hawaii State Species of Concern, ST = State Threatened
3. Location: MKSR = Mauna Kea Science Reserve (12,000+ ft), HP = Hale Pōhaku. √ = present or likely to be present. For MKSR column: A = Aeolian drift. R = Resident.

Section 2.2. Biotic Environment

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Table 2.2-7. Bird species found at Hale Pōhaku and MKSR

Community	Elevation (m)	Scientific Name	Common name	Origin[1]	Legal Status[2]	MKSR	HP	Refs	Notes
Subalpine Dry Forest	1800-2900	*Asio flammeus sandwichensis*	Pueo	E	FSOC		??	5	
Subalpine Dry Forest	1800-2900	*Branta sandvicensis*	Nene (Hawaiian goose)	E	FE, SE		??	2	
Subalpine Dry Forest	1800-2900	*Buteo solitarius*	'Io	E	FE, SE		??	5	
Subalpine Dry Forest	1800-2900	*Chasiempis sandwichensis*	Hawai'i 'Elepaio	E	FSOC		??	5	
Subalpine Dry Forest	1800-2900	*Hemignathus munroi*	'Akiapola'au	E	FE, SE		??	5	
Subalpine Dry Forest	1800-2900	*Hemignathus virens virens*	'Amakihi	E	FSOC		√	1,2	Noted as being common at HP. Listed as *Loxops virens* in Ref 1.
Subalpine Dry Forest	1800-2900	*Himatione sanquinea*	'Apapane	E	FSOC		√	1,2	
Subalpine Dry Forest	1800-2900	*Loxioides bailleui*	Palila	E	FE, SE		√	1,3	
Subalpine & Alpine	1800-3780	*Pterodroma sandwichensis*	'Ua'u (Hawaiian petrel)	E	FE, SE	??	??	2	
Subalpine Dry Forest	1800-2900	*Vestiaria coccinea*	'I'iwi	E	FSOC		√	6	
Subalpine Dry Forest	1800-2900	*Pluvialis fulva*	Kolea (Pacific golden plover)	I	FSOC		??	5	
Subalpine Dry Forest	1800-2900	*Acridotheres tristis*	Common myna	X			??	5	
Subalpine Dry Forest	1800-2900	*Alauda arvensis*	Sky lark	X			√	2	
Subalpine Dry Forest	1800-2900	*Alectoris chukar*	Chukar	X			??	5	
Subalpine Dry Forest	1800-2900	*Callipepla californica*	California quail	X			√	1,2	Listed as *Lophortyx californicus* in Ref. 1.
Subalpine Dry Forest	1800-2900	*Cardinalis cardinalis*	Northern cardinal	X			??	5	
Subalpine Dry Forest	1800-2900	*Carpodacus mexicanus*	House finch	X			√	1,2	Noted as being quite abundant.
Subalpine Dry Forest	1800-2900	*Coturnix japonica*	Japanese quail	X			??	5	
Subalpine Dry Forest	1800-2900	*Francolinus erckelii*	Erckel's francolin	X			√	1	

Community	Elevation (m)	Scientific Name	Common name	Origin[1]	Legal Status[2]	MKSR	HP	Refs	Notes
Subalpine Dry Forest	1800-2900	*Francolinus francolinus*	Black francolin	X			??	5	
Subalpine Dry Forest	1800-2900	*Garrulax canorus*	Melodious laughing-thrush	X			??	5	
Subalpine Dry Forest	1800-2900	*Leiothrix lutea*	Red-billed leiothrix	X			√	1	
Subalpine Dry Forest	1800-2900	*Lonchura malabarica*	Warbling silverbill	X			??	5	
Subalpine Dry Forest	1800-2900	*Lonchura punctulata*	Nutmeg mannikin	X			??	5	
Subalpine Dry Forest	1800-2900	*Meleagris gallopavo*	Wild turkey	X			??	5	
Subalpine Dry Forest	1800-2900	*Mimus polyglottos*	Northern mockingbird	X			??	5	
Subalpine Dry Forest	1800-2900	*Passer domesticus*	House sparrow	X			√	1,2	
Subalpine Dry Forest	1800-2900	*Phasianus colchicus*	Ring-necked pheasant	X			??	5	
Subalpine Dry Forest	1800-2900	*Serinus mozambicus*	Yellow-fronted canary	X			√	4	
Subalpine Dry Forest	1800-2900	*Zosterops japonicus*	Japanese white-eye	X			√	1,2	

Notes:

1. Origin: E = endemic, I = indigenous, X = introduced/alien.
2. Legal Status: FC = Federal Candidate for listing, FE = Federally Endangered, FT= Federally Threatened, FSOC = Federal Species of Concern, SC = State Candidate for Listing, SE = State Endangered, SSOC = Hawaii State Species of Concern, ST = State Threatened
3. Location: MKSR = Mauna Kea Science Reserve (12,000+ ft), HP = Hale Pohau. √ = present (recorded through surveys). ?? = Known to reside in that habitat type on Mauna Kea, but not recorded during bird surveys.

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Table 2.2-8. Mammal species found at Hale Pōhaku and MKSR

Community	Elevation (m)	Scientific Name	Common name	Origin[1]	Legal Status[2]	Location MKSR	Location HP	Refs.
Subalpine & Alpine	1800-4115	*Lasiurus cinereus semotus*	ʻOpeʻapeʻa (Hawaiian hoary bat)	E	FE	??	??	
Subalpine & Alpine	1800-2900	*Rattus rattus*	Black rat	X		??	√	5
Subalpine & Alpine	1800-2900	*Mus domesticus*	House mouse	X		√	√	1,4
Subalpine & Alpine	1800-2900	*Ovis aries* (also called *Ovis ovis*)	Feral sheep	X		√	√	2,3
Subalpine & Alpine	1800-2900	*Ovis musimon*	Mouflon sheep	X		√	√	3
Subalpine & Alpine	1800-2900	*Capra hircus*	Feral goat	X		√	√	1
Subalpine & Alpine	1800-2900	*Bos taurus*	Cattle	X		H	H	5
Subalpine Dry Forest	1800-2900	*Sus scrofa*	Pig	X		??	??	
Subalpine Dry Forest	1800-2900	*Felis catus*	Feral cat	X		??	??	5
Subalpine & Alpine	1800-2900	*Mus musculus*	Mouse	X		√	√	1,4
Subalpine Dry Forest	1800-2900	*Herpestes auropunctatus*	Mongoose	X			??	

Notes:
1. Origin: E = endemic, I = indigenous, X = introduced/alien.
2. Legal Status: FC = Federal Candidate for listing, FE = Federally Endangered, FT= Federally Threatened, FSOC = Federal Species of Concern, SC = State Candidate for Listing, SE = State Endangered, SSOC = Hawaii State Species of Concern, ST = State Threatened
3. Location: MKSR = Mauna Kea Science Reserve (12,000+ ft), HP = Hale Pōhaku. √ = present (recorded through surveys). ?? = Known to reside in that habitat type on Mauna Kea, but not recorded at HP or MKSR.

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3 Activities and Uses

Mauna Kea is considered sacred in the Hawaiian culture, the *piko* (umbilical cord) that connects the island-child of Hawai'i to the heavens (Maly and Maly 2005). Access to the summit region by early Hawaiians most likely was limited. The cultural and economic activities of the traditional Hawaiians had little impact on the natural resources of the higher elevations. The Adze Quarry in the Mauna Kea Ice Age Natural Area Reserve was prized in part for unique stone outcrops formed by intermittent glacial and volcanic activity; mining and collection of this geologic resource were two of the early economically driven uses of the mountain. Significant changes to the natural resources of the high elevation areas of Mauna Kea began in the late 1700s, primarily as a result of the introduction of domestic cattle, sheep, and goats to support human existence. The mid 20th century brought astronomical development to Mauna Kea, with infrastructure having lasting effects on the physical, biological, and cultural resources. More recently Mauna Kea has become a popular site for tourism and recreational use, drawing visitors from around the world to its summit to experience scenic terrestrial and astronomical vistas. The range of human activities results in on-going impacts to the natural and cultural resources of Mauna Kea.

This section describes the existing human environment, including activities, infrastructure, use levels and patterns, and changes over time that have, or may have, an impact on Mauna Kea's natural resources. An important component of this section is the consideration of potential future use levels, activities, and conditions. In addition to presenting information on the current and historical status (see Section 3.1), this section describes potential impacts and threats to natural resources associated with human use of the area (see Section 3.2). The primary concerns relating to human use of the area and potential impacts on natural resources are evaluating potential threats relating to different types of use and controlling activities and access. Existing conditions are discussed by "use type" including astronomical research and facilities (Section 3.1.1), scientific research (Section 3.1.2), recreational and tourism activities (Section 3.1.3), commercial activities (Section 3.1.4), and cultural and religious practices (Section 3.1.5). Since many of the threats and impacts result from more than one type of user, the discussion is organized by type of impact or threat (see Section 3.2). Where possible, attempts are made to discern the relative level of threat or impact from each of the various user groups.

3.1 Historical Development, Current Status, and Potential Future

3.1.1 Astronomical Research and Facilities

The summit of Mauna Kea hosts the world's largest ground-based astronomical observing site, considered to be the finest in the world. Physical characteristics that set Mauna Kea apart from other sites include: high altitude, atmospheric stability, minimal cloud cover (about 325 days per year are cloud free at the summit), low humidity, dark skies (because of its distance from urban development), minimal atmospheric pollutants, and the transparency of the atmosphere to infrared radiation. The trade wind inversion layer caps the upper layer of clouds at an approximate elevation of 7,000 ft (2,133 m) for most of the year resulting in a stable dry air mass above the inversion (see Section 2.1.4, Climate). Due to the location of the Hawaiian Islands within the northern hemispheric tropics, astronomers can observe the entire northern sky and nearly 80 percent of the southern sky.

3.1.1.1 Development of Summit Facilities

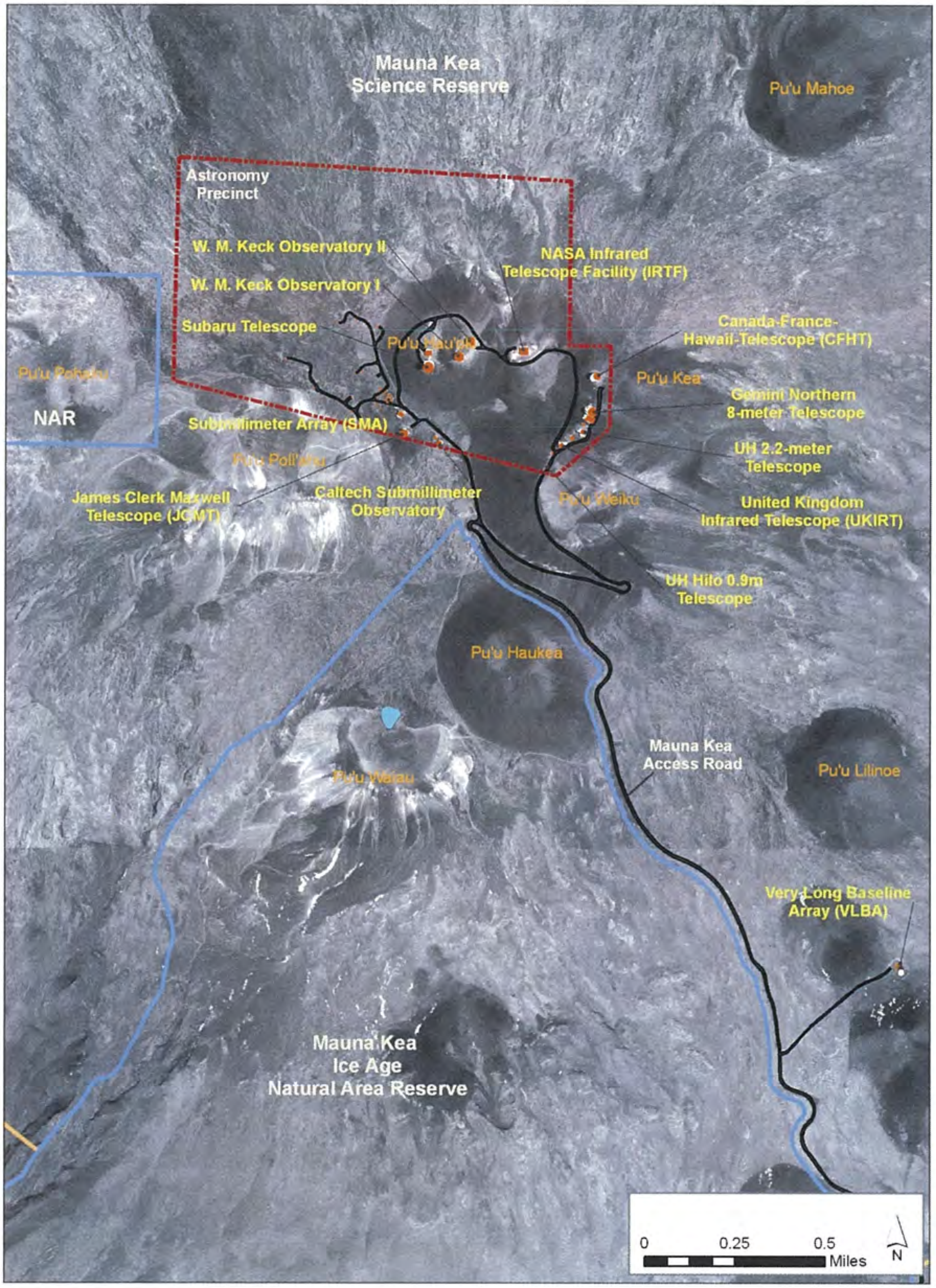
In the 1960s, the University of Hawai'i (UH) initiated an astronomical research program to attract global interest in constructing and operating telescopes in Hawai'i in scientific collaboration with UH. Haleakalā, and subsequently Mauna Kea, were targeted as ideal locations. A small site-testing dome (with a 12½ inch telescope) was built on Pu'u Poli'ahu in 1964, initiating Mauna Kea as a modern-day astronomical site. The Institute for Astronomy (IfA) was founded in 1967, to manage the observatories and facilitate collaboration. The Board of Land and Natural Resources created the Mauna Kea Science Reserve (MKSR) in 1968, granting UH a 65-year lease (Lease No. S-4191) for a scientific complex including observatories (see Section 1.4). The MKSR includes all land within a 2.5 mile radius of the summit, above about 11,500 ft (3,505 m), except for the area within the Mauna Kea Ice Age Natural Area Reserve (NAR) (see Figure 1-3). Since the creation of MKSR, thirteen observatories have been built on Mauna Kea, operated by eleven countries[1], and used by scientists from around the world. The observatories include nine optical and infrared telescopes, two single-dish millimeter- and sub-millimeter-wavelength telescopes, a sub-millimeter array, and a very long baseline array antenna (see Table 3-1 and Figure 3-1). In addition to full access to the UH 2.2 meter telescope, UH astronomers are guaranteed 10 to 15% of observing time on all the other telescopes on the summit of Mauna Kea. A series of general maintenance and upgrade projects have been completed, piecemeal, in association with telescope construction, funded by the sponsoring observatories. These projects included paving of portions of Mauna Kea (MK) Summit Access Road and construction of the Subaru construction cabins.

Table 3-1. Mauna Kea Telescopes (2008)
Source: http://www.ifa.hawaii.edu/mko/telescope_table.htm

	Name	Mirror	Owner/Operator[2]	Year Built
Optical/Infrared				
UHH 0.9m[3]	UHH 0.9-m telescope	0.9m	University of Hawai'i, Hilo	2008
UH 2.2m	UH 2.2-m telescope	2.2m	University of Hawai'i	1970
IRTF	NASA Infrared Telescope Facility	3.0m	NASA	1979
CFHT	Canada-France-Hawai'i Telescope	3.6m	Canada/France/UH	1979
UKIRT	United Kingdom Infrared Telescope	3.8m	United Kingdom	1979
Keck I	W. M. Keck Observatory	10m	Caltech/University of California	1992
Keck II	W. M. Keck Observatory	10m	Caltech/University of California	1996
Subaru	Subaru Telescope	8.3m	Japan	1999
Gemini	Gemini North Telescope	8.1m	USA/UK/Canada/Argentina/ Australia/Brazil/Chile	1999
Submillimeter				
CSO	Caltech Submillimeter Observatory	10.4m	Caltech/NSF	1987
JCMT	James Clerk Maxwell Telescope	15m	UK/Canada/Netherlands	1987
SMA	Submillimeter Array	8x6m	Smithsonian Astrophysical Observatory/Taiwan	2002
Radio				
VLBA	Very Long Baseline Array	25m	NRAO/AUI/NSF	1992

[1] U.S., Canada, France, the United Kingdom, Japan, Taiwan, Argentina, Australia, Brazil, Chile, and the Netherlands.
[2] AUI: Associated Universities, Inc.; NASA: National Aeronautics and Space Association; NRAO: National Radio Astronomy Observatory; NSF: National Science Foundation
[3] In 2008 the UH 0.6-m telescope (built in 1968) was replaced by the UHH 0.9-m telescope. Information detailed in Section 3 referring to production of solid waste, hazardous materials, and water use refers to the UH 0.6-m telescope facility since that was in operation at the time of data collection.

Figure 3-1. Mauna Kea Summit Facilities



3.1.1.2 Existing Infrastructure: MKSR, Summit Access Road, Hale Pōhaku

Infrastructure, in the form of buildings, roads, and utility lines, supports the existing observatories on Mauna Kea, both at the summit and at the mid-level Hale Pōhaku facility. The extent and installation of these facilities is described in detail elsewhere (e.g., construction documents, environmental impact statements). Most relevant for this plan is a general discussion of the existing facilities and their operations and use as they relate to actual and potential impacts on the natural resources of Mauna Kea, as the facilities currently operate, or as a result of changes (redevelopment, new facilities, decommissioning). Section IX of the 2000 Master Plan (Group 70 International 2000) provides a *Physical Planning Guide*, which contains guidelines for addressing future physical development of the MKSR (summit facilities and support facilities), including siting and design criteria, in the context of protecting natural and cultural resources. These guidelines defined a 525 acre (212 ha) Astronomy Precinct to consolidate astronomical development (see Figure 1-3). Specific site-development plans prepared by proponents of the facilities are subject to review and approval.

3.1.1.2.1 Buildings

The total disturbed area for the installation of the existing 12 observatories at the summit is approximately 17 acre (7 ha), of which 4 acre (2 ha) is impervious surface, and the remaining area being adjacent and mostly unpaved leveled areas and access roads or driveways (NASA 2005). As depicted on construction drawings, the foundation depths and sizes of the buildings vary, but can extend over a hundred feet below the ground surface and cover hundreds of square feet of surface area. Some of the building's useable areas are also located below grade. The VLBA antenna is situated approximately 1,590 ft (485 m) below the summit. The dish antenna and control building are accessed by a dirt-road spur from the Summit Access Road. Buildings at Hale Pōhaku include a support facility for the observatories, construction camp facilities, and Visitor Information Station (VIS) facilities. There is also a 0.74 acre (0.3 ha) exclosure supporting research into silversword and māmane forest restoration, which was established in 1972 (Scowcroft and Giffin 1983). This exclosure is managed by the Department of Land and Natural Resources (DLNR), and is not part of the UH facilities (see Figure 3-2).

3.1.1.2.2 Roads and Parking

The Summit Access Road extends 16.3 mi (26.2 km) from its intersection with Saddle Road to the summit, with an average width, including cuts and fills beyond the main route, of 45 ft (14 m) (NASA 2005). The road is paved along its entire length except for a 4.6 mile unpaved, gravel section that extends from Hale Pōhaku to the summit area (see Table 3-2).

Table 3-2. Coverage of Summit Access Road

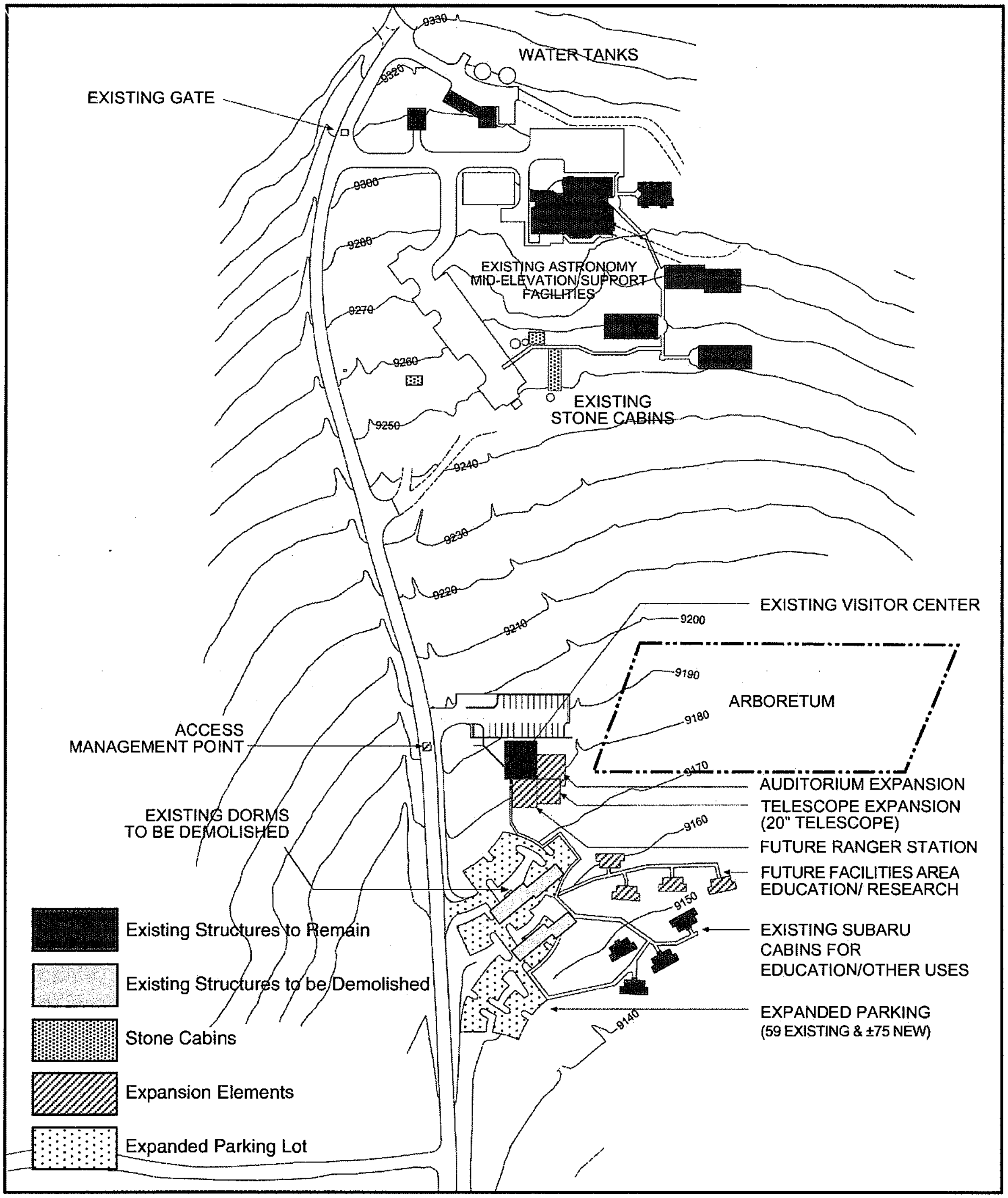
Data from (NASA 2005)

Road Section	Paved Length	Acres Covered	Unpaved Length	Acres Covered
Saddle Road to Hale Pōhaku	6.3 mi (10.1 km)	34 acre (14 ha)	—	—
Hale Pōhaku to the Summit	3.7 mi (6.0 km)	20 acre (8 ha)	4.6 mi (7.4 km)	25 acre (10 ha)
Summit loop	1.7 mi (2.7 km)*	9 acre (3.6 ha)	—	—
Total	11.7 mi	63 acre	4.6 mi	25 acre

* A portion of which is unpaved.

Figure 3-2. Hale Pōhaku Facilities

Figure IX-27 in (Group 70 International 2000)



Although there is no road maintenance plan, the unpaved portion of the road is graded approximately three times a week by Mauna Kea Observatories Support Services (MKSS) to keep it drivable, and when necessary, cinder pieces fallen from the roadside are collected and used to fill in ruts (Koehler 2008). Both the grading and other vehicles generate dust and other emissions, and move cinder material onto the road shoulder and downslope areas. In the spring of 2008, MKSS brought in basalt gravel from a quarry at Pōhakuloa to use as a substitute for the cinder on the most severely washboarded areas. As recommended by the Mauna Kea Management Board (MKMB) Environment Committee, the material was inspected for cleanliness and ants (MKMB Environment Committee 2007; Koehler 2008). This was the first time outside gravel has been used to cover the road surface (Koehler 2008). In addition, a soil additive designed to control dust (Durasoil) has been approved by the MKMB Environmental Committee and will be applied to limited stretches of the unpaved road, well below the summit (Koehler 2008). Based on the initial results of these road improvement strategies, it will be determined whether to continue to use Durasoil, the imported gravel, or both, and how frequently (Koehler 2008).

Future plans may include paving the unpaved portion of the summit access road and the remainder of the summit spur road, from the SMA building, past the Subaru Telescope to the Keck Observatory; however, concerns related to cost, environmental impacts, and facilitating access to the summit need to be evaluated.

There are three visitor parking areas along the Summit Access Road: Parking Area 1, just after the paved road begins; Parking Area 2, near the trailhead to Lake Waiau; and Parking Area 3, just past the junction of the access road and the summit loop. These areas are depicted on the map included in the safety brochure made available to workers and visitors, but are not identified by signage on-site. At the summit many visitors park near the UH 2.2m telescope if they plan to hike the summit trail. During the winter, before roads are fully cleared of snow and there are large numbers of private vehicles in the summit area, parking becomes congested and visitors park their vehicles along the road, wherever there is space. Commercial tour vehicles usually park in the area around the UH 2.2m telescope and Gemini Telescope during the sunset viewing times. For evening stargazing, there are designated parking areas for tour vehicles on lower portions of the mountain. Observatory vehicles park in designated areas near their buildings. Most parking areas are graded but unpaved.

3.1.1.2.3 Electricity and Communication

Underground power and communication lines supply Hale Pōhaku and summit facilities. Installation of the underground system to transmit electricity to the summit facilities began in 1985 and was completed in 1995. Rather than on-site generators, the facilities are now powered from a sub-station below Hale Pōhaku that is connected by overhead lines to the Humuʻula Radio Site. In the mid-1990s, underground fiber optic lines were installed to provide high speed communications capability to the observatories. One benefit of these lines was a reduction in personnel needed on-site at some of the observatories, as they can now be controlled remotely. Expansion of these systems would be needed if facilities are sited in new locations.

3.1.1.2.4 Solid Waste

Trash is generated and collected at summit observatories and Hale Pōhaku facilities. All trash containers are required to be covered and secured to prevent providing a food source for invasive fauna and to reduce the possibility of escaping debris, which can occur during periods of high winds that occur frequently. The observatories are responsible for removing their trash from the summit. Trash from Hale Pōhaku and the dormitories is taken off the mountain daily by the MKSS housekeeping staff and brought to the main Hilo office where it is removed by sub-contractors daily (Wilson 2008). Recent estimates are that approximately 4,400 gallons (16.7 kl) of solid waste per week are removed from the MKSR and Hale Pōhaku facilities for disposal at an off-site landfill (see Table 3-3) (NASA 2005). Additional material is generated over short periods during construction activities.

Table 3-3. Solid Waste Generated by MKSR Facilities
Data from (NASA 2005)

Facility	Trash Produced
UH (0.6-m) (24-in) and 2.2-m (88-in))	Two to three 30-gal (114-liter) bags weekly
CFHT	Four bins, 2 yd^3 (1.5 m^3) each, generated monthly
NASA IRTF	Three 30-gal (114-liter) trash bags weekly
UKIRT and JCMT	About one 30-gal (114-liter) trash bag for both facilities weekly
CSO	About 2,000 lb (900 kg) generated yearly
VLBA	One 30-gal (114-liter) bag weekly
W.M. Keck	3 yd^3 (2.3 m^3) dumpster emptied 1 to 2 times weekly
Gemini North	Several 50-gal (190-liter) trash bags weekly
Subaru Telescope	40 lb (18 kg) generated daily
SMA	Two to four 50-gal (190-liter) drums weekly
Hale Pōhaku Mid-Elevation Support Facilities	0.9 to 1.5 yd^3 (0.7 to 1.1 m^3) daily

3.1.1.2.5 Water

MKSS contracts with a trucking company to deliver potable water from Hilo to Hale Pōhaku and the summit observatories in 5,000-gallon-capacity (18,900 l) tank trailers owned by MKSS. Each observatory stores its own water and is responsible for maintenance of their water tanks. Water at Hale Pōhaku is stored in two beige-colored 40,000-gallon (151,400 l) tanks. Data from MKSS indicates that the Hale Pōhaku facilities (food, lodging, VIS) currently require approximately 30,000 gallons (113,500 l) of water weekly (Nahakuelua 2008). Water is trucked to the summit about twice a week for an annual total of approximately 502,500 gallons (1,902,000 l) (Koehler 2008). The annual use-quantities have remained fairly consistent over time, with a slight downward trend for the past seven years, likely in association with researchers shifting to remote facilities (see Table 3-4). It has been suggested that during peak snow periods visitor numbers increase, resulting in increased use of potable water and restroom facilities. Water use and wastewater generation both increase during construction periods. Increased use associated with future conditions will need to be numerically evaluated for the specific project. Any future development would require additional water storage tanks, water delivery, and a wastewater disposal system. It is possible that improvements to remote viewing technology will further reduce the number of staff and scientists at the Mauna Kea facilities, which will reduce water use correspondingly.

Table 3-4. Water Delivered to the MKSR Facilities
Data from (Koehler 2008)

FY (July 1 - June 30)	Total (gallons)
2002-03	608,000
2003-04	630,000
2004-05	548,000
2005-06	508,650
2006-07	532,625
2007-08	502,500

3.1.1.2.6 Wastewater

Each observatory owns an individual wastewater system (e.g., septic tank, cesspool) that has been permitted by the Hawai'i State Department of Health (DOH). Currently there are a total of eight septic systems and three small capacity cesspools (see Table 3-5). Site plans for individual septic systems are held by the respective facilities; however DOH files do include information for four summit facilities (Subaru, Keck I and II, SMA, and VLBA). Maintenance and inspections of observatory wastewater systems are the responsibility of the owner. Information as to how often these systems are inspected, what is inspected, and by whom is not centrally reported. Except for VLBA, UKIRT, and JCMT, these systems are periodically inspected and pumped to remove digested biosolids by private firms (NASA 2005; Koehler 2008). There have been no documented wastewater spills at the observatories since 1998 (see Section 3.2.3 and Table 3-11). There is no plan for the construction of a sewer collection system for the summit area (Group 70 International 2000).

Hale Pōhaku has three small capacity cesspools and six septic systems (see Table 3-6). The systems at dormitory A, the old construction camp, and the utilities buildings have not been upgraded and use the small capacity cesspools for wastewater disposal. At Hale Pōhaku's main common building, dormitories B, C, and the VIS, the wastewater systems have been upgraded to septic tanks that use the old cesspools as overflow leach fields to capture effluent discharges. Dormitory D was constructed with a septic system and no modifications have been made. A septic tank with a leach field is used at the new construction camp. DOH has site plans on file for the septic systems for most of the buildings at Hale Pōhaku (VIS, the main common building, dormitories B and C, and the construction camp housing cabins 1-4). The high-use septic tanks at the main common building, the VIS and dormitory B are checked weekly (Friday) by MKSS staff. All Hale Pōhaku systems are checked on a monthly basis (Koehler 2008). One leak was detected and corrected in 2008 (see Section 3.2.3).

Wastewater entering these systems is from domestic sources (toilets, sinks) and basic facilities cleaning water (e.g., mopping). As designed, biosolids settle out of solution and decompose within the septic tank. When liquid waste in a septic tank reaches the overflow, effluent discharges either into a cesspool or a leach field; both allow effluent to absorb into the substrate below the ground surface. Similar to septic tank systems, cesspools collect all waste; the solids slowly decompose in-situ and liquid effluent discharges from the holding chamber. Effluent discharges from both cesspools and septic systems likely contain contaminants, including nutrients such as phosphorus and nitrogen, as well as organic and inorganic by-products.

It can be conservatively approximated that all water trucked to the summit becomes wastewater with eventual subsurface disposal. Questions have been raised regarding the transport and fate of this effluent wastewater and the potential for its migration to and contamination of aquifers. The amount of water being discharged into the wastewater systems (~502,500 gallons/yr (1,902,000 liters/yr)) is a small percentage of the overall volume of water contained in the Waimea Aquifer that, at 2,969 ft (904 m) elevation, lies far beneath the Astronomy Precinct. Using the DLNR Commission on Water Resource Management (CWRM) value of the aquifer's annual sustainable yield, which is approximately 4.74 billion gallons, a conservative estimate of the annual recharge to the aquifer is 30 percent of the sustainable yield, or 1.42 billion gallons. As a result, the effluent wastewater discharge is 0.035 percent of the aquifer's annual recharge. See Section 2.1.3 for a discussion of the region's hydrology.

Table 3-5. Wastewater Treatment and Disposal Systems at MKSR Facilities
Data from (NASA 2005)

Observatory	Average Wastewater Flow Rate (gpd)	Treatment and Disposal System
UH 0.6-m (24-in) & 2.2-m (88-in)	115	2,500-gal (5-kl) septic tank and leach field
CFHT	295	Septic tank and leach field
NASA IRTF	50	1,450-gal (5-kl), two-compartment septic tank and leach field (90 linear ft (27 m))
UKIRT	111	1,130-gal (4-kl), two-compartment septic tank and leach field (75 linear ft (23 m))
CSO	65	7-ft (2-m) diameter, 10-ft (3-m) deep cesspool
JCMT	109	8-ft (2-m) diameter, 13-ft (4-m) deep cesspool
VLBA	31	7-ft (2-m) square-shaped, 10-ft (3-m) deep cesspool
W.M. Keck I & II	399	1,000-gal (4-kl) septic tank and 12-ft (4-m) deep seepage pit
Gemini	122	1,000-gal (4-kl) septic tank and 10-ft (3-m) deep seepage pit
Subaru Telescope	360	1,250-gal (5-kl) septic tank and two seepage pits
SMA	118	1,000-gal (4-kl) septic tank and leach field (265 linear ft (81 m))

Table 3-6. Wastewater Treatment and Disposal Systems at Hale Pōhaku Facilities
Data from (Koehler 2008)

Location	Septic Tank Volume (gal)	Septic Tank Pumping Schedule	Number of Cesspools	Cesspool Use	Current Flow (gpd)[4]	Design Use (gpd)[5]
Main Common Building	2,500	Every 3 months	2	Overflow leach fields	1,200	1,500
VIS	2,000	Every 3 months	1	Overflow leach field	1,200	1,250
Dormitory A (*cook staff only*)	None	None	1	Primary waste	100	500
Dormitory B	1,500	Every 9 months	1	Overflow leach field	750	1,600
Dormitory C	1,250	Every 12 months	1	Overflow leach field	600	1,000
Dormitory D	1,250	Every 12 months	0	N/A	400	1,000
NEW Construction Camp	2,000	Every 1.5 years (due to low usage); has only been pumped once	0	N/A	150	1,600
OLD Construction Camp	None	None	1	Primary waste	0	1,000
Utilities	None	None	1	Primary waste	100	500
Totals	10,500				4,500	9,950

[4] VIS, New Construction Camp and Old Construction Camp are the only metered flows, all others are estimates. Total flow is actual water delivered to Hale Pōhaku,
[5] These are estimates based on building capacities.

Four portable toilets are located at two summit area parking lots; two at the summit visitor parking area adjacent to the UH 2.2m telescope and two at Parking Area 3. The toilets can be moved between the sites depending upon need. The toilets are owned and serviced by Kona Lua, based in Kailua-Kona. Toilets are serviced every Saturday, which includes routine cleaning, maintenance, changing of flush chemicals, and pumping out waste. Waste is removed on-site by a pumping truck. Additional toilets can be requested by the Rangers to service high numbers of visitors during snow days, however this has not been done for several years (Wilson 2008).

3.1.1.2.7 Hazardous Materials

Solid and liquid hazardous materials are used in routine observatory operations and generate hazardous waste after their use.[6] A detailed accounting of the types and amounts of hazardous materials used and stored at the observatories and at the Hale Pōhaku facility is presented in Table 3-7 (NASA 2005). Each observatory has a written procedure for safety, handling, and disposal of hazardous wastes and emergency procedures for attending to spills. Licensed contractors transport all hazardous waste to a State-approved, off-site disposal facility in Hilo. There have been no documented spills of hazardous materials since 2004 (see Section 3.2.3 and Table 3-11).

Telescope operations may require glycol coolants; diesel fuel for emergency generators; hydraulic fluid; lubricants; compressed gases (e.g., carbon dioxide, helium, oxygen, nitrogen); mercury; mirror decoating acids (e.g., hydrochloric acid, potassium hydroxide, copper sulfate, hydrofluoric acid); and paints and solvents. The amounts used vary by facility, although data shows the Keck Observatory to be using and storing the largest amount, by volume, of hazardous materials (NASA 2005).

Hale Pōhaku has three underground storage tanks; one housing 11,500 gal (43,532 liters) of diesel and two housing 2,000 gal (7,570 liters) and 4,000 gal (15,140 liters) of gasoline, respectively. Tanks are located underground in front of the maintenance utilities shop and are believed to be approximately 25 years old. Due to the lack of secondary containment, in 1997 the tanks were retrofitted with a 24-hour a day sensor monitoring system that is checked daily (Nahakuelua 2008).

3.1.1.2.8 Mirror Washing

Five observatories (Keck, CFHT, Gemini, Subaru, and UH 2.2m) have their own facilities to conduct mirror washing activities (stripping aluminum from the reflecting surface of the mirror) at the summit. The other observatories bring their mirrors to one of those five for washing and recoating activities (McNarie 2004). At the Subaru telescope, wastewater generated when mirrors are washed has always been contained for off-site disposal, but from 1971 until 2001, the other observatories either disposed of the wastewater in either their onsite domestic wastewater disposal systems (UH, Keck I & II, Gemini) or in an open drain leading to the ground (CFHT). As part of the mirror re-aluminizing process, telescope

[6] In Hawai'i, hazardous wastes are administered by the DOH Solid and Hazardous Waste Branch (SHWB). See http://hawaii.gov/health/environmental/waste/hw/index.html for details. Hazardous materials transition into hazardous waste either by materials reaching their expiration date or the product being used. Hazardous waste has a regulatory definition that is triggered by the concentration of chemicals in materials. Hazardous waste is classified by amounts generated, from small to large, and is defined by mass or volume per calendar month. Users are required to report to the Environmental Protection Agency (EPA) when they generate a combined waste total equal to or greater than 100 kg per calendar month. This level triggers EPA to issue an identification number, which among other things lists the waste type and the facility name and address. The identification number is sent to DOH SHWB, which then conducts unannounced inspections of the site. Facilities are required to store, use, and dispose of hazardous materials and waste per the Resource Conservation and Recovery Act (RCRA). They are also responsible for developing a contingency plan to address potential spills or accidents.

mirrors must be removed from their protective ring girdle; a few of the girdle systems house mercury. There have been no documented spills of mercury since 1998 (see Section 3.2.3 and Table 3-11).

Concerns have been raised about potential impacts to natural resources that could have been caused by chemicals (e.g., aluminum, mild acid solution, alcohol, detergents) that may have been disposed of with mirror washing wastewater during 1971–2001. In 2001, wastewater management protocols were changed in response to concerns from community groups about the potential impact of this wastewater on the surrounding environment. All mirror washing effluent is now collected and trucked off the mountain for off-site treatment and disposal (McNarie 2004). It is estimated that the total amount of aluminum used on one 3-meter diameter mirror is approximately 15 grams (Koehler 2008). Limited analysis conducted on the fate and transport of metals contained in the effluent wastewater derived from mirror washing during the period it was discharged onsite found no substantial impacts (NASA 2005). However, it is our understanding that the fate, transport and potential impacts to substrate and downgrade waters from metals and other contaminate byproducts previously discharged into the septic systems, cesspools, and dry swales are unknown due to uncertainties regarding capture rates of byproducts in the waste systems and the hydrogeologic properties of the area (see Section 2.1.3).

3.1.1.2.9 Construction

Major construction activities at the summit, undertaken to build, redevelop, or deconstruct facilities, require approval, permits, and environmental analysis. Minor construction may be conducted as part of on-going facility maintenance, but these activities are subject to Conservation District Use Permit conditions and approval by MKMB. Construction could involve use of hazardous materials; generation of dust and debris; increased traffic and use of heavy equipment; noise and vibrations from jackhammers, wrecking balls and other equipment; excavation and disposal of excavated material; grading and filling; drilling and pouring concrete for piles, piers, footings and foundations; and installation of structures (e.g., antennas, buildings).

3.1.1.3 Off-site Support Facilities

In addition to the summit observatories, each of the telescopes is supported by off-site facilities. While most of these are located at the Science and Technology Park complex, at UH Hilo, the Keck Observatory and the Canada-France-Hawai‘i Telescopes are based in Waimea, and the VLBA is operated remotely from its headquarters in New Mexico. The installation of high-speed fiber-optic lines to the summit has facilitated an increase in remote operation of the facilities, and may reduce the number of astronomers traveling to the summit. The ‘Imiloa Astronomy Center of Hawai‘i, located at UH Hilo, opened in 2006 (http://www.imiloahawaii.org/) and provides visitors with an opportunity to discover the connections between Hawaiian cultural traditions and astronomical research conducted at Mauna Kea.

Table 3-7. Hazardous Materials Used and Stored at MKSR Facilities
Data from (NASA 2005)

Observatory	UH (0.6-m) (24-in) and 2.2-m (88-in)	Hale Pohaku Mid Elevation Support Facilities	SMA	Subaru Telescope	Gemini North	W.M. Keck	VLBA	JCMT	CSO	UKIRT	NASA IRTF	CFHT
Hydraulic Fluid	400 gal (1,500 l) in use, 150 gal (570 l) in storage; replaced every 5 years	Normally has less than 55 gal (208 l) on hand; recycle 760 l (200 gal) yearly	100 gal (380 l) in use, 40 gal (150 l) in storage	690 gal (2,600 l) reservoir, 55 gal (208 l) in storage	400 gal (1,500 l) in use; replaced as needed every several years	1,200 gal (4,500 l) in 55 gal use, (208 l) in storage	28 gal (106 l) in use, 20 gal (76 l) in storage; replaced yearly	Less than 30 gal (114 l) in use in both UKIRT and JCMT; less than 5 gal (19 l) in storage	100 gal (380 l) in use, 5 gal (19 l) in storage; added to equipment as needed	Less than 30 gal (114 l) in use in both UKIRT and JCMT; less than 5 gal (19 l) in storage	90 gal (340 l) in use, 5 gal (19 l) in storage; replaced as needed	300 gal (1,135 l) in use, 600 gal (2,100 l) in storage; systems replenished once in past 10 years
Paint and Related Solvents	About 38 10 gal (38 l) on site, mostly spray cans; several used per month as needed	Solvent, 50 gal (190 l) mostly in parts washer; recycled.	Paint and primer 12 gal (45 l) in use and storage; mineral spirits 2 g (7.6 l) in use and storage	None on site.	About 20 gal (76 l) in storage; thinner, several liters in storage; used maybe once per week.	Various amounts on site; used as needed	Acrylic roof coating 5 gal (19 l), spot repairs, once per year.	Less than 5 gal (19 l) onsite	Paint, 22 gal (83 l) on site for cosmetic touch up; thinner, 2 gal (7.6 l) on site	Less than 5 gal (19 l) onsite	50 gal (189 l) on site; used on monthly, basis depending on job requirements	10 gal (38 l) paint on site, used for occasional touch up
Oil and Lubricant	Lube, 20 to 30 gal (76 to 114 l)	Oil, less than 100 gal (380 l) in storage	Engine oil, 9 gal (34 l) in use, 10 gal (38 l) in storage; lubricant 10 lb (4.5 kg) in use, 10 lb (4.5 kg) in storage	Lubricant for periodic service of backup generator, none stored onsite	Grease, about 50 lb (23 kg), and oils about 100 gal (380 l) in storage	Oil, 1,000 gal (3,800 l) in use, 100 gal (380 l) in storage	Gear lube 5 gal (19 l) grease, 15 gal (57 l), and motor oil 2 gal (7.6 l)	Between UKIRT and JCMT, about 20 gal (76 l) stored on site	Grease, about 50 lb (23 kg) and lubricants, 12 gal (45 l) stored on site	Between UKIRT and JCMT, about 20 gal (76 l) stored on site	30 gal (114 l) stored on site.	Oil and lube, 25 gal (95 l) in storage
Mercury	Primary mirror support for 2.2-m (7.2-ft) only, 30 lb (13.6 kg) in use, 20 lb (9.1 kg) in storage	No mercury used	No mercury used	No mercury used	No mercury used, other than a few thermometers	1.4-m (4.6-ft) secondary mirror support; 13 lb (5.9 kg) in use, 17 lb (7.7 kg in storage	No mercury used	No mercury used	No mercury used	No mercury used	About 112 lb (51 kg) in support tube for primary mirror, none held in reserve	Mercury used in radial support tube for secondary mirror: 17 lb (7.7 kg) in use, 21 lb (9.5 kg in reserve

3.1.1.4 Future Land Uses

Proposed plans for future astronomical development on the summit are described in the 2000 Master Plan (Group 70 International 2000). In addition to the potential construction of new observatories, other possible changes to the astronomy facilities include redevelopment of existing sites (i.e., dismantling an existing facility and replacing it with a new one on the existing footprint), upgrades to or expansions of existing observatories, and removal of some obsolete observatories. Changes could also involve improving utility service. Any future observatory development would occur within the 525-acre Astronomy Precinct portion of the MKSR, as delineated in the 2000 Master Plan (Group 70 International 2000).[7] The Master Plan recommends protecting all of the major undeveloped pu'u and the intervening areas from development.

Other potential future land uses include projects to support the various other uses of Mauna Kea. Hale Pōhaku provides supporting infrastructure and services to support observatories, visitor use, and scientific research. Although no specific plans have been proposed, the 2000 Master Plan suggests some changes to these facilities including removal of some of the older construction camp buildings; use of the Subaru construction camp facilities to support education and research activities; expansion of the visitor center to include a larger interpretive center, an observatory, and ranger facilities; and expanded parking (see Figure 3-2) (Group 70 International 2000). Growing visitor numbers have prompted discussion about improved facilities to support recreational users, including a rest area in the snow play area at the base of 'Poi Bowl', designated scenic lookouts at the summit, designated visitor parking within the MKSR, and additional visitor parking at Hale Pōhaku (Group 70 International 2000). There are no current plans to pursue any of these changes.

3.1.2 Scientific Research

Mauna Kea is a tropical high altitude, alpine environment with unique biological, geological, and cultural features. Although there have been some ground-based scientific studies conducted, the main focus of scientific work on the mountain has been astronomy. Many of the previous natural resources studies have been conducted in association with project-based environmental analyses. A recent field-based cultural resources survey of the entire MKSR was conducted to document and map the locations of cultural resources (McCoy et al. 2009).

Although ecologists and biologists have long been interested in the high alpine environments on Mauna Kea (Goodrich 1826, 1833a, b; Lyons 1875; Alexander 1892; Mesick 1909; Baldwin 1915; Hitchcock 1917a; Hitchcock 1917b; Bryan 1918; Daingerfield 1922; Bryan 1923, 1926; Swezey and Williams 1932; Wentworth et al. 1935; Ueno 1936; Gregory and Wentworth 1937; Coulter 1939; Neal 1939; Hartt and Neal 1940; Bartram 1952; Warner 1960; Smith 1967; Mueller-Dombois and Krajina 1968; Landgraf 1973), it was not until the discovery of the wēkiu bug in 1979 that any in-depth and ongoing scientific research into the natural resources (biology) of the summit area began. The focus of most biological research at the summit has been on the wēkiu bug, and relatively little is known about the other species that reside there. Arthropods were intensively sampled at the summit in 1982, but in only a very limited area (Howarth and Stone 1982). Plants at the summit have been cataloged in detail (but only in small areas) on two occasions, once in 1935 (Hartt and Neal 1940), and again in 1982, in association with an environmental impact statement (Smith et al. 1982). Biological studies conducted specifically at Hale Pōhaku and the MKSR are listed in Section 2.2.2 within the various subsections (Plants, Invertebrates,

[7] The Institute for Astronomy (IfA) provides guidance on research and science, while future development of telescope on Mauna Kea is reviewed by the MKMB, OMKM and Kahu Kū Mauna. It is envisioned that MKMB, OMKM and Kahu Kū Mauna will be taking the lead on reviewing and updating the current Master Plan.

Birds, Mammals). Details on research conducted on the wēkiu bug are included in Section 2.2.2.2. The focus of biological research at the summit has switched from cataloging species diversity to understanding the ecology of specific organisms of interest, such as the wēkiu bug. Very little research has been done at Hale Pōhaku, although this is changing with increased interest in the invertebrate community there (Brown 2008; Medeiros 2008; Oboyski 2008). Māmane woodlands, as a whole, have been researched intensively with the primary aim of restoring degraded vegetation communities (see Section 2.2.1, Plants) and protecting the endangered Palila (see Section 2.2.3, Birds). Most of this research, however, has focused on areas of more intact māmane woodland, such the western slope of Mauna Kea.

Interest in the processes and products of Hawaiian volcanoes have prompted scientific inquiry for centuries; investigations of Mauna Kea compiling a substantial portion of these (Washington 1923; MacDonald 1945; Stearns 1946; Woodcock et al. 1966; Porter 1972a; 1975; Wood 1980; West et al. 1988; Dorn et al. 1991; Wolfe et al. 1997; Sherrod et al. 2007). At high elevations on Mauna Kea, a dry climatic regime and low rainfall persist, resulting in little surface runoff and low erosion rates. Disturbance to the geologic features, especially those caused by recent human presence, are generally well preserved and difficult to erase. Evidence of the formation and retreat of three glacial events believed to have occurred during the Pleistocene has been well documented (Porter 1975; 1979a; Dorn et al. 1991; Lockwood 2000), as has the unique presence of permafrost (Woodcock et al. 1970; Woodcock 1974). Other topographical focal points of past and on-going study include the geomorphologic evolution of the summit and flank areas such as Lake Waiau. Meteorological attributes of Mauna Kea such as precipitation, surface pressure, dew point, and wind regimes, as well as their influences on local hydrology, air quality, and viewscape have been the subjects of numerous studies (Stearns and Macdonald 1946; Blanchard 1953; Chen and Wang 1994, 1995a; Chen and Wang 1995b; Nullet et al. 1995; Arvidson 2002; da Silva 2006). Other climate investigations have included portions of Mauna Kea's lower elevation flanks (Chen and Wang 1995a; Hotchkiss et al. 2000) and neighboring high elevation locations on Kauai and Maui (Billings 1979; Nullet and Giambelluca 1990; Loope and Giambelluca 1998).

The Office of Mauna Kea Management (OMKM) both funds and provides logistical support for scientific studies on the natural environment, including research to understand microhabitat and microclimate selection by the wēkiu bug, initiated in 2001, and analysis of meteorological data. Additional studies are planned in support of recommendations made in this NRMP (see Section 4.1). The existing facilities at Hale Pōhaku are occasionally used to support visiting scientists, other than astronomers, who are conducting research on the mountain, and they have the potential to provide greater support for such scientists in the future. As use of the mountain for ground-based scientific research grows, managers must consider the potential impacts of further studies, weighed against potential benefits. Recent scientific studies commissioned by OMKM give significant consideration to the potential impacts on natural and cultural resources in the MKSR and involve consultation with Kahu Kū Mauna (an advisory group on matters of Hawaiian cultural resources on Mauna Kea), the MKMB Environment Committee, and the MKMB. Rarely does the MKMB Environment Committee go against recommendations made by Kahu Kū Mauna; however, temporary weather stations were established at specific sites to collect data associated with wēkiu bug studies against Kahu Kū Mauna's advice (Businger 2008). Considerations were given to cultural concerns, potential impacts on the physical resources (e.g., disturbance of cinder during installation and trail-carving through repeated site access), and minimizing visibility by painting the structure to blend into the background (to reduce visits by curious persons and potential vandalism) (Mauna Kea Management Board 2007).

3.1.3 Recreational and Tourism Activities

Mauna Kea has long been a site for tourism and private recreational activities including hiking, hunting, snow-play and sightseeing. Visitors are drawn by the natural beauty, scenic vistas, and accessible high peaks. Most of the upper elevation land is under the jurisdiction of the State of Hawai'i, including the MKSR, the Mauna Kea Forest Reserve, and the Mauna Kea Ice Age Natural Area Reserve (see Figure 1-4). The rules governing allowable activities in these areas differ (see Section 1.4). The Mauna Kea State Recreation Area is located at a lower elevation of 6,500 ft (1,981 m) and provides facilities to support recreational campers and hunters.

Studies of the optimal use of the recreational resources of Hawai'i in 1964 looked at the manner and extent to which the lands around Mauna Kea should be developed for outdoor recreation (McIntosh and Milstein 1964). Although at the time visitor use was approximately 14,000 persons per year (compared with 400,000 for nearby Hawai'i Volcanoes National Park), the unique recreational advantages of Mauna Kea (e.g., big game and bird hunting, skiing, and viewing of features such as the Adze Quarry and evidence of Pleistocene glaciation) were considered potential draws (McIntosh and Milstein 1964). Even so, the study concluded that that development of the area's recreational capacity or commercial development would yield minimal financial returns, due the limitations of the area (i.e., limited water supply, remote location, limited facilities, and minimal publicity) (McIntosh and Milstein 1964).

Tourism has increased over the past several decades due to easier access and a greater number of organized commercial and educational tours (see Section 3.1.4). Although there is no official registration system to track users, OMKM has been keeping detailed records on the number of people visiting the VIS and the summit since the ranger program began in 2001 (Nagata 2007). MKSS estimates that in 2002, 105,000 visitors stopped at the VIS (Good 2003). Byrne (2008) indicates similar estimates of greater than 100,000 visitors per year over the past few years. Over the past few years (2006-2008), the total of all types of summit visitations by vehicles ranged between approximately 30,000-32,000 (OMKM unpublished data).[8] Observatory vehicles and visiting 4-wheel drive vehicles represent the largest percentage of total vehicles on the mountain, with over 11,000 of the former and over 10,000 of the later, in 2008 (OMKM unpublished data). It is possible that recreational visitors to Mauna Kea will increase with the completion of the Saddle Road realignment.[9] Ranger estimates indicate an average of about 30-40 non-commercial visitors a day to the summit, most of them staying less than 30 minutes (OMKM Rangers 2007). It is anticipated that as tourism on the Big Island continues to grow, and with the ongoing improvements to Saddle Road, more tourists and recreational visitors will visit Mauna Kea in coming years. Currently OMKM rangers estimate that most recreational visitors are from the mainland or overseas, but there is no official tracking of visitor demographics (OMKM Rangers 2007).

Most visitors to Mauna Kea know little or nothing about the unique natural resources of Mauna Kea. Many think "it's only rock," while a small proportion of visitors are aware of 'the bug' (wēkiu bug). About 10% of the general public is aware of Lake Waiau, though its recent inclusion in the "Big Island Revealed" guidebook has made it a more popular visitor destination (OMKM Rangers 2007).

[8] The reference (OMKM unpublished data) refers to data from OMKM database on Ranger patrol reports, ongoing collection 2001–present. Data is housed in a Microsoft Access database at the OMKM main office. For the period of June 2001 to April 2005, observatory vehicle totals reported by Ranger staff may have been inadvertently double or even triple counted.

[9] Providing numerical estimates would be pure speculation. Even if rental car companies allow people to drive on Saddle Road, it is not known whether driving on the unpaved portion of the Summit Access Road would be allowed or prohibited.

Figure 3-3. VIS Parking Lot (February 23, 2008)

3.1.3.1 Visitor Services

The Visitor Information Station of the Onizuka Center for International Astronomy, established in 1986 at Hale Pōhaku, provides information on safety and hazards, astronomy, the observatories, and natural and cultural resources for independent travelers (Good 2003). From 1986 until 2000 the VIS was a part-time venture. It is now open daily from 9am – 10pm, providing information to both daytime visitors and nighttime stargazers. The VIS, including the gift shop, is staffed by paid employees and volunteers (more than 170, many from UH Hilo) through MKSS. Both employees and volunteers receive training to enable them to provide interpretive information. Signs on the outside of the building describe the dangers associated with traveling to the summit (see Figure 3-4), and staff are present to answer questions and provide information. The VIS website (http://www.ifa.hawaii.edu/info/vis/) provides information for those planning a visit, including weather and road conditions, safety information, names of tour companies, VIS-sponsored events, and links to related information about Mauna Kea.

At the VIS people can read informational panels about the telescopes, geological resources, and the wēkiu bug. To educate visitors on Mauna Kea and its unique environment, there are interactive displays, handouts, and videos (derived from the *First Light* video (PBS Hawaii 2004)) (see Section 4.4). The VIS staff and rangers play the videos for visitors, including Japanese language versions, either upon request or if they are trying to garner interest from visitors. *Mauna Kea: A Guide to Hawai'i's Sacred Mountain* was published in 2005 as a guide for visitors on the cultural and natural history of the mountain, along with its current activities and uses (Lang and Byrne 2005). Many visitors focus their attention at the VIS on the gift shop and spend little time looking at the displays or watching videos (VIS Staff 2007). The proceeds from the store go into a revolving fund to support VIS activities. There are public restrooms at the VIS, a few outdoor picnic tables, self-serve hot beverages, and covered trash receptacles outdoors.

The VIS offers an evening stargazing program that has gained popularity in recent years and is now offered daily. Many visitors attend this program after driving to the summit to watch the sunset. The stargazing program is not available to those participating in commercial tours. The VIS also conducts weekly summit tours every Saturday at 1 p.m., to visit the Keck I and the UH 2.2m telescopes. Guests must provide their own 4-wheel drive transportation to the summit. Attendance varies, but on occasion the VIS will have up to 20 or 30 people participating in these tours (VIS Staff 2007). Other VIS events include monthly programs on current astronomical research occurring on Mauna Kea and presentations on cultural aspects of Mauna Kea. Public stargazing programs and all VIS activities are provided free of charge using donations from the observatory facilities. Preliminary plans exist for expanding and improving the VIS facilities to provide an enhanced experience for visitors (Group 70 International 2000; Good 2003).

Figure 3-4. Visitor Information Station Signage Explaining Hazards at Mauna Kea

The Keck Observatory has a visitor gallery that is usually open to the public during the weekdays. The Keck Observatory has a 15-minute video, an interactive kiosk, two public restrooms and a viewing area with partial views of the Keck I telescope and dome. The Subaru Observatory offers guided tours of their facility for those who sign up on their website. In addition to the public restrooms at the VIS and the Keck Observatory (where availability is limited), there are some portable latrines in the summit vicinity.

3.1.3.2 Rangers

OMKM officially began its ranger program in 2002, after an initial trial program (June 2001) designed to help determine their duties and responsibilities. There are five full time ranger positions. The rangers are hired by MKSS using OMKM funds. Two rangers are on duty daily, with three working on Saturdays. Shifts are three days on (two thirteen hour days and one twelve hour day) per week, and four days off, with most rangers staying at the Hale Pōhaku facilities during their days on. The rangers typically have diverse backgrounds, from those with cultural ties to the land, to those drawn to the mountain because of astronomy, to those looking to share their knowledge about the important natural resources of the area. Rangers receive on the job training from other rangers.

OMKM Rangers use the VIS as a base when they are not out on patrol, providing an additional resource to visitors. A key function of the rangers is to ensure the safety of visitors to Mauna Kea. Rangers advise visitors of weather conditions, the potential hazards associated with ascending the mountain (e.g., altitude sickness, road conditions), and recommended approaches to safely visiting Mauna Kea. They provide emergency assistance when necessary, including oxygen and water. Education is another important component of the ranger's daily activities. They distribute the safety brochure, provide information on the unique natural and cultural resources, identify the various observatories, direct visitors to established hiking trails, and educate visitors on prohibited or destructive activities. Rangers are made available, as needed, to support activities such as movie making, to ensure that impacts by film crews are minimal (e.g., by limiting climbing on hillsides and trampling vegetation). Rangers also perform site maintenance activities including coordinating litter removal ('an ever present responsibility') and trail maintenance to deter use of non-established trails.

Rangers conduct patrols by car to the summit four times daily, with the last patrol at sunset. A primary purpose of these patrols is to observe and document the activities of the general public, observatory personnel, and commercial tour operators. This is partially accomplished by monitoring the road and vehicle traffic and documenting the number and types of vehicles at the summit or in transit (e.g., observatory, visitor, commercial). The patrol reports document weather conditions; how many hikers visit Pu'u Poli'ahu, Pu'u Kūkahau'ula (Pu'u Wēkiu, summit peak), and Lake Waiau; visitor type and activities; ranger activity (e.g., trail maintenance, litter pick-up); and research activity. These reports are faxed to the OMKM office daily and entered into a Microsoft Access database. This database has records dating back to 2001 and can be queried for information on a variety of topics. Patrols also permit rangers to interact with visitors at the summit who may want information or directions, to evaluate the health and safety of visitors, to educate people on various aspects of Mauna Kea, and to provide guidance on permitted and prohibited activities. Much of the interaction that rangers have with visitors is related to providing them with information that they did not know (this includes people engaging in prohibited activities and walking in areas they should not). The ranger records provide valuable data on use of the area.

The rangers wear uniforms and drive State-owned vehicles identified as ranger vehicles. Although it is not a park, many visitors liken Mauna Kea to national or state parks, and VIS staff report receiving inquires from people looking to get their national park passport book stamped (VIS Staff 2007). Some visitors also believe the rangers have law enforcement powers. Although this perception likely has the benefit of reducing the human impact of visitors (e.g., making them less likely to litter and to respond favorably to requests to stay on trails), the rangers do not have any enforcement authority if they observe misconduct or legal infractions. This lack of authority is linked to the lack of rule-making authority for the area (see Section 1.4.2.3) and reduces OMKM's overall ability to protect both natural and cultural resources. DLNR Division of Conservation and Resources Enforcement (DOCARE) is tasked with providing enforcement, though personnel do not maintain a presence on Mauna Kea. Twice a year rangers conduct inspections of each observatory for compliance with their conservation district use permits.

3.1.3.3 Hiking

Native Hawaiians traveled to Mauna Kea for religious and healing purposes and to procure stone from the Adze Quarry. According to Maly and Maly (2005), "Travel across the *'āina mauna* (mountain lands) of Mauna Kea is documented in native traditions, which describe *ala hele* (trails) passing from the coastal lowlands through the forest lands; along the edge of the forests; across the plateau lands of the Pōhakuloa-Ka'ohe region, and to the summit of Mauna Kea. These *ala hele* approached Mauna Kea from Hilo, Hāmākua, Kohala, Kona, and Ka'ū, five of the major districts on the island. Only Puna, which is cut off from direct access to the mountain lands, apparently did not have a direct trail to the *'āina mauna.*" Historic trails, created in the nineteenth and early twentieth centuries, either followed old trails or cut across new areas. They were often traveled on horseback for purposes of forestry, ranching, hunting, and recreation (Maly and Maly 2005). These trails, originating from all directions, form part of Mauna Kea's landscape, with access paths carved from the lower elevations to Lake Waiau and the summit region. The Kūka'iau-'Umikoa Trail served as a route from the Hāmākua area, on the north side of the mountain, to

Waiau, on the south side of the summit. The Mauna Kea-Humuʻula Trail provided access to the summit from the south, originating at the Humuʻula Sheep Station in the saddle.

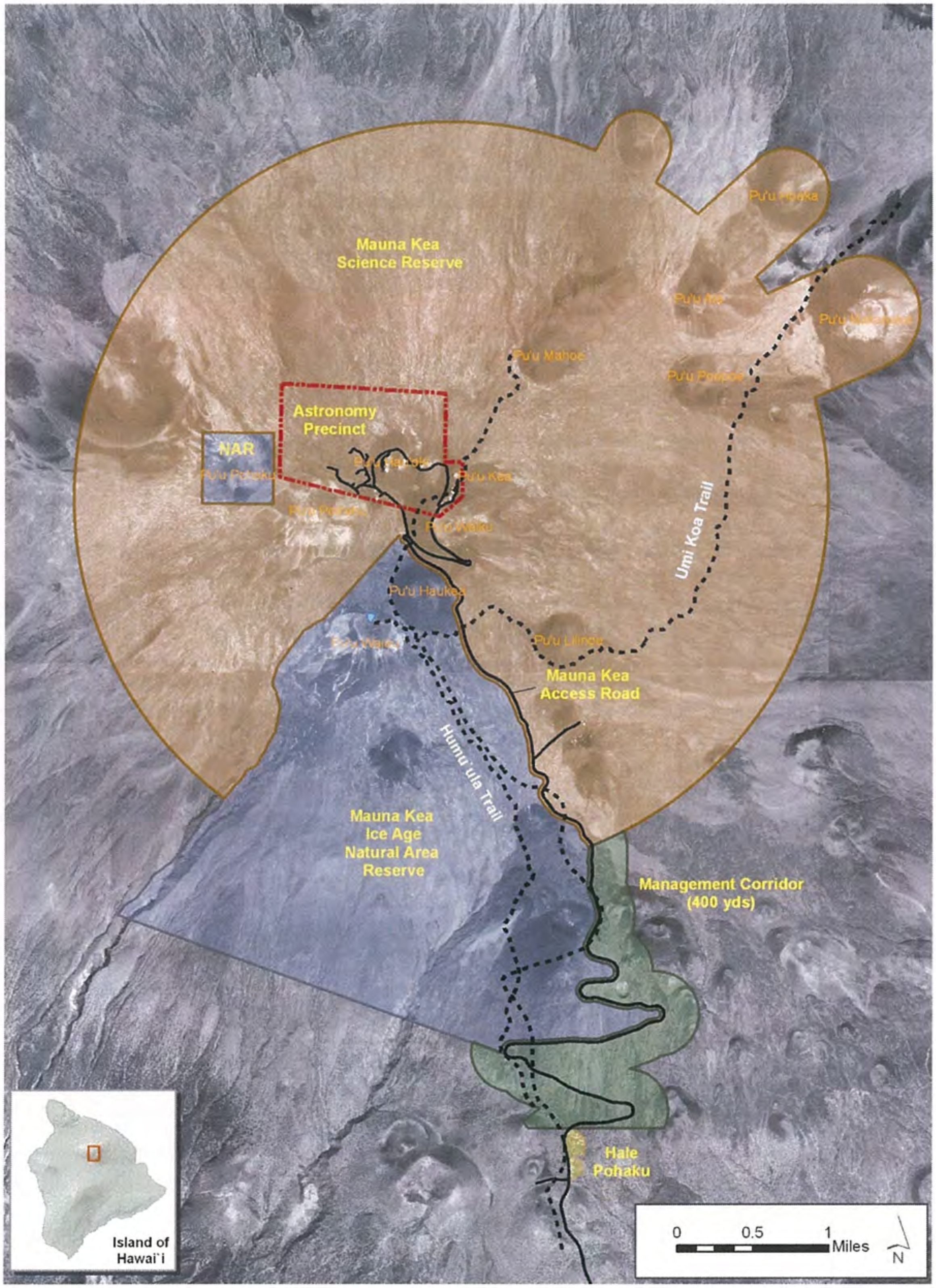
Hiking is currently a popular day-use activity for some visitors to Mauna Kea. There are no camping facilities within the UH Management Areas. There are a few established (but unmarked) trails in the summit region and other trails at lower elevations (see Figure 3-8). A general map of the area, with some trail designations, is included within one of the handouts distributed at the VIS: "Visiting Mauna Kea Safely and Responsibly" (developed by OMKM). For those unfamiliar with the area it is advisable to get recommendations and directions from either the VIS staff or the rangers. Ranger reports between 2002 and 2008 suggest that approximately five to six thousand hikers use the summit region trails every year (see Table 3-8) (OMKM unpublished data). This represents the number of hikers counted by the rangers for the five points of access most commonly used: the Mauna Kea Ice Age NAR trail (to Lake Waiau), the Mountain Trail, the trail up Puʻu Poliahu, the Summit Trail, and the trail along the access road (see Table 3-8). In addition to those who hike the short trail to the summit (Puʻu Wēkiu), many use a secondary trail to access it from the parking lot of the UH 2.2m telescope. This secondary trail is used approximately 20 times a month by visitors (OMKM Rangers 2007) and crosses documented wēkiu bug habitat. The main trail to the summit is about 300 ft (91 m) up the road, unmarked, and not easily seen. Hikers have also been observed off-trail in the summit region, where they may damage wēkiu bug habitat and disturb previously undisturbed cinder. Rangers will provide directions to people at the summit looking to find the trails, educate people about the sensitive landscapes, and try to discourage use of the secondary trail by sweeping and raking the disturbed track to make it less visible.

One off-road-vehicle trail, 900–1,200 ft (274–366 m) long, to the top of Puʻu Poliʻahu, was frequented in the past by drivers looking to explore. The trail was originally cut for the installation of the University of Arizona Site Test Telescope, but in 2001, as vehicle access was not required for any operational needs and because Kahu Kū Mauna was concerned about disturbance to cultural sites and disrespect to Hawaiian culture, OMKM closed the road. MKSS tore up and raked the old road bed and installed large boulders to block vehicle access. A sign denoting Puʻu Poliʻahu as a sacred site was also erected. A few hikers now climb the trail, but visits appear to be infrequent (OMKM Rangers 2007). Rangers discourage visitors from visiting the Hauʻoki Crater, documented wēkiu bug habitat, but this is often difficult since the footprint trails persist and attract more visitors. Although it is not part of the MKSR, some visitors to Mauna Kea hike about a mile (from the road) to visit Lake Waiau, and approximately 10 visitors a month walk off-trail up Puʻu Hau Kea and to the Adze Quarry (OMKM Rangers 2007).

Table 3-8. Number of Hikers by Trail
Data from OMKM unpublished data

Trail	2002	2003	2004	2005	2006	2007	2008
Lake Waiau	719	1,235	1,003	1,076	1,215	1,271	785
Mountain Trail	100	371	347	365	352	441	433
Pu'u Poliahu	102	142	75	241	77	53	57
Summit Trail	4,198	3,730	3,431	4,885	4,077	3,766	2,909
Access Road	91	258	196	227	166	188	195
Total	5,210	5,736	5,052	6,794	5,887	5,719	4,379

Figure 3-5. Hiking Trails of Mauna Kea



Other trails around Hale Pōhaku include the trail through the silversword exclosure and the dirt access-road/firebreak encircling much of the mountain, which is used primarily by hunters. There are also hiking trails, West Ridge and Pu'u Kalepeamoa (Lang and Byrne 2005). Outside the UH Management Area boundary, these two trails are located directly across the Summit Access Road from the VIS and lead to Pu'u Kilohana and Pu'u Kalepeamoa, respectively. The silversword enclosure trail, West Ridge, and Pu'ukalepeamoa are the more popular trails (Byrne 2008); however, how often any of these trails is used and by whom is not monitored.

Trails at lower elevations provide additional access points to the mountain. In mid 2007, the Division of Forestry and Wildlife (DOFAW) opened up two existing trails to off-highway recreational use (Kawashima 2008). Both trails are used by hikers, mountain bikers, ATVs, hunters, motorcycles, horses, and 4-wheel-drive vehicles. Two check-in stations have been built for these trails, which serve two primary functions, to document trail use over time and to aid in search and rescue teams when people become lost or injured. Check-in stations are marked by signs and have sign-in sheets for visitors to write their names and activity. The DOFAW Na Ala Hele Trail and Access Program maintains check-in stations for off-highway recreational trails. Check-in stations began collecting visitor data in 2007.

3.1.3.4 Snow-Play

In 1913, *Mid-Pacific Magazine* carried an image captioned "Wai'au lake is the only lake in Hawai'i on which ice skating may be enjoyed" (Frear 1913). The first recorded skier on Mauna Kea took to the slopes in February 1936, as documented in an article in *Paradise of the Pacific* (Lewis 1937). Skiing expeditions continued (Dickie 1967), and snow-play (skiing, snowboarding, sledding) is now a common winter pastime on the Big Island when the conditions are right. Some visitors load up the beds of their pick-up trucks with snow and haul it down to lower elevations for "winter" fun. As described in Section 2.1.4, snowfall on Mauna Kea's summit is sporadic, with the winter months of January–March most likely to have suitable ski days. Other than for plowing the roads (conducted by MKSS) and directing parking, there is no logistical support for snow operations on the summit and it is difficult to control use and access. Rangers close the road at Hale Pōhaku until they receive confirmation that conditions are safe for visitors to proceed up the mountain. Sometimes people wait overnight in their cars for the opportunity. The primary area used for snow play, known as the Poi Bowl, is located directly east of the Caltech Submillimeter Observatory—in part because it is accessible by road both at the top and bottom of the run (see Figure 3-6 and Figure 3-7). This area is utilized by the wēkiu bug (Eiben 2008), although it may not represent prime wēkiu bug habitat (Englund et al. 2006). Many visitors institute a shuttle system to ensure that there is a car and driver to pick them up at the bottom of the run and drive them back to the top. These north-facing slopes maintain the snow the longest. Heavy snowfall brings visitors to a location east of the summit, which is a longer trail that requires a hike from the bottom, back to the roadway. Because there are no designated trails or ski lifts, visitors often hike off-trail hiking to reach the ski runs, and if there is not enough snow they hike on open cinder between the snow-covered areas.

Vehicle and visitor traffic to the summit may be particularly high on snow days, especially when they fall on weekends. Many people (especially locals) visit the mountain only where there is snow (see Figure 3-7). As many as 600 vehicles have been recorded traveling to the summit on heavy snow days, and each of these is likely carrying several passengers (OMKM unpublished data).

Figure 3-6. Ski Areas on Mauna Kea

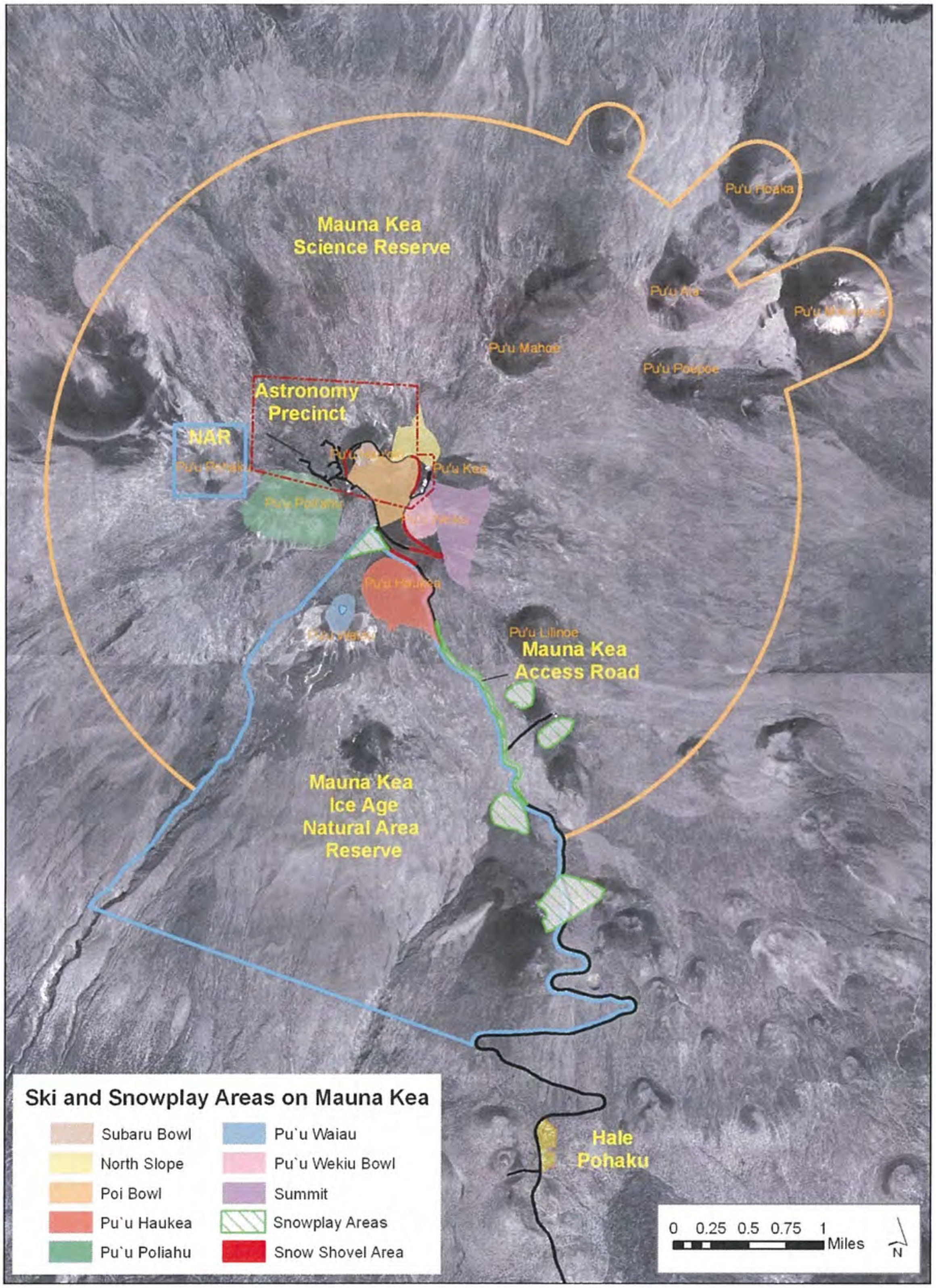
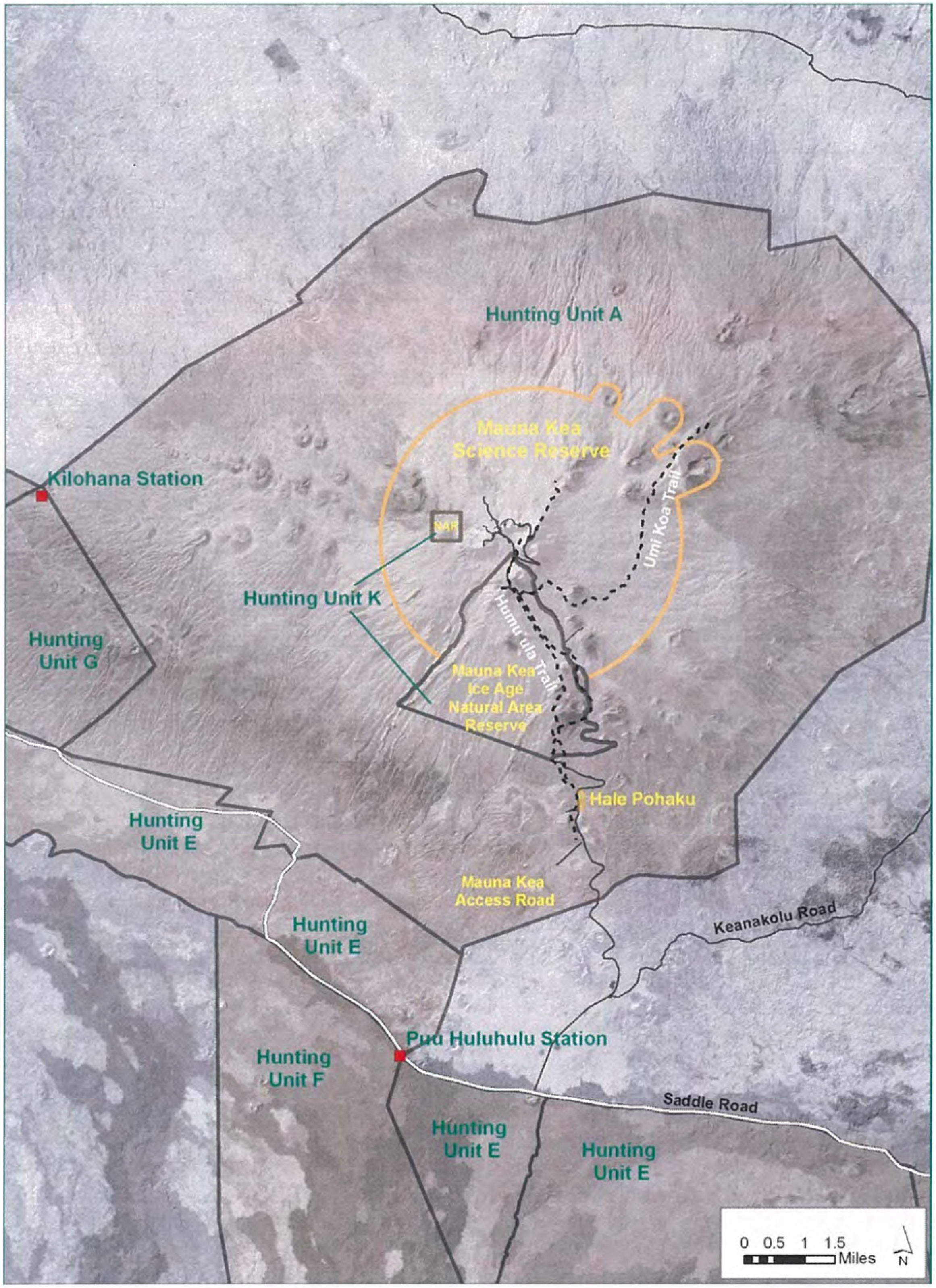


Figure 3-7. Snow Play on Mauna Kea

3.1.3.5 Hunting

As described in Section 2.2.4, mammals were introduced to Hawai'i in the late 1700s as a local food source. Livestock populations thrived, but landscapes were permanently altered by over-grazing and subsequent erosion. Although animal-control activities were conducted in the early 1900s, maintenance of game animals for hunting was a management goal again by mid-century. By the late 1940s the population of game mammals on Mauna Kea was allowed to increase to enable sustained harvest by hunters. The State maintained facilities at Pōhakuloa to support recreational hunters on Mauna Kea, which was regarded as a "hunter's paradise" (Anonymous 1948). According to the U.S. Fish and Wildlife Service, "The numbers of feral sheep and goats grazing on the ranges of the various islands also created problems in the loss of habitat—the destruction of cover and subsequent erosion of the soil. Today the goats, sheep, and pigs are classed as game and are hunted as 'mainlanders' hunt deer. Hunting, in some areas, has reduced this 'game' to such low numbers that seasons must be imposed to insure "future sport" (Department of the Interior: Fish and Wildlife Service 1950). Guides advertised big game hunting expeditions, touting "…as a general rule, shooting can be regarded as 'guaranteed,' with a limit of two sheep and two pigs per day" (Collins 1957). As a result of a lawsuit filed to protect designated critical habitat for the endangered Palila, the māmane-naio forest (see Sections 2.2.3.1 and 2.2.4.1.2), a Federal court ordered the eradication of sheep and goats from Mauna Kea, in 1979. Although this goal was nearly achieved by 1981 through State-conducted eradication efforts (Scowcroft and Conrad 1992), the animals are still present on the slopes of Mauna Kea, and hunting continues to be a popular recreational and subsistence activity with local residents.

Figure 3-8. Hunting Areas on Mauna Kea



DLNR has divided hunting areas into units, each with its own set of regulations (see Figure 3-8). On the Big Island, Hunting Unit A is the Mauna Kea Forest Reserve and Game Management Area. Unit K covers the Big Island Natural Area Reserve properties, including the Mauna Kea Ice Age Natural Area Reserve. It operates under the same regulations as Unit A. Adjacent units E and G span Saddle Road and include hunting access points via Pōhakuloa Training Areas 1, 2, 3, and 4. Hunters with vehicles access the mountain through existing trails. Hunters on foot use gates or jump the fence (Mellow 2008).

There are two check stations for hunters to document hunting use, the type and number of animals taken. The Pu‘u Huluhulu Hunter Check Station is located at the bottom of Summit Access Road, for hunters accessing the mountain via Hale Pōhaku, Mauna Kea State Recreation Area, the Pōhakuloa pipeline, and Pōhakuloa Training Area. The Kilohana Hunter Check Station is located on the southwest side of the mountain, off of Saddle Road, at the 43-mile marker. It is accessed via Pu‘u La‘au Road and is for hunters accessing the mountain via this point.

Signs mark the access routes to the hunting areas around the Hale Pōhaku and higher on Summit Access Road. An access/firebreak road often used often by hunters circles the east, north, and west sides of Mauna Kea for 32 mi (52 km), at about 9,000 ft (2,740 m), within the Mauna Kea Forest Reserve. It is a 4-wheel-drive road, unpaved and infrequently maintained, and is accessed from just below Hale Pōhaku or from the Kilohana Hunter Check Station.

In Unit A, DLNR regulations (Title 13, Chapter 123, Rules Regulating Game Mammal Hunting) limit hunting to wild pigs, wild sheep, and wild goats. Pig, sheep, and goat hunting is year-round, with a bag limit of one pig per hunter per day and no bag limit for sheep or goats, nor is there a requirement of evidence of sex or species. Although there are no statistics, bird hunting (Title 13, Chapter 122, Rules Regulating Game Bird Hunting, Field Trials, and Commercial Shooting Preserves) is likely minimal in the summit area because few birds are sighted; it is more common around Hale Pōhaku, as there are many game bird species in the subalpine area. Although hunters are known to start looking for animals as far up as 12,000 ft (3,660 m), mammal hunting typically takes place at lower elevations on Mauna Kea in the DLNR Mauna Kea Forest Reserve where the animals are more numerous.

Hunter check-in station data is collected following a fiscal year (July 1-June 30) and tallied by the DOFAW office in Hilo. The number of hunting trips to hunting areas on Mauna Kea increased from 394 in 2005 to 1,091 in 2007 and 1,356 in 2008; however the average mammal take remained the same with approximately 0.3 animals per hunting trip (DOFAW Game Mammal Harvest Report).[10] Number of game bird hunting trips increased from 1,453 in 2004 to 2,765 in 2007 and was 1,909 in 2008. Bird harvest numbers remained relatively consistent with approximately 1-2 birds per the average 3.8-hour hunting trip (DOFAW Game Bird Harvest Report). Harvest data for the two Mauna Kea check-in stations for 2004-2008 mammal and bird harvests are presented in Table 3-9 and Table 3-10. As funding permits, additional hunting data is also collected through hunter surveys conducted by DOFAW and the results of both data sets reported in the Pittman-Robertson Annual Performance Report for the Game Management Program.[11] Result summaries reported within the FY2005 Annual Performance Report indicate a significant and systematic but uneven potential underestimate of hunter effort and harvest by check-in station data (Johnson 2008). As described in Section 2.2.4, DOFAW conducts feral ungulate control on Mauna Kea, during which 200 to 500 sheep, goats, and mouflon are removed from Mauna Kea each year

[10] The game harvest reports for Mauna Kea are available from the DOFAW Hilo office.

[11] The Federal Aid in Wildlife Restoration Act, commonly called the Pittman-Robertson Wildlife Restoration Act, was initially passed in 1937. The Act authorizes the Secretary of the Interior to provide federal aid to state fish and game departments for wildlife restoration projects.

(Fretz 2008). Additionally, the staff at Mauna Kea Ice Age NAR has shot about 25 animals within the NAR over the last three years (Hadway 2008).

Daytime hunting is a permitted use in the MKSR under the terms of the lease between UH and BLNR, "pursuant to the rules and regulations of the Board" (DLNR 1995). The lease stipulates that hunting "must be coordinated with the activities of UH." Commercial hunting operations are prohibited in the MKSR under the 1995 Management Plan.

Table 3-9. 2004 – 2008 Mauna Kea Check-in Station Data: Mammals

Data from Hawai'i Island Game Mammal Harvest Report

Year*	Feral Sheep		Mouflon Sheep		Pigs		Goats		Annual
	Rams	Ewes	Rams	Ewes	Boars	Sows	Billys	Nannys	Totals
2004	0	0	59	46	13	14	0	0	132
2005	7	5	48	28	12	9	0	0	109
2006	1	0	95	66	10	14	0	0	186
2007	0	0	215	116	13	15	0	0	359
2008	0	0	272	158	25	9	0	0	464
Total	8	5	689	414	73	61	0	0	1250

* Fiscal year, July 1-June 30

Table 3-10. 2004 – 2008 Mauna Kea Check-in Station Data: Birds

Data from Hawai'i Island Game Bird Harvest Report

Year*	Quail	Pheasant	Chukar	Francolin	Turkey	Dove	Grouse	Peafowl
2004	791	66	1088	652	129	1	0	0
2005	1676	62	1349	1022	91	3	0	0
2006	1256	150	1338	1353	163	8	0	0
2007	1226	157	1574	1093	209	31	0	0
2008	493	78	627	659	22	0	0	0
Total	5442	513	5976	4779	614	43	0	0

* Fiscal year, July 1-June 30

3.1.4 Commercial Activities

3.1.4.1 Commercial Tours

Commercial tours are a popular way for out-of-town visitors, including cruise ship passengers, to journey to Mauna Kea. Since most rental car companies prohibit the use of their vehicles on Saddle Road, and a 4-wheel-drive vehicle is recommended for driving to the summit, many individuals choose to join an organized tour. DLNR was legally responsible for the commercial permits through 2005, when the UH Board of Regents (BOR) accepted official responsibility to regulate commercial activities on UH-leased lands on Mauna Kea. This change followed the establishment of OMKM and the presence of rangers on the mountain, a presence that DLNR did not have. The BOR gave OMKM the responsibility of issuing permits and collecting fees from the nine commercial operators conducting tours on Mauna Kea. OMKM met with the commercial operators in 2006 to discuss potential changes to the permitting process. Recommendations were reviewed by the MKMB and the Kahu Kū Mauna Council, presented to the

BOR, and accepted in November 2006. OMKM revised the terms and conditions of the commercial permit system. It increased monthly fees from $2 per passenger with a minimum monthly fee of $54 to $6 per passenger or a minimum of $1,200/month. The revision also instituted requirements for insurance coverage, a security deposit, penalties for non-compliance, data reporting via daily, monthly, and annual reports, and attendance at periodic meetings. Each of the nine permitted operators is allowed two evening tours per day, with no minimum restrictions on the number of daytime or sunrise tours until further notice (UH Office of Mauna Kea Management Commercial Tour Use Permit Requirements). The maximum number of passengers per vehicle is 14 with a total capacity including the driver not to exceed 15. The number of commercial vehicles in or on the premises is not to exceed 18 at any time and no more than two standard commercial tour vehicles or one modified vehicle per tour operator are allowed in the VIS parking lot at any one time.

Although the frequency of non-permitted commercial tours on the mountain has decreased substantially (OMKM unpublished data), data shows the number of visitors to Mauna Kea via commercial tours is increasing. DLNR estimates that between 1999 and 2005, these numbers grew from 24,164 to 43,877. During this same period yearly fees collected by DLNR increased from $48,562 to $87,838. The fees now being collected by OMKM are expected to exceed $250,000 in FY2008. Unlike the funds collected by DLNR that went into the State's General Fund, funds collected under OMKM from the permitting process are deposited into a revolving fund used to support management of the mountain.

A typical evening tour picks up passengers from hotels in either Kona or Hilo and arrives at the VIS around 4pm, allowing time for their clients to eat a picnic lunch and acclimate to the altitude. All commercial vehicles must exit the VIS parking lot by 5pm in order to ensure there is enough parking for individual visitors participating in the free evening public stargazing program. After driving to and spending sunset at the summit, each of the tour operator vehicles descends to a pre-determined viewing location, where they set up telescopes for stargazing. Although the commercial tours generally allow little time for hiking, the short trail to the summit of Pu'u o Kūkahau'ula (Pu'u Wēiku) may be an option. After a few hours of stargazing, the clients are returned to their hotels. The entire tour takes between seven and nine hours. Some companies have begun to offer sunrise tours in addition to the popular evening stargazing tours. Tour vehicles are allowed on the summit from ½ hour before sunrise until ½ hour after sunset. Although the tour guides are knowledgeable about the natural and cultural resources of Mauna Kea, and provide safety information to their clients about the potential dangers associated with rapid ascent to high altitude, there is currently no OMKM requirement that informational materials be presented to tour participants.

3.1.4.2 Other Commercial Activities

As the management body with responsibility for the MKSR, OMKM receives requests for various other commercial uses of Mauna Kea include filming, concessions, bio-prospecting, resource extraction, and special events. Filming is the most common request, and while all permits are initiated through the Hawai'i Film office, OMKM has the responsibility for reviewing and approving the applications. OMKM currently receives about 30 requests for filming every year, most of which are granted. Ranger support is provided to film crews on Mauna Kea to educate them and minimize potential negative impacts on the mountain's resources. Currently each use request is considered by OMKM staff for compatibility with the overall mission of the Master Plan. All film requests are reviewed by OMKM, which may consult with observatories and MKSS to ensure the proposed activity would not interfere with their operations.

3.1.5 Cultural and Religious Practices

The summit of Mauna Kea is a *wahi pana* (legendary place), a temple, the dwelling place of the gods and the resting place of many. Hawaiians who adhere to traditional beliefs view themselves as caretakers of the *'āina* (land), with a responsibility to care for the resources in a way that is respectful of their cultural heritage. The relationship between the land and the people creates a strong bond between Hawaiian culture and the landscape. Cultural sites (historic and contemporary) are located throughout the summit region and religious practices are undertaken by a range of practitioners (McCoy et al. 2009). Kahu Kū Mauna was established to provide guidance to the MKMB on cultural matters, and they are consulted for advice on proposed activities or for guidance on how to deal with activities that may have occurred on the mountain (see Section 1.4.2.1).

Although cultural activities may be documented by the rangers in their daily observation reports, there is no estimate of the level of use of the mountain by cultural practitioners. Lake Waiau and the Adze Quarry are destinations of interest, as is the summit pu'u. Signs of activity within the past few years (e.g., shrines, burials) were noted by Pacific Consulting Services, Inc. (PCSI), a firm hired to conduct an archaeological inventory of the MKSR, during their fieldwork (2005 to 2008), including off-trail use throughout the region (McCoy et al. 2009). An *ahu lele* (platform for spiritual offerings) constructed at the summit attracts both cultural practitioners and curious visitors. Rangers noted a drop in visits to the summit when it was temporarily dismantled. Visitors also engage in non-Hawaiian cultural practices, such as a Christian exorcism that was conducted on the summit shrine. Upon observing the activity, the rangers asked OMKM for guidance and did not disrupt the activity, but made sure that participants left no visible traces of their activities (OMKM Rangers 2007). In addition to on- and off-trail use, cultural practitioners may move stones around to build shrines and may leave offerings of perishable and non-perishable items in the summit region. Recent observations have noted many modern day 'crystal shrines' being constructed and a big stone "head" placed on an historical shrine (McCoy et al. 2009).

3.2 Impacts and Threats

The Mauna Kea ecosystem is unique and easily disturbed. Many of the human use impacts stem from uneducated visitors (see Section 4.4, Education and Outreach) and loosely regulated and minimally managed access. Concerns related to access extend to all types of users, including those associated with the observatories and other scientific activities, recreational and commercial users, and those participating in cultural practices. Potential impacts include: pollution, construction activities (dust, traffic, water use), visual disruption, habitat alteration (including disturbance of previously undisturbed natural areas), disturbance of cultural sites, and use conflicts. Threats from various user groups will vary in type and intensity, factors that must be considered when developing management recommendations. Increased emphasis on educating all users through outreach and on-site programs, along with stricter access management has the potential to reduce the severity of threats and their impact on natural resources.

The following sections describe the threats and related impacts of human use to natural resources.[12] Since many of the impacts result from more than one user group, the discussion is organized by type of impact, with relative impact levels from the user groups described to the extent possible.

[12] Many of these threats and related impacts also affect cultural resources. See McCoy et al. (2009) for details.

3.2.1 Cinder Disturbance

The surfaces of cinder cones and adjacent lava fields on Mauna Kea are vulnerable to geomorphologic alterations caused by direct human contact (see Section 2.1.2). Continued hiking and walking over the cones crushes small, individual pieces of cinder leaving trails and footpaths that may negatively affect the viewshed and create dust-sized particles that can be wind-blown. Fugitive dust generated off of trails, unpaved road sections, and other exposed areas, as well as from construction activities is an ongoing concern to resource managers (see Section 3.2.2).

Infrastructure impacts on wēkiu bug habitat. Since the 1960s, approximately 62 acres (25 hectares) of potential wēkiu bug and other arthropod habitat has been lost to infrastructure development, including roads, parking lots and telescope facilities (Richardson 2002). The first comprehensive assessment of arthropods inhabiting Mauna Kea's summit documented the vulnerability of their habitat to construction activities (Howarth and Stone 1982). More construction has occurred since then, resulting in damage to the tephra cinder habitat from crushing, grading, obliteration by infrastructure, and dust generation. One particular development, the construction of the Subaru Telescope (completed in 1999), resulted in loss of habitat on Pu'u Hau Oki, where high numbers of wēkiu bugs had previously been found. DLNR approved a construction grading plan that allowed the summit of this cinder cone to be cut and graded and sidecast material pushed into the crater—filling it to a depth of approximately 40 ft (12.2 m), and excavation of the crater rim, resulting in a horseshoe-shaped crater. The material was subsequently graded to reduce visual impact. A study conducted in 1999 demonstrated that wēkiu bugs were still fairly abundant on Pu'u Hau Oki, in the areas of the inner crater walls and crater bottom that had been modified during construction of the observatory. This suggests that the wēkiu bugs are able to recolonize previously disturbed areas (Howarth et al. 1999).

The main activities that disturb cinder include

- Road grading and travel by vehicles
- Hiking and off-road vehicle use
- Activities associated with infrastructure, such as construction, decommissioning, and removal; installation and maintenance of utilities
- Scientific inquiry

Road grading and travel by vehicles. Road grading is conducted approximately three times per week on the unpaved portion of the Summit Access Road, to eliminate washboarded areas. Grading activities also spread cinder that is collected from road kickouts along the length of unpaved sections of the access road. An extremely porous and friable material, the cinder is easily crushed by vehicles traveling up and down the mountain. In 2008, gravel from neighboring Pōhakuloa Training Area Rock Quarry was brought in as substitute for the cinder (Koehler 2008). Potential secondary impacts from importing gravel include introduction of invasive species and the use of bonding chemicals of unknown fate and transport through the environment. Accidents are also possible, and disturbance of native cinder may result if the vehicle is pushed off of the road or from recovery efforts. Between mid 2001 and early 2008, OMKM rangers reported 52 accidents along the access road from Hale Pōhaku to the summit, 41 of which occurred above Hale Pōhaku (OMKM unpublished data).

Hiking and off-road vehicle use. Within MKSR there are several trails that could be considered established, however only four are monitored by OMKM rangers: the trail to Lake Waiau, the Mountain Trail, the trail to Pu'u Poliahu, and the trail to the summit. There are no permanent markers identifying any of the trails. During times of no snow, the established trails are easily seen and provide well-defined paths guiding visitors to places of interest. When snow is present, hikers choose more random paths across the landscape. New trails are created when visitors or researchers opt to explore new terrain, compacting substrate, disturbing areas adjacent to the path, and expanding the existing trail network.

New trails are easily etched into the landscape making them obvious to other users and impacting the existing viewscape (see Section 2.1.2) (see Figure 3-9). Due to lack of signage and a maintained trail network, a faint trail used infrequently may be discovered by others and become more established and impacted. Trails exposed to high use that have not been designed to minimize impacts to viewshed or reduce vulnerability to erosion processes may accelerate local surface erosion and viewshed impacts. Such trails may become hazardous as the slope becomes steeper. Over time, many small irreversible impacts such as ground cover disturbance and compaction may have a negative effect on existing biological communities, such as the arthropod community that requires loose cinder. Except where the snow is deep enough to completely cushion the impacts of footsteps, these types of impacts to the ground surface most likely occur whether snow is present or not. In addition, unrestricted access during the winter months may give the false impression that similar activities are non-problematic when the snow is gone, which is not the case.

Recreational use of 4-wheel-drive and other all-terrain vehicles (ATVs) is known to occur on the lands surrounding the MKSR. Not permitted within MKSR property boundaries, instances of such activity have been very infrequent, and are promptly stopped by MKSS personnel and OMKM Rangers. In areas where cinder features are located, impacts from the vehicles are similar to those associated with foot trails: crushing of cinders, compaction of surfaces, and generation of dust. The primary differences between foot and vehicle trails are in the severity of the impacts due to heavier weight of ATVs and their larger "footprint" and in the potential for petrochemical spills.

Figure 3-9. Hiking Trail to Summit of Mauna Kea

Infrastructure. The cinder cones of the Mauna Kea summit region are some of the most pristine and well preserved cones anywhere in Hawai'i. Of the more than 20 cinder cones in the MKSR, only five show signs of human modification from the construction of observatories and supporting infrastructure (Pu'u Poli'ahu – road; Pu'u Kea, Pu'u Hauoki and the unnamed cone immediately west of Pu'u Hauoki – grading for observatory sites; south and west slopes of Pu'u Wēkiu – road construction) (Lockwood

2000). Some of this change may be irreversible, as restoring sites to their pre-impact topographic geometries will prove nearly impossible, such as has occurred on cinder cones that have been flattened or craters filled (see Section 4.3). Siting of new or redeveloped telescopes on existing or previously disturbed sites can help minimize impacts to the biological and physical environments. However, future proposed facilities may impact previously undisturbed areas. Decommissioning activities will likely involve some earth movement when removing structures or re-grading sites, although most of the area will have been previously disturbed. Infrastructure installation and improvements associated with new or redeveloped facilities (e.g., power supply and communications infrastructure, wastewater treatment facilities) may necessitate sub-surface work, including excavating utility trenches and other structures. Construction activities can disturb cinders through crushing by heavy equipment; excavation and disposal of excavated material; grading and filling; drilling for piles, piers, footings and foundations; and destabilization or sidecasting of cinder associated with removal of retaining walls. Both construction and decommissioning will result in increased vehicular traffic and higher axel weights.

Scientific inquiry. Geological and hydrological research at Mauna Kea has included limited invasive investigations (e.g., excavating, drilling holes) that disturbed both surface and sub-surface features. The tools, machinery, equipment, or chemicals used as part of these investigations are potential sources of direct impacts to surface and sub-surface resources. Impacts to the geology and associated viewscape can also occur as researchers walk to and from specific sites, disturbing and crushing cinder and incising trails into the landscape.

3.2.2 Air Pollution

Currently the air quality at the summit of Mauna Kea is thought to be quite good (based on air quality measurements taken on Mauna Loa), although it is not actively monitored. Human-caused contributors to air pollution at the summit include vehicle exhaust, chemical fumes from observatory construction and maintenance activities, and fugitive dust from road grading and construction or other activities conducted on unpaved surfaces. Although air pollution is not now considered to be a pressing issue, as vehicular traffic to the summit increases, the impact of vehicles on air quality, from exhaust and dust generation, can be expected to increase as well.

Dust deposited on snowfields has the potential to decrease surface albedo, which accelerates snow melt, and increases thaw-depth of permafrost (Walker and Everett 1987). Additionally, fine, aerosol-sized particles that become suspended in the airshed above the telescopes may adversely affect cosmic viewing.

Air pollution (including dust) can impact vascular plants in several ways, including greatly reducing photosynthesis, transpiration, and water use efficiency; increasing leaf temperatures (with potentially serious effects during periods of high temperatures); and by lowering primary production (growth) (Sharifi et al. 1997). Air pollution and dust are also known to impact the growth of lichen and moss and community diversity (Hutchinson et al. 1996).

Dust impacts on wēkiu bug habitat. It is hypothesized that deposition of dust can adversely impact wēkiu bug habitat by filling interstitial spaces between cinder, one of the vital components of the bugs habitat (see Section 2.2.3) (Howarth et al. 1999). In addition to filling the interstitial spaces used by wēkiu bugs, dust can have a direct impact on some insects, by acting as a desiccant (Alstad et al. 1982). It is unknown whether wēkiu bugs, or other summit arthropods, are susceptible to desiccation by dust. Although these species are adapted to living in very arid conditions, a heavy dust layer could potentially desiccate wēkiu bug eggs, or make it more difficult for wēkiu bugs to obtain the moisture they need from substrate (Eiben

2008). Additionally, a heavy layer of dust could bury prey items, making foraging more difficult (Eiben 2008).

The main activities that have the potential to generate air pollution include

- Road grading and travel by vehicles
- Activities associated with infrastructure, such as construction, decommissioning, and removal; installation and maintenance of utilities

Road grading and travel by vehicles. Road grading and vehicle traffic are currently the most significant contributors to dust generation on Mauna Kea (see Figure 3-10). Vehicles crush and kick-up cinder as they travel on the unpaved portion of the Summit Access Road or the 4-wheel-drive roads, creating a great deal of airborne dust. The dust disperses along the road corridors, coating the ground surface. Vehicle exhaust is another potential contributor to air pollution. See Section 2.1.5.1 for more information on air pollution generators and potential impacts to air quality.

Figure 3-10. Road Grading on Mauna Kea Summit Access Road

Infrastructure. Construction and maintenance activities contribute to air pollution through vehicle and heavy equipment exhaust, dust generation, and use of volatile compounds during building construction and routine maintenance (cleaning). The use of best management practices to control dust during these activities (e.g., using water to wet down sites) helps to limit the amount of airborne particles. The impacts to air quality from other pollutants are likely to be temporary because the nearly constant winds at the summit would quickly disperse the pollutants these activities generate.

3.2.3 Substrate and Groundwater Contamination

Contamination of soils, substrates, Lake Waiau, groundwater, and aquifers is a potential side effect of a variety of human activities on the mountain. If significant, contaminant releases may have adverse effects on biological and water resources, human health, and visual resources (e.g., discoloring). Spills can fill interstitial spaces or result in the disturbance of cinder substrate. Transport of contaminants through the substrate has the potential to impact the quality of both surface water and groundwater. Direct toxic impacts on flora or fauna are also possible. The highest probability of impact is from petroleum products (e.g., fuel for vehicles and backup generators, lubricants, and cleaning fluids) and human waste. The main activities that have the potential to impact substrate and water quality include

- Travel by vehicles
- Release of hazardous material and petroleum product use by observatories and support operations
- Transport of hazardous materials off-site
- Sewage generation

Travel by vehicles. Vehicles are a potential pathway for release of liquid petroleum products into the environment, primarily through leaking (e.g., fuel lines, break lines, coolant), but also as a result of accidents and spills. Little information exists on the current extent of this problem, but it is possible to make some informed predictions about how the range of users, vehicle types, and use-levels relate to the potential threat level. Four-wheel-drive vehicles are prone to under-carriage damage that may not be apparent to operators, resulting in fugitive releases of contaminants. Their use in off-road environments puts less-frequently visited and monitored areas at risk. Recreational users traveling to Mauna Kea are either tourists in rental cars or local residents. Although vehicles visiting the summit stay on the road, accident-related discharge of contaminants and generation of fugitive contaminants from leaks are potential impacts. Vehicles operated by staff (observatories, OMKM, MKSS) comprise a high percentage of traffic to the summit, but are regularly maintained to ensure reliable performance, which reduces potential of fluid leakage. The frequency of use of vehicles and machinery for construction and maintenance depends upon need and is variable. While these vehicles are also potential sources of petroleum leaks, they, like the staff vehicles, are subjected to regular inspections to minimize potential contaminants (Nahakuelua 2008).

Use of hazardous materials. Hazardous materials utilized and stored at the observatories are listed in Table 3-7. The presence and use of hazardous materials at the observatories and the transport of hazardous waste off-site introduces the possibility of spills or leaks. There have been documented incidents, beginning in 1979, involving spills or leakage of hazardous materials (e.g., mercury, diesel fuel, ethlyene glycol, and sewage) (see Table 3-11, (NASA 2005)). These incidents were reported to DOH, and in all cases, clean-up was conducted in accordance with emergency spill response procedures. Some spills occurred inside buildings or on concrete structures, limiting their impact on the outside environment and potential impact on natural resources. Elemental mercury is used in four of the telescopes and is of particular concern to human health. The best available information suggests that while mercury spills have occurred (NASA 2005), spilled amounts occurred during mirror re-aluminizing activities and were small (McNarie 2004). Backup generators use diesel fuel, which is stored on-site. Secondary sources of contamination from generator equipment include waste oil and coolant (e.g., ethylene glycol). Any discharge of lubricants or solvents into the sanitary waste stream or directly onto the landscape outside the buildings could be problematic. In the past, there have been instances in which cinder was contaminated and then excavated to contain the potential effects of the spill; this approach has the secondary effect of cinder disturbance. Impacts are minimized by adhering to approved plans for storage, transport, and emergencies.

Sewage generation. The cesspools, septic tanks, and associated leach fields at the summit and Hale Pōhaku have been designed to meet State DOH permit requirements for sanitary waste systems. With telescope facility upgrades, many of the original cesspools have been replaced with septic tanks. Currently there are eight septic tanks with leach fields or disposal pits and three cesspools (NASA 2005). Solid and liquid waste discharged into these approved systems should minimize direct discharge of solid waste in the effluent and into the ground and allow for physical and bio-processing. However, the fate and transport of the effluent after discharge, and its likely impact on groundwater (either shallow or deep) is almost entirely speculative because the hydrogeology of the summit is poorly understood (see Section 2.1.3).

Surface or sub-surface contamination as a result of sewage leakage is potentially problematic. A two-gallon sewage spill from an incorrectly installed septic line contaminated cinder and snow in wēkiu bug habitat in the Pu'u Hauoki crater in 1998 (NASA 2005). Although the impacted material was removed and the leak repaired, other leaks outside the sewage systems could result in disturbance and damage to cinder substrate, including wēkiu bug habitat. In March 2008 approximately 500-1,000 gallons of sewage overflowed from the VIS septic tank onto the ground and was reabsorbed. The incident was reported to DOH (Koehler 2008).

Human waste from visitors using the area is another potential pathway for contamination of substrate and sub-surface water. Public restroom facilities at the summit include portable latrines at the UH 2.2m telescope parking lot and the parking lot just past the junction of the access road and the summit loop, and indoor facilities in the Keck Observatory visitor's gallery. With limited public facilities available for use, the greatest possibility for impact is most likely during snow-play days when there are hundreds of people in the summit area. Portable latrines are pumped weekly and the biosolids trucked off the mountain (see Section 3.1.1.2.6). The potential for accidental spills during weekly transport of the biosolid effluent and associated flush chemicals off the mountain is also a concern.

3.2.4 Erosion

Erosion is a natural process whereby wind, water or ice detaches soil particles and transports them from their original location. In general when water, in either solid or liquid phase, is the eroding agent, movement of particles follows the force of gravity. However, wind transported particles can be lifted and carried to higher elevations in ascending air parcels, resulting in deposition either upslope or downslope. Erosion rates are a function of the erodibility of ground surface and erosivity of the agent inducing particle displacement and transport. Human activities that reduce groundcover and concentrate overland flow increase erodibility and erosivity respectively, resulting in increased erosion rates. The summit area of Mauna Kea is subjected to all three agents of erosion. Due to the prevalence of wind on the mountain, exposed areas, including roads and trails are vulnerable to erosion by wind nearly year round. Erosion rates by water at the summit area are regulated in part by the high porosity of the surface cover allowing infiltration of precipitation into the ground surface, and by limited precipitation. In areas where compaction has occurred infiltration is reduced, resulting in increased runoff and erosivity. Below the summit region, in areas such as Hale Pōhaku, where surface conditions are dominated more by soil than volcanic substrate, erosion rates are higher due to the greater erodibility of the soils (Gerrish 1979). Activities that increase the potential for accelerated erosion include

- Road grading and travel by vehicles
- Hiking and off-road vehicle use
- Activities associated with infrastructure, such as maintenance and construction
- Concentration of storm water runoff generated off buildings and impervious areas

Table 3-11. Hazardous Material and Sewage Spills Associated with Astronomy Operations on Mauna Kea
Data from (NASA 2005; Koehler 2008)

Date	Location	Material(s)	Incident/Response
1979 (estimated)	CFHT Facility (indoors)	Hydraulic fluid	A hydraulic system filter clogged, leading to the backfilling of a drain, which overflowed and caused roughly 0.5 gal (1.9 l) of hydraulic fluid to spill onto an optical tube. There is also anecdotal recollection of a spill and cleanup related to a burst hydraulic pump in the early years of observatory operation.
1982	Now known as the summit area construction staging area	Diesel fuel	During a biological survey, Howarth and Stone (1982) noted an area of staining (194 ft^2 (18 m^2)) on the ground near a temporary generator and suspected a diesel fuel spill. The generator has since been removed.
1989	NASA IRTF (indoors)	Mercury	A mercury spill (20 lb (9 kg)) resulted from the puncture of the primary mirror support ring. Cleanup was performed in accordance with written observatory procedures using commercial products designed for mercury recovery.
October 3,1990	CFHT Facility (indoors)	Mercury	Mercury spill from a pinched secondary mirror support bladder. Facility was evacuated temporarily during cleanup. Approximately 0.41 lbs (180 g) spilled but fully contained within the observatory building.
1995	W.M. Keck Observatory (indoors)	Mercury	Three mercury spills have occurred at the observatory: – August 10, 1995, while working on f/15 secondary, resulting in a 1 tsp (5 ml) spill. – September 15, 1995, while working on f/15 secondary mirror, resulting in a 7 tbsp (100 ml) spill. – November 6, 1995, while transferring mercury between containers, resulting in a spill of 1 to 2 tsp (5 to 10 ml). All three spills occurred in the mirror handling room, and were cleaned up promptly. None resulted in any mercury seepage into the ground or the septic system. As a result of these incidents, the observatory revised mercury handling and response procedures. No subsequent mercury spills have occurred.
November 3, 1995	Mauna Kea Access Road near Very Long Baseline Array	Diesel fuel, engine and hydraulic oil	Truck involved in construction of SMA overturned, causing fuel tank and engine lines to rupture, releasing approximately 60 gal (227 l) of fluids onto surface cinder; impacted media were excavated and removed by truck owner within 24 hours.
September 3, 1996	Subaru Telescope	Ethylene glycol	Release occurred when a pallet carrying two 55 gal (208 l) containers failed, and the containers fell to the cinder and ruptured. Cleanup was performed immediately to recover free liquid and excavate affected cinder. All contaminated materials were bagged and disposed of.
1998 (estimated)	UH 2.2-m Telescope facility (indoors)	Mercury	More than five years ago a few drops of mercury escaped on several occasions while the mirror support ring was being drained or refilled during the recoating process. These were cleaned up according to the UH mercury cleanup procedures.

Date	Location	Material(s)	Incident/Response
January 15, 1998	Subaru Telescope	Sewage	Improper installation of septic tank led to freezing, which created a clog and a spill of about 2 gal (7.6 l) on the ground and snow. A plumber repaired the clog, and the observatory added cinder atop the septic system to insulate against freezing.
June 5, 1998	CFHT facility (indoors)	Mercury	In order to align a lens, a pool of mercury was lifted to the bottom of the lens to create a reflected image. During the procedure about a "thimble full" of mercury spilled from an overflow dish to the concrete floor. The mercury was cleaned up quickly. Afterward, recommendations were made for additional training and better equipment for containment.
1990 to 2000 (date estimated)	Caltech Submillimeter Observatory	Hydraulic fluid	In past years, on a few occasions, small amounts of hydraulic fluid seeped out of joints in the dome hydraulic system and dripped onto the concrete pad under the dome. No fluid traveled beyond the concrete pad. An ongoing hydraulic system inspection program detects any seepage source. The source is eliminated, and all traces of fluid on the concrete pad are immediately cleaned up.
2003 (date estimated)	Hale Pōhaku	Crankcase oil and hydraulic fluid	Crankcase oil and hydraulic fluid leaked from a piece of equipment. The soil was excavated, tested, and sent to a landfill in compliance with State health department regulations. The facility has taken measures to reduce the likelihood of this type of spill recurring.
2003	Hale Pōhaku	Transmission oil	Two oil drips beneath an old truck used to transport mirror for the Joint Astronomy Center. Total amount of the leakage estimated at less than 1 qt (950 ml). The Joint Astronomy Center dug out cinders under drip areas and removed them for disposal. Absorbent pads were used to stop further drips; the truck was removed.
2003	Smithsonian Astrophysical Observatory Submillimeter Array	Hydraulic fluid	Hydraulic leak onto asphalt, about 0.5 qt (473 ml), caused by decayed seals. Cleaned using approved "pig-mat" absorbent material, which was disposed of appropriately.
1998 to 2004	Caltech Submillimeter Observatory	Sewage	A review of records indicates five overflows of the domestic wastewater system occurred over a 16-year period. The overflows were accidental and small, on the order of several liters (gallons).
February 2004	Smithsonian Astrophysical Observatory Submillimeter Array	Diesel fuel	Diesel leak onto asphalt, less than 4 qt (3.8 l), caused by decayed seals. Cleaned using approved "pig-mat" absorbent material, which was disposed of appropriately.
March 30, 2004	W.M. Keck Observatory	Propylene glycol	The spill occurred during testing of an auxiliary glycol cooler when one of the hoses accidentally became dislodged from its barbed fittings. Spill estimated between 20 to 30 gal (76 to 114 l), with approximately two-thirds escaping outside the facility. The California Association for Research Association (CARA) Safety Officer handled spill response; affected cinder was contained, removed, and disposed of at a local landfill. The observatory notified OMKM, which advised on disposal.
March 22, 2008	Hale Pōhaku	Sewage	Approximately 500-1,000 gallons of sewage overflowed onto the ground from the VIS septic tank – due to some blockage. The incident was reported to DOH. The waste on the ground was quickly absorbed and back to normal within a few days.

Road grading and travel by vehicles. Vehicular traffic and road maintenance activities accelerate the rate of erosion and material movement from and along the unpaved section of the Summit Access Road. As they drive up and down the mountain, vehicles crush gravels and push materials off of the road surface into roadside ditches and culverts. Larger pieces collect there until removed by maintenance crews. Smaller sediment particles are transported down the mountain in the roadside drainage ditches and in gullies, depositing in places where their movement is obstructed or in level sections of the ditches. Storm water runoff moves through ditches and is often discharged from culverts onto unprotected surfaces creating headcuts[13] and erosion; this is particularly evident at off-road drainage locations surrounding the Hale Pōhaku facilities.

Hiking and off-road vehicle use. Vehicle and foot traffic in unpaved areas can increase erosion, particularly at Hale Pōhaku where groundcover is comprised of finer particles than found in the summit region. Also, more people visit Hale Pōhaku, including visitors, residents, and staff. For example, two of the more popular hikes are the West Ridge and Puʻukalepeamoa trails located just outside the UH Management Areas boundary and immediately across from the VIS. These trails, in addition to being on steep slopes and consisting of poorly designed pathways, are at many points completely devoid of cinder groundcover, leaving only extremely fine particles and a compacted trail base. The compacted base of the pathway limits the amount of water that can percolate into the ground, increasing the volume of water flowing downhill and removing sediment along the way. On the steeper sections, the finer particles create a slippery surface and hikers step out onto adjacent vegetated and rocky areas with better footing. This results in an increased footprint of the path, accelerated erosion, and scaring of the landscape.

Like foot traffic, ad hoc vehicle paths can also result in the concentration of runoff and associated increases in erodibility and soil loss. While immediate impacts from vehicles are likely more severe than those from foot traffic, due to the greater weight and larger footprint of the vehicles, in both instances, reoccurring disturbance of any area will cause significant compaction and degradation, substantially increasing erosion potential and extent.

Infrastructure. As a result of the low amount of precipitation and the high porosity of the ground surface at the summit, there is no evidence of erosion by surface runoff at any of the existing observatory sites (NASA 2005). During preparation of this report the authors visited locations throughout summit area and did not observe significant erosion caused by runoff off observatory structures. Runoff is generated from the impervious sections of the Summit Access Road and is routed into drainage ditches aligned along the road shoulder. Spaced intermittently along the Summit Access Road, large culverts underneath the road drain water from the upslope or mountain side of the road to the downslope side. While the volume of water moving through these systems is often small and intermittent, over time the fragile ground cover where the water pours out of the culverts is impacted. Movement of the substrate is evidenced by rocks found in the drainage ditches and cinder-filled drainage holes of the retaining walls (see Figure 3-11). Silt, rocks and small boulders fill culvert inlets, and rills and gullies at culvert mouths gradually become larger and more incised as the water travels downslope (see Figure 3-12). These processes are intermittent and changes are gradual, but they have the potential to eventually undermine the integrity of the road and negatively impact the viewshed.

Road drainages are cleaned approximately every four to five years and cinder buildup behind retaining walls has necessitated emptying only twice within the past 18 years (Koehler 2008). Construction activities can increase the potential for erosion. At summit locations, construction-related disturbance and

[13] Headcut is a location where a sudden change in ground elevation occurs, usually at the leading edge of a gully. Headcuts often result in rapid erosion and incision of the runoff channel.

crushing of cinder ground cover would most likely increase displacement of cinder to down-slope locations and increase the potential for dust generation and its movement offsite.

Due to greater visitor counts and concentrations at Hale Pōhaku than at the summit, erosion impacts appear to be more extensive. Etched pathways and blocked drainage culverts were noted in the vicinity of the VIS parking lot and there are currently no sidewalks, signs, or other infrastructure guiding the visitor to specific destinations and away from 'natural' areas. When the parking lot is full, visitors park along the Summit Access Road. This creates a potential safety issue for those walking along roadside drainages, as well as concern for impacts to the landscape due to trampling. The unsightly appearance of the area may also have a negative effect on how visitor perceive the need to care for the mountain (see Figure 3-13).

3.2.5 Solid Waste Generation

Litter and larger fugitive trash impacts the visual aesthetics of the MKSR and degrades the landscape. In addition, it may interfere with deposition of food resources in the aeolian ecosystem, shade out vegetation, and damage geological resources upon impact. Food waste may provide a resource to support pest species and predators of native biota. Collection of debris is also of concern as the removal activity may do more harm than the actual debris if people or vehicles crush cinder in sensitive habitats (Howarth et al. 1999). The main activities and users that produce solid waste include

- Observatories and support facilities (trash)
- Construction (materials)
- Recreational users (litter, snow-play debris)
- Commercial tour groups (litter)
- Cultural practices (offerings)

Trash generated by the observatories and Hale Pōhaku is contained, collected on a regular basis and transported off-site to approved sanitary waste facilities. The potential exists for some of this trash to escape collection or to be blown about as a result of high winds at the summit. Similar concerns exist for construction material and debris, though best management practices are implemented to reduce the extent. Recreational and commercial tourists also contribute to debris found on the mountain. Litter (e.g., cigarette butts, plastic bags, broken glass) may result from the active discarding of waste or inadvertent disposal (e.g., as a result of high winds). Rangers report pick-up trucks heading to the summit on snow days with loose trash in their beds, which is likely to blow out in the windy conditions at the summit (OMKM Rangers 2007). In the spring, when the snow melts, snow-play trash is found on the mountain, including broken skis, snowboards, and general litter. While not "trash," cultural and spiritual offerings are another source of uncontained material often left in the summit area.

Figure 3-11. Mid Mountain Drainage Infrastructure

Figure 3-12. Summit Road Drainage Gully

Figure 3-13. Off-Road Parking and Erosion Across from the VIS

3.2.6 Noise Generation

The primary receivers that might be disrupted by excessive noise are the human users of the mountain (e.g., scientists, cultural practitioners, recreational users). There is also the potential that noise generated by certain activities or systems would have an impact on biological resources. The main activities that produce sound to levels above natural background resulting in the generation of noise include

- Travel by vehicles
- Observatory operations
- Construction operations (e.g., heavy equipment use, drilling, excavation)

Ambient sound levels at Mauna Kea are low, with vehicle traffic and wind providing the dominant background. Observatory operations create minimal noise, while construction activities create intermittent, though sometimes significant, disruptions (see Section 2.1.5). An example of one potential noise impact illustrates the types of considerations that are currently evaluated prior to implementing a project. The Subaru Telescope requested permission to install a Sound Detection and Ranging (SODAR) unit on the roof of their control building to monitor local wind speeds and the thermodynamic structure of the atmosphere. In response to concerns from the MKMB, studies were conducted to evaluate the transmission of sounds (called "pings") from the system. Results of this test, combined with an expert opinion from a member of the MKMB Environment Committee, provided information allowing the conclusion that the frequency and decibel level of the pings would not pose a problem for the occasional bird in the vicinity or for resident insect life.

3.2.7 Invasive Species

The potential impacts of invasive species on the fragile ecosystems of Mauna Kea are described in detail in Section 2.2. Many of the mountain's native ecosystems have already been impacted by introduced animals and plants. However, invasives remain a continuing threat. Virtually any user, vehicle, equipment, or material that comes to Mauna Kea can be an unintentional carrier. Although Mauna Kea's higher elevations are somewhat insulated from invasives, due to its inhospitable environment, certain species have been able to survive. The main activities and users that may introduce invasive species include

- Construction and maintenance (materials, vehicles, equipment)
- Road grading (importing gravel)
- Landscaping (materials, at lower elevations)
- Observatories and support facilities (materials, vehicles, researchers)
- Recreational users (hikers, hunters; footwear and vehicles)
- Cultural practitioners (offerings)

Construction and maintenance. Construction and maintenance activities may introduce invasive species to Hale Pōhaku and MKSR through several pathways. Invasive species can be transported on footwear or tires, on heavy equipment, in fill material, or can be contained in shipments of materials. Most species introduced through these pathways will be small (seeds, insects), although larger species (such as rodents) may be found in shipping containers containing supplies or equipment.

Road grading. Like construction activities, road grading can introduce invasive species through contaminated materials (e.g., ants living in gravel brought in for the road) and on the equipment used to deliver gravel. The grading equipment is housed at Hale Pōhaku and can pick up "hitchhikers" at the storage yard and carry them up the summit road. Until 2008, all material used on the roads was cinder obtained from areas adjacent to the roadway (Koehler 2008). At the request of MKSS, the MKMB Environment Committee reviewed and concurred with a proposal to import gravel from a quarry located within the Army's Pōhakuloa Training Area (PTA). Required inspection protocol includes thorough inspection of all gravel brought to Mauna Kea for ants by an entomologist and wash-down of the delivery trucks (MKMB Environment Committee 2007).

Landscaping (lower elevations). Landscaping materials, such as plants and mulch, used at facilities can also harbor invasive species, as can equipment, clothing, and the shoes of the landscaping staff. Currently, minimal amounts of landscaping materials are utilized at Hale Pōhaku and there is no outdoor landscaping at the summit facilities. According to the terms of the lease between the Board of Land and Natural Resources (BLNR) and UH (Lease No. S-4191), "In order to prevent the introduction of undesirable plant species in the area, the Lessee shall not plant any trees, shrubs, flowers, or other plants in the leased area except those approved for such planting by the Chairman." Invasive species such as eucalyptus trees and California poppies have been purposefully planted in the past at Hale Pōhaku as part of landscaping or reforestation projects.

Observatories and support facilities (materials, vehicles, researchers). Invasive species can be accidentally transported in the goods and belongings of visiting scientists, on and in equipment transferred from other astronomical facilities or manufacturing plants, and via vehicles traveling to and from other parts of the island to the mid-level and summit facilities. There is already at least one high-elevation-adapted invasive species at the summit (a ground-hunting spider, *Meriola arcifera*) that possibly arrived from another astronomical site in South America (see Section 2.2.2.2.2). Researchers (such as biologists) who use off road vehicles (or hike in muddy areas) at other locations on the Big Island and then travel to Hale Pōhaku or the MKSR are also potential vectors for invasive species. However, it should be noted that a good proportion of these researchers are aware of the problem and clean their equipment and shoes before moving between areas.

Recreational users (hikers, hunters). Hikers and hunters can inadvertently function as vectors and import invasive species to Hale Pōhaku and MKSR through seeds stuck in the mud on their hiking shoes and vehicle tires, and through deliberate releases (to establish populations of game species). Most of the deliberate introductions of game species (birds, mammals) occurred in the past, but it is possible that new introductions could still occur illegally. Hunters operating 4-wheel-drive vehicles are likely to spread seeds and invertebrates from other portions of the island, due to their extensive use of unpaved hunting roads, which often have plants, especially weedy species, growing in or alongside of them (Thomas 2008). Anyone who has driven a 4-wheel-drive vehicle off-road is familiar with the large amount of material picked up from mud puddles, roadside weeds, and dusty areas. Although hunters may have an impact on the areas' natural resources through general access and use, the removal of non-native vertebrates (e.g., sheep, mouflon) has a beneficial effect on the habitat by eliminating individual animals that damage native vegetation. However, current hunting rates are not high enough to eliminate the population of feral sheep on Mauna Kea, even in conjunction with current feral ungulate control efforts conducted by DOFAW (see Section 2.2.4 and Section 3.1.3.5). Tourists arriving at Hale Pōhaku and MKSR in rented vehicles are also capable of spreading invasive species, although to a lesser extent, due to the fact that they usually stick to paved roads and their vehicles are regularly washed at the rental agencies.

Cultural practitioners. Cultural practitioners can spread invasive species in ways similar to recreational users. In addition, many cultural practitioners bring items that are intentionally left on site as offerings. These items may harbor invasive species, unbeknownst to the practitioners, such as weed seeds and insects, or they may attract non-native birds or small mammals looking for food.

3.2.8 Habitat Alteration

Habitats on Mauna Kea are home to unique species, some found nowhere else in the world. Any discussion of habitat disturbance necessarily involves other threats, including cinder disturbance, invasive species, and pollution. The impacts of habitat alteration on resident species are described in Section 2.2. The main activities and users that cause habitat disturbance include

- Construction and infrastructure
- Off-road vehicles and off-trail hiking
- Recreational users (hikers, snow-players, and hunters [through off-trail use and feral ungulates])
- Cultural practitioners (off-trail use)
- Scientific inquiry (off-trail use, direct sampling)

Construction and infrastructure. Previous summit development has disturbed areas of wēkiu bug habitat, and construction at Hale Pōhaku has resulted in the removal of small areas of māmane woodlands. Building facilities in new areas at the summit may disturb the habitat of lichens and resident native arthropods in areas of new facilities and associated construction. Structures may alter wind patterns, change the pattern of snow drifts, and affect the natural deposition of aeolian drift that supports the wēkiu bug and other arthropod populations. The alteration of wind patterns could either enhance or reduce the quality of wēkiu bug habitat, depending on how windflow patterns are altered.

Off-road vehicles and off-trail hiking. Off-road vehicle use and off-trail hiking can impact habitats through crushing of cinder (MKSR) or increased erosion (Hale Pōhaku), and through direct damage to native flora and fauna (e.g., crushing, trampling). There are no permanent barriers preventing vehicles from leaving the Summit Access Road, although access points where off road driving is known to occur are blocked with rocks. It has been postulated that people may be less aware of the sensitive habitat when they visit Mauna Kea in the summertime, since they are used to having free range over the slopes in the winter (OMKM Rangers 2007).

Recreational, cultural and scientific uses. Hikers, hunters, cultural practitioners, and researchers can all alter habitat by trampling, removing plant and animal material, introducing invasive species, creating new trails and creating new structures, such as shrines. The past has seen the greatest and most devastating impacts to the subalpine and alpine plant communities on Mauna Kea through the intentional maintenance of feral ungulate populations for recreational hunting. These feral ungulates have nearly destroyed the māmane woodlands and have reduced the once abundant Mauna Kea silversword populations to near zero. The impact of feral ungulates on the natural resources of high elevation areas of Mauna Kea far outweigh any other impact from human activities within the subalpine and alpine[14] environments. Other invasive species, introduced accidentally or on purpose, have also contributed to the destruction of the subalpine and alpine communities. Invasive plants (primarily grasses) work in conjunction with feral mammals to suppress regeneration of māmane woodlands. See Sections 2.2.1 and 2.2.4 for more information.

3.2.9 Sample Collection and Incidental Take

Human activities on Mauna Kea can result in the reduction of plant and animal populations through both sample collection and incidental take (the unknowing or accidental killing or removing of an organism). Sample collection occurs mainly as the result of scientific research conducted at Hale Pōhaku and the

[14] Excluding the summit (alpine stone desert) ecosystem, where feral ungulates do not occur.

MKSR; amateur collectors and tourists also occasionally collect plants and animals. For example, some research activities (e.g., trapping, collection of botanical samples) may result in the death or removal of the organism being studied. Arthropod sampling often results in the death of the specimens, even when researchers use live trapping methodologies (Englund et al. 2002; Englund et al. 2007). Most studies endeavor to employ sampling methodologies designed to minimize direct and incidental take, but some take does occur. Incidental loss can occur through habitat disturbance by repeated access to an area (e.g., trampling and crushing from hiking or driving), during construction activities, accidents, and fires.

3.2.10 Fire

Although there are few vegetated areas susceptible to fire in the MKSR, fire is a potential threat to habitat in the subalpine zone at Hale Pōhaku. Prior to the introduction of invasive grass species, wildfires were most likely infrequent in the subalpine zone. Invasive grasses increase the risk of fire in the subalpine zone by providing a source of continuous fine fuels in areas that previously had naturally discontinuous fuel beds, due to the patchy nature of the subalpine communities (Smith and Tunison 1992; Hess et al. 1999). These risks have also become greater with the reduction in animal populations that once fed upon the invasive grasses, reducing their fuel load. Potential sources of ignition include vehicles from both accidents and malfunctioning exhaust systems (especially on unpaved hunting roads), improperly disposed cigarettes and matches, arson, camp fires at lower elevations, lightning, and military training activities at PTA. Three major fires have been documented by MKSS, all located on the southern slopes of Mauna Kea, five to ten miles east of the Summit Access Road and below 9,000 feet (Koehler 2008). Control efforts were provided by the County Fire Department, the State Department of Forestry and Wildlife, and Pōhakuloa Training Area. MKSS donated water to the State Department of Forestry and Wildlife to help control these fires.

3.2.11 Climate Change

It is hypothesized that global warming will alter the climate of the Hawaiian Islands by inducing changes to precipitation frequency and amounts. This in turn is expected to alter the spatial distribution and density of flora in both the subalpine and alpine ecosystems of Mauna Kea. The exact changes to the precipitation and temperature regime and subsequently the plant life are unknown due in part to the complexity of the climatic system and the data necessary to generate precise model outputs. It is unlikely that the human-use activities occurring on Mauna Kea are contributing proportionally more to climate change than those occurring at other elevations in Hawai'i, or at other locations on the Earth. That is, all human activities that involve the consumption of fossil fuels are contributing to global climate change, and any activities that can reduce this consumption will help reduce the impacts of climate change. The potential impacts of climate change on Mauna Kea high-elevation ecosystems are discussed in detail in Section 2.2.1.3.6.

3.2.12 Cumulative Impacts

Each human use or activity that occurs on Mauna Kea may have multiple impacts. Table 3-12 shows the interrelationships between the activities that occur on Mauna Kea and the threats to natural resources identified in the above sections. This table demonstrates the need for a holistic approach to natural resources management—simply controlling one human use or activity is unlikely to eliminate the associated threats. When attempting to reduce the impact of a threat to natural resources, all sources of the threat must be examined and if found to be significant, addressed.

Although the threats to natural resources occurring from the various human uses of Mauna Kea are discussed separately above, in reality, the overall impacts of human activities (combined with those of natural events such as weather patterns) are often greater than the sum of their individual parts. Threats to the survival of the Palila offer a good example of this. The Palila faces the cumulative impact of habitat destruction, the spread of invasive plants, browsing by feral sheep, predation by rats and cats, and the gradual effects of climate change on the distribution of māmane woodlands. Any one of these threats, working alone, would probably not condemn the bird to extinction, or at least could be relatively easily addressed by natural resource managers. However, the combination of these threats, if left unchecked or if treated in a piecemeal manner, will likely result in the loss of this species. Making the matter more difficult, the control of one threat often leads to the worsening of another threat. For example, the removal of feral cats may lead to an increase in rat populations. The example of the Palila identifies the importance of understanding the complexity of natural systems and the variety of factors that may play into the survival of any given species or resource. Thus it is in the best interest of natural resource managers to identify, prioritize, and attempt to control as many threats to a given resource at the same time as is possible, and to carefully monitor the results of their actions. It is also necessary for each user group to understand that their activities affect the overall status of the natural resources on Mauna Kea, and that no one type of user alone is responsible for the damage occurring there.

Table 3-12. Potential Impacts of Specific Activities

Impact/Threat	Activity							
	Astronomical Research (Operations)	Infrastructure (Construction & Maintenance)	Scientific Research	Recreation and Tourism				Cultural & Religious Practices
				Tourist	Hiking	Hunting / Off-Road	Commercial	
Disturbed Cinder	X*	X	X	X*	X	X	X*	X
Air Pollution	X*	X*	X	X*	X	X*	X*	
Substrate & Groundwater Contamination	X	X	X	X		X	X	X
Erosion	X*	X	X	X*	X	X*	X*	X
Solid Waste Generation	X	X	X	X	X	X	X	X
Noise Generation	X	X	X	X		X	X	
Invasive Species	X	X	X	X	X	X	X	X
Habitat Alteration	X	X	X	X	X	X	X	X
Sample Collection & Incidental Take	X	X	X	X	X	X	X	X
Fire		X		X	X	X	X	X

*Primarily through vehicle traffic

4 Introduction to Component Plans

Section 4 of the Mauna Kea Natural Resources Management Plan (NRMP) provides guidelines for the establishment of OMKM's Natural Resources Management Program (NRM Program). The overarching goal of the NRM Program is to preserve, protect and enhance the natural resources within the UH Management Areas on Mauna Kea, in order to promote long-term sustainable use of the sites. Achieving this goal requires understanding and monitoring of the status of natural resources on Mauna Kea; preventing and controlling threats to natural resources; preserving, enhancing and restoring sensitive ecosystems; conducting education and public outreach; and managing information and natural resources data. Each of these natural resources management needs is addressed in separate component plans.

Section	Component Plan
4.1	Natural Resource Inventory, Monitoring and Research
4.2	Threat Prevention and Control
4.3	Natural Resources Preservation, Enhancement, and Restoration
4.4	Education and Outreach
4.5	Information Management

Each component plan explains why it is needed; details the goals and objectives of the component plan; provides a brief review of the current understanding of the natural resources and management needs addressed by the component; and provides recommended management actions to meet the stated goals and objectives. The component plans also identify areas where management needs overlap and resources can be shared while still accomplishing the goals of each component plan. In these cases, readers are referred to other component plans, providing a more accurate overall needs assessment, and enabling easy cross-referencing. Wherever possible, recommended management actions are prioritized according to need, based on our current understanding of the natural resources on UH Management Areas.

The management actions are provided as recommendations and a resource, and it is not the intention of this NRMP that all of the management activities be implemented by OMKM. A subset of the management actions will be implemented depending on available levels of staffing and funding. Additionally, some management actions may be discovered to not be appropriate upon collection of additional information on the status of the natural resources, through baseline inventory and long-term monitoring efforts. If a recommendation is implemented and it results in an action that would require ground disturbance or alteration of the existing environment, a separate environmental analysis will be conducted in compliance with existing State law. Prioritization of the actions is intended to provide a means to determine which management actions would have the most impact on natural resources protection and management. A high rank indicates that the action would afford the highest level of resource protection, and/or is perceived as being an important management action given the current understanding of natural resources on UH Management Areas.

The management actions detailed in the component plans are based on the principles of ecosystem management[1] and are aimed at maintaining ecosystem integrity, diversity, and health. The description of each management action also considers the potential impacts of conducting the action on natural and cultural resources. Coordination with other agencies, adjacent landowners, and the public, along with development of collaborative initiatives are encouraged whenever possible. Further information on the

[1] An ecosystem consists of the plants, animals, and microorganisms within an area, the environment that sustains them, and their interactions. An ecosystem can range in size from a tiny site containing only a few species, such as an isolated wetland, to a huge area containing thousands of species, such as a tropical rainforest.

management principles upon which the recommended management actions are based is provided in Section 1.2. Programmatic management recommendations for establishing the Natural Resources Management Program are presented in Section 5.1.1, with reference to further detail in other sections, as applicable.

4.1 Natural Resources Inventory, Monitoring and Research Program

4.1.1 Introduction

Science-based natural resource management depends on obtaining quality data about the status of biological and physical resources. Inventory, Monitoring and Research (IM&R) programs provide these data. Comprehensive and well-designed IM&R programs allow managers to determine the status of natural resources, track changes in resources over time, identify new threats before they become established, measure progress towards meeting management objectives, and plan future research and management (Elzinga et al. 1998; Oakley et al. 2003). Data collected from IM&R programs can assist managers with 1) identifying areas that can be restored and preserved and 2) prioritizing management actions based on geographic area and sensitivity. Results from the IM&R programs can also be used to inform stakeholders of management successes or issues of concern, and to increase public trust and support for management actions. Demonstrated success in implementing management actions may result in an increased likelihood of support and funding for future projects.

A baseline inventory, or initial survey, establishes the current status of the area under management at the beginning of a natural resources management program. Many of the decisions and paths taken by the management program will follow from the results of the baseline inventory. Monitoring begins after the completion of the baseline inventory and tracks selected resources over time. Decisions on what resources to monitor over the long term will be based on the results of the baseline inventory and the objectives of the management program. By design, the baseline inventory is more comprehensive and inclusive than the monitoring program, and therefore it is more labor-intensive and expensive.[1] Research programs may begin after the baseline inventory is completed, or at any time during long-term monitoring. The purpose of the research component is to answer questions and fill in data gaps that are beyond the scope of the inventory and monitoring programs, but are necessary to understand and manage the resources and advance the body of knowledge.

Monitoring and research should not be conducted in isolation, but, rather, integrated with management to allow for implementation of best informed management decisions. Although resource managers are continually required to make management decisions under conditions of uncertainty, monitoring and research data provide a basis for making informed decisions and for revisiting those decisions as new information is gained. The cyclic process of linking monitoring and research with management is called adaptive management (see Figure 1-1). Effective IM&R programs must provide information relevant to current management issues and also anticipate, where possible, future management issues based on what is currently known about the status of the natural resources and threats to these resources (National Park Service 2006). The IM&R programs must be based on the best scientific methods available, produce quality data, and be implemented in a timely manner. Data must be collected and entered regularly and it must be accessible to managers. In turn, managers must integrate new information into their decision-making processes (National Park Service 2006).

Successful IM&R programs require systematic planning, data collection, and analysis of data. The right types of data must be collected to determine if progress is being made towards management goals. Monitoring is repeated over time, and in some cases may extend over long periods before it can be determined that a particular action, or set of actions, has been successful, or that a particular management goal has been met. Because of this, measures of success should include recognition for positive progress

[1] At this writing, a baseline natural resources inventory has not been completed for the UH Management Areas on Mauna Kea (Mauna Kea Science Reserve, the Access Road, and Hale Pōhaku), but a cultural resources (archeological) inventory has (McCoy et al. 2009).

towards a goal, not just meeting the goal. Whenever practical, management activities should include short-term and long-term monitoring goals, to help determine the success or failure of the actions. This IM&R component plan describes the general, property-wide, IM&R efforts to be conducted at UH Management Areas on Mauna Kea. Monitoring activities that track the effectiveness of specific management actions (e.g., response of an invasive species to control efforts) are addressed in the component plan where that management action is described (e.g., Section 4.2 Threat Prevention and Control; Section 4.3 Natural Resources Preservation, Enhancement, and Restoration).

A great deal of time, effort, and thought over the years has gone into the development of natural resource inventory and monitoring programs used by natural resource managers. The National Park Service (NPS) has developed excellent guidelines for the development of inventory and monitoring programs, and is in the process of developing standardized monitoring protocols[2] for many different types of natural resources (see the NPS monitoring page, at http://science.nature.nps.gov/im/monitor/index.cfm). The methodology used for the development of the inventory and monitoring program for UH Management Areas follows the guidelines developed by the NPS. See Section 4.1.1.3 for information on the methods used.

4.1.1.1 Choosing Focal Natural Resources

Inventory, monitoring, and research efforts targeted at gathering information to guide management decisions should, initially, focus on filling identified information gaps. Because an inordinate amount of time, money, and effort would be needed to inventory and monitor all the natural resources at the UH Management Areas, successful inventory and monitoring programs must focus on a subset of the natural resources present. The natural resources selected for inventory, monitoring, and research must be chosen carefully, and should represent the overall health of the ecosystem, be important indicator species or physical resources, be protected or rare species, or have important human values. Natural resources to choose from when developing the inventory, monitoring, and research programs include water, air, soil, geological resources, plants and animals, and the various ecological, biological, and physical processes that act on those resources (National Park Service 2006). In the case of this Natural Resources Management Plan (NRMP), inventory, monitoring, and research efforts will focus on 1) native species (or communities) of concern, 2) important or unique physical features, 3) stressors that are known or suspected to impact native species and communities (e.g., invasive species, human use, soil erosion), and 4) basic properties and processes of ecosystem health (e.g., water quality).

The purpose of the baseline inventory is to provide a general snapshot of the ecological integrity of the UH Management Areas; therefore, the number of resources surveyed will be larger than the number monitored. A subset of the natural resources included in the inventory will be chosen for long-term monitoring. It is not necessary to monitor every plant or animal population, or every abiotic process on the properties. The research program will focus on an even smaller subset of natural resources, with the goal of filling data gaps identified during inventory and monitoring. The natural resources to be inventoried are listed in Table 4.1-2, and the resources suggested for long-term monitoring are listed in Section 4.1.2.2 and discussed in more detail in Section 4.1.4. Potential research projects are outlined in Section 4.1.4.

In addition to deciding what natural resources to include in the IM&R programs, it is also necessary to decide *where* IM&R projects will take place. The ecosystem approach to natural resources management does not recognize property lines or political boundaries. Because of this, it will sometimes be necessary

[2] See Section 4.1.1.2 for information on monitoring protocols.

to conduct IM&R activities outside the boundaries of the UH Management Areas. For example, invasive species do not care whether a property is managed by a private landowner or a government agency. Invasive species management efforts will, in many cases, require cooperation or collaboration between adjacent landowners to ensure success. Where permissible, it is recommended that other surrounding land managers adopt IM&R protocols similar to or the same as those presented here or by the National Park Service for Hawai'i Volcanoes National Park and Haleakalā National Park. This will ensure comparability of results of natural resource monitoring data and research projects across property boundaries.

4.1.1.2 Program Protocols

Protocols are the methods used and the step-by-step instructions needed to conduct inventory, monitoring, and research projects. Protocols should

1. Document the questions being asked
2. Describe how the project will answer the questions
3. Describe the sampling framework and survey design
4. Provide step-by-step procedures for collecting, managing, and analyzing the data
5. Provide guidance on how the data will be presented (e.g., frequency and type of reports)
6. Allow for a testing period and evaluation of the effectiveness of the procedures before they are accepted for long-term monitoring or research (Oakley et al. 2003).

It is necessary to develop detailed protocols to be used in IM&R programs, to ensure that changes in the status of natural resources observed during monitoring and research are real, and not simply artifacts of differing methods of collecting data by different people (Oakley et al. 2003). According to Oakley et al. (2003), "protocols are 1) a key component of quality assurance for monitoring programs to ensure that data meet defined standards of quality with a known level of confidence, 2) necessary for the program to be credible, so that data stand up to external review, 3) necessary to detect changes over time and with changes in personnel, and 4) necessary to allow comparisons of data among places and agencies." Protocols should include a narrative section that explains the rationale for the monitoring and research, and provides measurable objectives, a sampling design, field methodology, data analysis and reporting, personnel requirements, training procedures, and operational requirements for the program; a set of standardized operating procedures that provides step-by-step instructions on how to carry out all aspects of the narrative; and any supplementary material needed to support the protocol (e.g., maps, photographs, previous reports, and data). The contents of the protocol narrative, as adopted by the NPS are presented in Table 4.1-1. See Oakley et al. (2003) for more information.

Although inventory, monitoring, and research program goals and protocols are outlined in this management component, it will be the task of the Natural Resources Coordinator (NRC)[3] to determine, at the time of development and implementation of the IM&R programs, whether the suggested protocols represent best available scientific knowledge and technology (both of these are subject to rapid advancements), and to fill in protocol details, such as sampling locations, and timing. This includes the task of writing the protocol narrative and developing the standardized operating procedures.

[3] See Section 4.1.3.1 for more information on the Natural Resources Coordinator.

Inventory and Monitoring Protocols

When possible, recommended inventory and monitoring protocols (e.g., methodology, effort, time of year) should be consistent with past studies and surveys in order to simplify comparison of the results and identification of trends. However, in some cases, there are no previous protocols. This is the case for many of the resources at Mauna Kea Science Reserve (MKSR) and Hale Pōhaku, where, either data have never been collected or data collection has not been done in a quantitative or systematic manner.[4] In these cases, use of established monitoring protocols from other agencies managing similar ecosystems is recommended, as it will allow for comparison of data between land managers faced with similar ecological conditions and challenges.

For natural resources on UH Management Areas with no established protocols, monitoring protocols should be based on those used by other agencies in Hawai'i (e.g., DLNR, NPS, USGS, and USFWS). As DLNR did not have any monitoring protocols available at the time of creation of the first draft of this NRMP, protocols produced by the National Park Service Pacific Network,[5] and in particular those being developed for other high elevation locations in Hawai'i such as Haleakalā and Hawai'i Volcanoes National Park, were used as guidelines. These protocols are currently under development by the NPS and are available for use for other natural resource managers (HaySmith 2008). If DLNR protocols are not available at the time of implementation of inventory and monitoring activities, it is recommended that the OMKM NRC check with NPS to determine if the protocols for Haleakalā and Hawai'i Volcanoes parks have been finalized, before beginning the inventory and monitoring programs. In the absence of monitoring protocols from DLNR or the National Park Service Pacific Network, this plan uses monitoring protocols developed for similar ecosystems found in the mainland United States and Canada. When no protocols were available from established monitoring programs (as was the case for arthropods), survey methodologies were obtained from the scientific literature or other reputable sources. The NRC should review current scientific literature and consult with local experts before implementing these methods, to ensure that the best available methodologies are used.

To the greatest extent possible, the methodologies used for the baseline inventory should be the same as the long-term monitoring protocols, unless otherwise specified, or decided upon by the NRC upon implementation of the inventory and monitoring programs. Any reasons for changing protocols should be documented and included in the next NRMP update. Care should be taken that the same units of measurement (e.g., plant density or pitfall trap capture rates [bugs/day]) are used in the baseline inventory and in long-term monitoring. This ensures that data from the baseline inventory can be compared to the data from long-term monitoring.

Research Project Protocols

As with the inventory and monitoring protocols, the protocol for each research project should be well thought-out and developed, describing the methods used and the step-by-step instructions for conducting the project. This is especially important in long-term research projects that may be conducted over several years, and by different staff. Ideally, the methodologies used in the research projects should be compatible with those used for the baseline inventory and long-term monitoring. Care should be taken to ensure that units used are similar so that direct comparison between the research project results and monitoring can be easily achieved.[6]

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[4] An exception to this is the ongoing study of the wēkiu bug at the summit by OMKM and Bishop Museum, where investigators have tried to standardize the trapping techniques and the timing of survey work.

[5] Publicly available monitoring protocols developed by the NPS Inventory and Monitoring Program for a variety of natural resources are posted at: http://science.nature.nps.gov/im/monitor/protocoldb.cfm.

[6] For example, it would be far more useful to record plant densities as number of plants per square meter in both research project plots and long-term monitoring plots than to have density recorded in the monitoring plots and percent cover recorded in the research project plots.

It is envisioned that research projects will be carried out after the completion of the baseline inventory (including data analysis and preparation of the baseline inventory report). This will allow for refinement of the research questions asked, a more accurate prioritization of research needs, and identification of other, perhaps more pressing, research questions. The locations (sites) where the research should be conducted will also be clarified by the results of the baseline inventory. Any methodologies presented in this plan for research projects can (and should be) changed as needed, to ensure that the results of the research project are compatible with the baseline inventory results.

Research projects must be carefully designed to ensure they answer the questions posed. All research projects should have clear and testable hypotheses (predictions), and the methodologies chosen for each study must be able to test the hypotheses.

Table 4.1-1. Guidelines for long-term monitoring protocols: recommended protocol narrative content

1. Background and objectives
    a. Background and history; describe the resource issue being addressed
    b. Rationale for selecting this resource to monitor
    c. Measurable objectives
2. Sampling design
    a. Rationale for selecting this sampling design over others
    b. Site selection
        i. Criteria for site selection; define the boundaries or population being sampled
        ii. Procedures for selecting sampling locations; stratification, spatial design
    c. Sampling frequency and replication
    d. Recommended number and location of sampling sites
    e. Recommended frequency and timing of sampling
    f. Level of change that can be detected for the amount and type of sampling being instituted.
3. Field methods
    a. Field season preparations and equipment setup (including permitting and compliance procedures)
    b. Sequence of events during field season
    c. Details of taking measurements, with example field forms
    d. Post-collection processing of samples (e.g., lab analysis, preparing voucher specimens)
    e. End-of-season procedures
4. Data handling, analysis, and reporting
    a. Metadata procedures
    b. Overview of database design
    c. Data entry, verification, and editing
    d. Recommendations for routine data summaries and statistical analyses to detect change
    e. Recommended reporting schedule
    f. Recommended report format with examples of summary tables and figures
    g. Recommended methods for long-term trend analysis (e.g., every 5 or 10 years)
    h. Data archival procedures
5. Personnel requirements and training
    a. Roles and responsibilities
    b. Qualifications
    c. Training procedures
6. Operational requirements
    a. Annual workload and field schedule
    b. Facility and equipment needs
    c. Startup costs and budget considerations
7. References

Source: Oakley et al. 2003

4.1.1.3 Developing an IM&R Program

The methodology used to develop this IM&R component plan included

- Compilation of current information on Mauna Kea subalpine and alpine ecosystems and existing data and knowledge gaps through literature research, consultation with local experts, and stakeholder input (see Section 2)
- Review of past research and monitoring activities on Mauna Kea
- Review of available spatial data (Geographic Information System (GIS) database) and determination of spatial data needs for a successful monitoring program
- Review of the literature on monitoring program development and monitoring protocols
- Review of other successful monitoring programs and monitoring protocols and discussions with monitoring program managers and developers (e.g., Inventory and Monitoring Program at NPS)
- Identification of important abiotic and biotic resources (physical features, species, communities, ecosystems) and threats to these resources through literature research and consultation with subject matter experts and stakeholders
- Consultation on management and monitoring priorities with OMKM staff and the Environment Committee, local experts, and stakeholders
- Prioritization of natural resources to be inventoried, monitored, and researched based on the above information.

Materials to support the development of the monitoring program and monitoring protocols by the OMKM NRC are maintained in the EndNote library (see Section 4.5). These include pertinent guidance, articles, and reports on development of monitoring plans and protocols. Sample monitoring protocols and a copy of the NPS Pacific Islands Network Monitoring Plan (HaySmith et al. 2005) have been provided to the OMKM librarians for use by OMKM natural resources staff.

The overall frameworks for the inventory, monitoring, and research programs are described in this component. It is beyond the scope of this NRMP to develop complete and ready-to-implement inventory, monitoring, and research programs, in part because many of the long-term monitoring objectives and research projects will depend on the results of the initial baseline inventory that needs to be conducted on the UH Management Areas, and thus cannot be anticipated or described here. However, the steps needed to develop the inventory, monitoring, and research programs, currently known monitoring and research goals and objectives, and examples of useful monitoring and research protocols are presented. The first task of the NRC will be to complete the process of developing the IM&R program. To ensure success, the program must then be followed carefully over time. Future updates to the NRMP should modify management actions as deemed appropriate, following interpretation of the collected data. Any changes to the overall IM&R, and to individual monitoring and research protocols need to be thoroughly documented in future updates.

4.1.1.4 IM&R Program Goals

The first step in developing the IM&R program is to establish the goals and objectives of the program.[7] The goals and objectives of the Mauna Kea natural resources IM&R program are:

	Program Goals and Objectives	Section
Goal IMR-1	Determine baseline status of the natural resources (Baseline Inventory).	4.1.2.1
Objective 1	Establish baseline inventory survey protocols that are compatible with long-term monitoring protocols.	
Objective 2	Collect baseline inventory data.	
Objective 3	Refine long-term monitoring and research priorities based on results of baseline inventory.	
Goal IMR-2	Conduct long-term monitoring to determine the status and trends in selected resources to allow for informed management decisions.	4.1.2.2
Objective 1	Determine which resources to monitor.	
Objective 2	Establish monitoring protocols and write monitoring plans.	
Objective 3	Conduct regular monitoring efforts.	
Objective 4	Identify new data gaps.	
Goal IMR-3	Conduct research projects to fill natural resource knowledge gaps that cannot be addressed through inventory and monitoring.	4.1.2.3
Objective 1	Identify and prioritize research projects.	
Objective 2	Develop research protocols and obtain funding.	
Objective 3	Conduct research projects and present results.	
Objective 4	Evaluate the information obtained and adjust management actions as necessary.	
Goal IMR-4	Create efficient, cost effective IM&R programs.	4.1.3.1
Objective 1	Complete as much inventory, monitoring, and research as possible using in-house staff and resources, interagency collaboration, and volunteer labor.	
Objective 2	Streamline monitoring and research efforts, to minimize expenses and impacts to natural resources.	
Objective 3	Carefully choose natural resources to inventory, monitor and research.	
Objective 4	Use scientifically and statistically sound sampling protocol to ensure that the data collected is usable and can be successfully analyzed.	
Goal IMR-5	Measure progress towards performance goal of preserving, protecting, and restoring Mauna Kea ecosystems.	4.1.3.2
Objective 1	Collect the right data and ensure data quality.	
Objective 2	Analyze data to identify trends in natural resources status and to answer specific management questions.	
Goal IMR-6	Increase communication, networking, and collaborative opportunities to support natural resource management and protection.	4.1.3.3
Objective 1	Produce reports to inform stakeholders, public, and collaborating agencies about the status of the natural resources.	
Objective 2	Identify opportunities for collaborative data collection and resource management.	

[7] A goal is a brief statement of the overall purpose of a program. An objective is a more detailed statement that provides additional information about the purpose or desired outcome of the program (NPS 2006). Monitoring objectives should be realistic, specific, and measurable. An example of a monitoring objective is to "detect new localized populations of invasive non-native plants before they become established at high densities."

These goals and objectives are addressed in the following sections. The objectives can be thought of as specific steps that must be taken to reach the goal. Each objective contains a set of actions that will help OMKM meet the objective and overall goal.

4.1.2 Program Specifics

This section addresses the establishment of the baseline inventory, long-term monitoring, and research programs for the UH Management Areas. It provides general information on the goals and objectives of each of the programs. Detailed information on baseline IM&R projects for specific natural resources found on UH Management Areas (e.g., birds, plants) is provided in Section 4.1.4.

4.1.2.1 Baseline Inventory

Goal IMR-1: Determine baseline status of the natural resources (Baseline Inventory)

Establishing a solid baseline data set describing the distribution, abundance[8], condition[9], and diversity of natural resources is time and labor intensive, but necessary if natural resource personnel wish to understand the resources they are to manage and determine if management actions are having the desired effects. The initial labor-intensive survey is referred to as the baseline inventory. In the following years (during long-term monitoring), only subsets of the natural resources will be monitored or surveyed, in order to reduce costs and minimize impacts on the natural resources being monitored. Because the long-term monitoring is by necessity focused on a reduced number of natural resources, it is recommended that baseline inventories be conducted every twenty years (or as needed, depending on the resource being managed and conditions of the UH Management Areas). It is also recommended that additional detailed baseline inventories be conducted, as needed, in areas proposed for development. These baseline inventories should be conducted at the time the development is proposed, within the footprint of the area to be developed. It is recommended that these inventories also include a buffer of at least 1,640 ft (500 m) around the project footprint. This is especially important if the proposed area has not previously been included as an actual survey point in another baseline inventory. The purpose of conducting baseline inventories in areas of proposed development is to determine if the area contains sensitive resources such as protected species or unique geological resources, which need to be protected or mitigated for. However, without conducting baseline inventories in other portions of similar habitat on the mountain, it is difficult to know whether the proposed project area is more or less important or unique than surrounding areas. Thus, it is important to understand the distribution of natural resources over a larger area, rather than simply studying the area of proposed impact.

Baseline inventories have multiple purposes. The first is to record locations and abundances of species and abiotic natural resources found on the properties, so that the current status of the site may be understood. The second is to identify any problem areas or areas of special concern that may need additional attention in the future. These may include areas with rare, threatened, or endangered plant populations, patches of invasive plants that should be removed, and areas of physical hazards. The third is to collect quantitative data that can be used to compare future monitoring results against, and identify trends and detect changes. Fourth is to continue building the spatially-linked GIS database of the natural resources on Mauna Kea to facilitate and support monitoring, planning and management efforts (see

[8] Abundance is used to define a species' or feature's population size, absolute count, or density.

[9] For biological resources condition indicates the health of an individual or population, and/or reproductive status. For abiotic resources, condition refers to physical attributes.

Section 4.5). Geospatial maps (GIS layers) can be created that depict species locations, abundance and habitats, and to delineate physical features of historic and scientific value, culturally important sites, and use areas. These geospatial layers can be overlain to define management areas that may be considered off-limits for future development or suitable for future management activities. Conversely, the spatial analysis can help identify best-site alternatives for future development, both at the summit and at Hale Pōhaku, while minimizing impacts to cultural and natural resources.

The natural resources that should be considered for inclusion in the baseline inventory, along with the priority of need for inclusion, are presented in Table 4.1-2. For information on how resources and activities were prioritized, see Section 4.1.4. Although the table detailing those resources to include in the baseline inventory is presented separately from the list of resources to include in the long-term monitoring program, there are many overlaps between the two, especially in the areas of field survey protocols and ideas for making the programs cost effective and efficient. Many of the cost-saving measures and ideas for such things as inter-agency collaboration and methods of obtaining data that are presented in Section 4.1.3 are applicable for the baseline inventory program, as well as for long-term monitoring. Please note that while all the natural resources found on UH Management Areas are included on the table below, it is not recommended that OMKM attempt to conduct baseline inventories on all of them, because to do so would be prohibitively expensive and time consuming. The resources to include in the inventory will have to be selected by the OMKM NRC (see Section 4.1.3) and the Mauna Kea Management Board (MKMB) Environment Committee. It is recommended that the focus of the baseline inventories be on high priority items, with medium and low priority items added in as time and funding allows.

Table 4.1-2. Natural Resources to Consider for Inclusion in Baseline Inventory[10]

Resource Category	Hale Pōhaku	MKSR	Priority	Background Section
Physical				
Geology	Geological features	Geological features	Medium	2.2.1
Surficial Features and Soils	Hiking trails / Off-road trails	Hiking trails / Off-road trails	Medium	2.2.2
	Ground condition in and around stormwater systems	Ground condition in and around stormwater systems	Low/ Medium	
	Soils	Soils	Low	
Hydrology	N/A	Lake Waiau	Low	2.2.3
	Seeps and streams	Seeps and streams	Low	
	Locations of known chemical discharges	Locations of known chemical discharges	High	
Climate and Weather	Meteorological parameters	Meteorological parameters	Low	2.2.4
	N/A	Snow water equivalent and snow pack depth	Low	
Air Quality and Sonic Environment	Dust distribution/concentration	Dust distribution/concentration	Low	2.2.5
	Ambient background noise	Ambient background noise	Low	
Biological				
Plants	T&E* Species	T&E Species	High	2.2.1
	Māmane woodlands	Alpine stone desert	High	
	Invasive plants	Invasive plants (along road)	High	
	Subalpine shrublands	Alpine shrublands	Medium	
	Subalpine grasslands	Alpine grasslands	Medium	
Invertebrates	Native pollinators (bees, moths)	Summit arthropods	High	2.2.2
	Invasive wasps and ants	Invasive arthropods	High	
	Snails	Alpine arthropods (below summit)	Medium	
	Other native arthropods	Other native arthropods	Low	
Birds	All birds	Hawaiian Petrel	High	2.2.3

[10] This table presents a summary of the general categories of natural resources found in UH Management Areas, with details on what could be inventoried at Hale Pōhaku and in the MKSR, along with the perceived priority, and the pertinent background section of this NRMP that provides more information on the natural resource category.

Resource Category	Hale Pōhaku	MKSR	Priority	Background Section
Mammals	T&E Native Species (Hawaiian Hoary Bat)	N/A (No native species found in MKSR)	High	2.2.4
	Herbivores (sheep, goats)	Herbivores (sheep, goats)	High	
	Predators (cats, mongoose, rats)	Arthropod Predators (rats, mice)	Medium	
	Seedeaters (mice, rats)	Seedeaters (mice, rats)	Medium	

*Threatened and endangered

Objective 1: Establish baseline inventory survey protocols that are compatible with long-term monitoring protocols

Actions

1. Establish baseline survey protocols based on best available monitoring protocols (e.g., NPS or USGS protocols applicable to high-elevation areas in Hawai'i).[11] Protocols should be documented in report format.
    a. Quantitative rather than qualitative methods should be used whenever possible, because data on abundance and distribution is more useful than simple presence/absence data.[12]
    b. Survey methodologies used should, when possible, be similar to those promulgated, or already employed, by federal and state agencies (such as NPS, USGS, DLNR).[13] In this plan, NPS methodologies are applied or recommended whenever possible, because their monitoring programs are already under development.
    c. For some groups of organisms with extremely high diversity and abundance, such as invertebrates[14], it may be necessary to conduct the baseline inventories in two tiers: the first would be a list of all species (or functional groups) found on the properties, while the second would be a more quantitative survey of the abundances of species of interest (such as keystone[15] species or protected species). The findings from the first tier will help identify what would be studied in more detail in the second tier. This may be necessary to limit the overall costs associated with detailed survey work.

Objective 2: Collect baseline inventory data

Actions

1. Hire consultant teams or contractors to complete the baseline inventories. Contracting out the baseline inventory work is necessary due to the inherent broad scope, sizeable acreage, and quantity of data to be reviewed and analyzed. The amount of work required would be beyond the abilities of an in-house team to complete within a reasonable time period (one to two years).
    a. Provide methodologies to be followed in the Request for Proposal (RFP), to inform bidders of the scope and requirements of the project.

[11] Although the baseline inventory surveys are more intensive (cover a broader variety of species and a larger number of sampling plots) than the long-term monitoring surveys, the data should be compatible and comparable.

[12] Qualitative methods can be used when quantitative methods are not possible or are prohibitively expensive or time consuming.

[13] DLNR does not have monitoring protocols for the Mauna Kea Ice Age NAR or other properties on Mauna Kea. If DLNR does develop inventory and monitoring protocols, an attempt should be made to ensure that protocols are similar to and compatible with those being used by OMKM. Alternatively, DLNR could adapt protocols recommended within this report.

[14] Study of the wēkiu bug has been ongoing for a decade. Therefore some baseline data exists for the summit invertebrate community, but is lacking for the remainder of UH Management Areas.

[15] A keystone species is a species that plays a pivotal role in an ecosystem and upon which a large part of the community depends. Māmane trees are an example of a keystone species in the subalpine zone of Mauna Kea.

   b. Require, as part of the Scope of Work, that the contractors follow the established protocols (to prevent contractors from utilizing their own methodologies, which may not be compatible with future monitoring efforts).[16]
   c. Require Global Positioning System (GPS) data to be collected at survey point locations.
   d. Require that all data (including measurements and survey results) be entered into and submitted in a GIS dataset consistent with OMKM GIS protocols, ensuring compatibility with OMKM GIS (see Section 4.5).
   e. Request that contractors search historical archives for data, collections, and images pertinent to the natural resources of Mauna Kea. Although unlikely to be quantitative in nature, this information would be useful for determining historical conditions on Mauna Kea, to use as a reference point for resource management and restoration efforts (see Section 4.3).
2. Conduct baseline inventories for plants, invertebrates, vertebrates, and physical resources. A baseline survey of cultural and archaeological resources has already been conducted for the MKSR (McCoy et al. 2009). Surveys for different groups of natural resources should be conducted simultaneously and on the same plots, to the greatest extent possible, to allow for exploration of relationships between groups. Proposed survey methodologies are included in the OMKM EndNote library (see details in Section 4.1.4). The following actions are recommended as part of the baseline inventory
   a. Obtain high-resolution aerial photos of the UH Management Areas to pre-screen for areas of interest (e.g., māmane woodland; isolated silversword populations; or areas heavily infested by invasive plants), identify problem areas and issues (such as erosion), and record visual conditions at time of baseline inventory.
   b. Determine locations for transects and plots
      i. Divide Hale Pōhaku, Access Road, and MKSR into grids.
      ii. Randomly locate transects or sample points within each grid.
      iii. Add additional areas of interest that are not covered by the randomly located survey points (e.g., silversword population in MKSR).
      iv. Plot out proposed survey locations on GIS software to identify potential problems (e.g., access, sensitive cultural resources). Remove points with potential problems and replace with another randomly selected location within the same grid. Visiting some grid spaces may not be feasible, and these may be excluded from the surveys.
   c. Go into the field and record actual plot and transect locations with GPS. Mark monitoring plots with permanent plot markers, where permissible and feasible.[17]
   d. Conduct all survey work in the same location within each grid cell, so that plant, invertebrate, and vertebrate surveys would all occur at the same locations. The size of the sampling plot, or frequency of sampling along the transect will depend on organism being studied.
   f. Multitask where possible; for example, a survey team could record bird species on one pass of the transect and then record a different element, such as plant density or diversity, on the return).
   g. Conduct surveys at appropriate times (both daily and seasonally) for organisms being surveyed (e.g., peak activity during early morning for birds, during peak flowering of

[16] If no protocols are publicly available at the time of development of the RFP, it would be possible to require that proposals include methodologies to be used. The proposals would then have to be reviewed by unbiased (not related to the proposer) experts in the natural resource to be inventoried for scientific merit. At a minimum, OMKM should determine the number of plots and the areas to be included in the inventory.

[17] Installing permanent plot markers may not be possible on the summit, where cultural considerations may prevent driving permanent plot markers into the substrate.

māmane trees for nectarivorous birds, peak fruiting period for seed-eating birds). This may necessitate multiple visits to each site at different times of day and during different seasons.

   h. To minimize the impact on the landscape, through cinder compaction or soil erosion, and prevent leaving visible trails, field crews should attempt to access survey plots from different directions or different trails each time it is visited during a single survey season. Whenever possible, field crews should attempt to walk on larger rocks and boulders when accessing particularly vulnerable wēkiu bug habitat.

3. Create a GIS database with the results from baseline inventory (see Section 4.5, Information Management).
4. Update species-list tables presented in Section 2.2, Biotic Resources of this NRMP.

Objective 3: Refine long-term monitoring and research priorities based on results of baseline inventory

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Actions

1. Using results of surveys, identify areas of concern or interest for future management, monitoring, and research.
2. Use baseline inventory results to further clarify long-term monitoring goals and to target resources of concern.
   a. Note any problems with data or survey techniques that are discovered during the baseline inventory efforts, and adjust the long-term monitoring protocols to overcome these problems. If problems are serious enough that they may preclude use of the baseline inventory data for future comparisons, it will be desirable to repeat the particular baseline inventory using more appropriate methodology.

4.1.2.2 Long-Term Monitoring

Goal IMR-2: Conduct long-term monitoring to determine the status and trends in selected resources, to allow for informed management decisions

Long-term monitoring is the only scientifically valid way to measure trends in the condition of natural resources on UH Management Areas. Data from long-term monitoring is necessary to assess the efficacy of management and restoration efforts, to provide early warning of impending threats, and to provide a basis for understanding and identifying meaningful change in complex natural systems (National Park Service 2006). Conducting long-term monitoring is integral to the process of adaptive management. Designing a long-term monitoring program requires 1) determining which resources to monitor, 2) establishing monitoring protocols and writing monitoring plans, 3) conducting monitoring efforts and analyzing data, and 4) identifying new data gaps to be filled by future monitoring. The monitoring program should be reviewed and updated every five years to ensure that it is addressing new data gaps. Details regarding monitoring needs for specific natural resources, and appropriate monitoring methodologies, are presented in Section 4.1.4. Detection of threats and observation of undesirable short-term and long-term changes to Mauna Kea ecosystems by means of long-term monitoring are discussed further in Section 4.2, Threat Prevention and Control.

Objective 1: Determine which resources to monitor

In many ways the resources chosen for long-term monitoring will depend on the results of the baseline inventory, and thus it is not possible to identify the exact resources that should be monitored on the UH Management Areas in this first draft of the NRMP. However, based on a review of scientific literature, interviews with local experts, and input from the OMKM Environment Committee and the public, a preliminary list of resources to be considered for long-term monitoring efforts is presented in Table 4.1-14 and in Section 4.1.4. This is not an exhaustive list, as there will likely be new issues raised by the baseline inventory and day-to-day experiences of the NRC that will need to be addressed by monitoring. Conversely, resources that are identified here as being worthy of monitoring may later be determined to be less important and may be dropped from the monitoring program. As an example, it may be discovered that another agency or group is collecting the same data as OMKM, and it may be possible to use this data rather than have OMKM staff continue to collect it.

It should be noted that while the majority of the natural resources found on UH Management Areas are included in Table 4.1-14, it is not recommended that OMKM attempt to monitor all of these resources, because to do so would be prohibitively expensive and time consuming. The resources to include in long-term monitoring will depend in part on which resources were included in the baseline inventory, and will have to be selected by the OMKM NRC (see Section 4.1.3) and the MKMB Environment Committee.

Actions

1. Complete baseline inventory work and data analysis.
2. Determine which species of concern (Threatened or Endangered Species, rare species, Candidate Species) occur on UH Management Areas. Protected species not previously recorded on UH Management Areas will need to be added to the monitoring plan and may require special monitoring protocols.
3. Identify resource monitoring efforts that would best aid decision-making by management or contribute to adaptive management; for example, monitoring invasive species targeted for elimination or native species or communities targeted for restoration efforts.
4. Determine a final list of natural resources to be monitored, using information obtained from baseline inventory, as well as information from other local agencies on what they are monitoring.
5. Prioritize resource monitoring efforts by urgency of need. For example, geologic features may not need to be monitored yearly, while populations of invasive plants or protected native species may need yearly, or more frequent, monitoring, depending on their population dynamics.

Objective 2: Establish monitoring protocols and write monitoring plans

Section 4.1.1.2 discusses the development of protocols for the monitoring plan. To the extent possible, the monitoring protocols should include

- Evaluation of potential ecological impacts of sampling protocols (e.g., crushing cinder, incidental take, dust, introduction of non-native species) and recommendations for low-impact sampling techniques
- Support for adaptive management, including evaluation of the effectiveness of management actions
- Identification of potential collaborations with existing programs such as Department of Land and Natural Resources (DLNR) Natural Area Reserves System (NARS), DLNR Division of Forestry and Wildlife (DOFAW), U.S. Fish and Wildlife Service (USFWS), U.S. Geological Survey (USGS), and National Park Service (NPS)

- Evaluation of potential conflicts between cultural considerations and natural resources monitoring, and solutions to these conflicts

Actions

1. Check with federal and state agencies regarding the availability of monitoring protocols for high elevation areas in the Hawaiian Islands. The NPS protocols are currently under development but will likely be completed by the time OMKM is ready to begin long-term monitoring efforts.
    a. If protocols are not yet available, ask DLNR, USGS, and NPS personnel to recommend sampling methodologies.
2. Using the above protocols as guidelines, develop monitoring protocols appropriate for the conditions at Hale Pōhaku, the Summit Access Road, and MKSR. Develop monitoring protocols for the following major groups and resources:
    a. Physical resources and abiotic conditions
        i. Soil (stability and natural and human induced erosion)
        ii. Soil condition in and around waste water systems
        iii. Water (Lake Waiau and at sites of seep and spring discharges)
        iv. Climate and weather (rainfall, snowfall, temperature)
        v. Air quality
    b. Plant communities
        i. Māmane woodland
        ii. Alpine Shrubland
        iii. Alpine Grassland
        iv. Alpine Stone Desert
    c. Invertebrates (native and invasive)
        i. Arthropods
        ii. Snails (if present)
    d. Birds (native and invasive)
    e. Mammals (native and invasive)
3. If the monitoring protocols are substantially different from those used in the baseline inventory, determine their compatibility with baseline data and conduct trials to work out any problems with methodologies employed.
4. Consult a statistician to ensure that monitoring protocols are statistically sound and that data will be usable.
5. Enlist monitoring experts, such as personnel from USGS or NPS, to review monitoring protocols, if they are substantially different from protocols developed by other agencies for use in Hawaiian high elevation ecosystems.
6. Finalize monitoring protocols and put together final monitoring program plan.
7. Periodically review and evaluate the success of the monitoring program.
    a. Is monitoring occurring on schedule?
    b. Are the monitoring personnel able to keep up with the required field and office work?
    c. Are the data collected useful for tracking the state of the natural resources?
    d. Are the field data collection and data entry protocols easy to implement and do they result in quality data?
    e. Any problems with data collection or processing should be reviewed, and the monitoring protocols updated to correct the problem.
    f. A thorough review of the monitoring program by the completion of the second year of implementation is recommended, to catch and correct problems early.

Objective 3: Conduct regular monitoring efforts

As discussed later under Section 4.1.3.1, it is not necessary to monitor every plot within the UH Management Areas annually. Annual monitoring will still occur, but a portion of the monitoring will shift locations according to a predetermined annual rotation. The balance of the monitoring will occur annually at special areas of concern on the UH Management Areas, and every two to five years at other plots, depending on how frequently the resources in these plots need be monitored. An example schedule is presented below.

Actions

1. The plots to be monitored for a given year will be determined by the monitoring protocols.
2. Develop an annual calendar showing monitoring dates and locations. This will ensure that the field personnel and NRC schedules are kept open for these periods and that no conflicting events are scheduled.
3. Analyze previous year's monitoring data before starting the current year's monitoring. This will allow for detection of problems with the previous year's data and for the collection of replacement data if the problems are insurmountable. This step is critical to ensuring that flawed methodologies are not used unknowingly, year after year, to collect data that is unusable for future analyses.
4. Review monitoring protocols well before beginning fieldwork, to ensure that personnel are familiar with the procedures to be used, and that equipment is in working order.
5. Enter monitoring data into database immediately after collection, store backup hard and electronic copies in secure, fireproof and waterproof locations.
6. Analyze the current year's data, ideally immediately following collection.
7. Produce the annual report for delivery to MKMB and Environment Committee.
8. Share monitoring data with other agencies collecting similar data, and with public, as appropriate.

Sampling monitoring schedule (based on HaySmith et al. 2005)										
Plot Set	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
A	X	X	X	X	X	X	X	X	X	X
B	X	X				X	X			
C		X	X				X	X		
D			X	X				X	X	
E				X	X				X	X
F	X				X	X				X

Objective 4: Identify new data gaps

Identifying new data and knowledge gaps is part of the cycle of adaptive management. To identify new gaps, the NRC will use the results from the baseline inventories and long-term monitoring efforts, as well as articles in the current scientific literature, and will communicate with local experts and other land managers in Hawai'i. The gaps identified can then be addressed in future years, through new long-term monitoring surveys and additional research projects.

Actions

1. Analyze data obtained from the baseline inventory and long-term monitoring as soon as it is available.
2. Stay abreast of current scientific literature that pertains to natural resources that occur on the UH Management Areas. Other scientific studies may identify knowledge gaps or relationships pertinent to the management of UH Management Areas.

3. Collaborate, cooperate, and communicate with other state and federal agencies and programs that deal with land management on Mauna Kea and in other high-elevation systems in Hawai'i. These agencies and people may have information pertinent to UH Management Areas that is not available in the scientific literature.
4. Look for relationships between the natural resources (biotic and abiotic). For example, native plant density at Hale Pōhaku may be found to be negatively correlated with invasive plant density, or it may be found to be unaffected by invasive plants, but instead highly correlated with annual rainfall.
5. Use the spatial analysis capabilities of GIS system to identify areas of interest, and look for relationships between biotic and abiotic factors, and changes in population boundaries.
6. Update monitoring plan and monitoring protocols regularly, to address newly identified data gaps.
    a. Review the monitoring plan yearly, checking for needed changes or deficiencies.
    b. Update the plan every five years, or as needed, based on the findings of the yearly reviews.

4.1.2.3 Research Program

Research studies, short- and long-term, are needed to improve the understanding of ecosystem functioning and the requirements of individual species in the subalpine and alpine regions of Mauna Kea. Basic biology and ecology research on habitat requirements of species, their life cycles, and their major predators is crucial for designing any long-term preservation or restoration plan. Species-level research and protection is an appropriate approach to stem the population decline of species already recognized to be under threat. However, ecosystem integrity depends on the maintenance of intact natural communities, not just individual species. Therefore, it is recommended that OMKM approach the protection and enhancement of the populations of unique native species found on Mauna Kea with an emphasis on maintaining and promoting intact native plant and animal communities. Species-specific research is a necessary approach to obtaining baseline information, but studies of community and ecosystem dynamics are equally important.

Goal IMR-3: Conduct research projects to fill natural resource knowledge gaps that cannot be addressed through inventory and monitoring

Knowledge gaps that impede clear understanding of the subalpine and alpine ecosystems were identified in Section 2 of this NRMP and are reviewed in Section 4.1.4. While the inventory and monitoring activities described in Sections 4.1.2.1 and 4.1.2.2 can provide much of the information needed by natural resource personnel, there are some gaps in the data and knowledge that must be addressed through scientific research, rather than through passive observation and monitoring. The Research Program addresses knowledge and data gaps that must be addressed through applied research. This section describes the formation of the research program. Detailed research questions and projects for specific natural resources are presented in Section 4.1.4.

As additional information becomes available on the status of the natural resources on Mauna Kea, through inventory, monitoring, and research, new knowledge gaps will be identified that will need to be addressed through additional scientific research. These knowledge gaps should be identified and recorded by the NRC and integrated into the next update of the NRMP.

The research questions and projects identified in this plan (see Section 4.1.4) can be addressed by OMKM natural resources personnel, by hired consultants, by other state or federal agencies, by graduate students or faculty at the University of Hawaiʻi and other universities—and in some cases, by volunteer groups and organizations. The methods and research teams chosen to accomplish the research goals will depend on the complexity of the research question (how much effort, how long it will take, how complicated the project is), available funding, the opportunities for collaboration and cooperation that are available when the project starts, and the creative problem-solving abilities of the OMKM natural resources staff. All research projects should be written up as research proposals and submitted to OMKM for review by the OMKM Environmental Committee and Kahu Kū Mauna before research begins.

Objective 1: Identify and prioritize research projects

A variety of short- and long-term research studies are needed to improve the understanding of ecosystem functioning and the requirements of individual species in the subalpine and alpine regions of Mauna Kea. Researchers should attempt to balance species-specific research projects with studies of community and ecosystem dynamics. Given the large number of research questions (see Section 4.1.4), it will be necessary to prioritize research projects. An initial attempt has been made to prioritize potential research projects identified in Section 4.1.4. However, projects should be reprioritized once the initial baseline inventory has been conducted and more information is available regarding the status of natural resources on UH Management Areas.

Actions

1. Review results of baseline inventory and long-term monitoring to modify list of research questions (see Section 4.1.4).
2. Prioritize research projects using the following criteria:
    a. Immediacy of need for information (e.g., a question that must be answered quickly in order to prevent a significant decline in conditions in natural resources. An example would be a study of control methods for a new invasive species that threatens to spread rapidly throughout UH Management Areas.).
    b. Status of resource being researched (e.g., research on Endangered species may be prioritized over research on a native but non-threatened species or community).
    c. Time scale that the natural resource operates on (e.g., research into natural resources that respond very quickly to perturbations should be prioritized over those that are slower to respond).
    d. Broadness of applicability (e.g., a research project that can provide information that will be useful for management of a variety of natural resources, or a large area, should be prioritized over those that are applicable to only a single resource or a small area).
3. Develop a list of research to be conducted and a broad timeline[18] for conducting it. The list should be updated and revised regularly to reflect new information, available funding, and other pertinent factors.

[18] It is difficult to create a precise research timeline as scheduling of various projects will be dependent on many external factors including availability of funding and appropriate scientists to conduct the work. However, it is still possible to develop a relative timeline where research projects are prioritized according to perceived need. Categories of prioritization could include general time ranges (1–5 years; 5–10 years) or level of need (Urgently required for daily management; Useful but not urgent; Opportunistic).

Objective 2: Develop research protocols and obtain funding

Once research projects have been prioritized or reprioritized, it will be necessary to develop the research protocols for the top-priority projects and, for projects that require it, obtain any additional funding necessary to conduct them. Because the protocol will determine the timeframe of the project as well as its cost (including equipment, man-hours, consulting fees), it must be completed before obtaining funds, to ensure that funds are adequate.

Actions

1. Review literature and consult with local experts regarding methodologies best suited to answer research questions.
2. Determine where the research project will be conducted and determine if enough replicates can be established to ensure statistical rigor. Consult with a statistician as needed.
3. Explore opportunities for collaboration or cooperation with other land management agencies, especially if the resource being studied crosses property boundaries.
4. Review research protocols to ensure compatibility of data with the data obtained from the baseline inventory and long-term monitoring.
5. Estimate man-hours needed to conduct the research and determine the cost of any needed supplies and equipment.
6. If additional funding is needed to complete the project, develop a research proposal or work with OMKM to obtain funding.
7. Finalize research project protocol; obtain peer review from other natural resource managers and local experts, if feasible.[19]

Objective 3: Conduct research projects and present results

Actions

1. Conduct research project, or invite outside investigator(s) to conduct project.
2. For long-term projects (more than one year), regular monitoring of results is recommended, to determine if the project is proceeding as planned. If the project appears to be failing, or if results are far from the predicted results, it may be desirable to cut short the research project or revise the protocols. This should be done if the project appears to be having a negative impact on natural resources, such as causing a decline in native species or severe habitat degradation.
3. Enter and analyze data as soon as possible. Ideally data should be entered into the database immediately following collection.
4. Prepare a report detailing results of project. For long-term projects, a brief summary report should be prepared annually, for the MKMB and the Environment Committee.
5. Share results of research projects through attendance at conferences and meetings, publication in scientific journals, publication on OMKM website, and in press releases, as appropriate and desired.

[19] Alternatively, research protocols can be developed by the entity, agency, or consulting team proposing to do the project, or development of research methodologies can be requested as part of the scope of work in the RFP put out by OMKM.

Objective 4: Evaluate the information obtained and adjust management actions as necessary

Actions

1. Evaluate the success of the research project. Did it answer the research questions asked? (If not, it may be necessary to revise protocols and conduct additional research.)
2. If data gaps or additional questions were identified during the project, enter these into the list of data gaps presented in Section 4.1.4, and update list of research questions.
3. Use the information obtained from research projects to improve management of resources, as needed (adaptive management), or to justify current actions, if they are questioned.

4.1.3 Implementation and Logistics

This section describes goals and objectives designed to increase the success and usefulness of IM&R projects conducted on UH Management Areas toward the ultimate goal of protecting Mauna Kea's natural resources. In part this will be achieved by maintaining efficient programs, measuring progress, and developing collaborative efforts that address IM&R needs from an ecosystem approach.

4.1.3.1 Maintaining Efficiency

Goal IMR-4: Create efficient, cost-effective inventory, monitoring, and research programs

Creating efficient, cost effective IM&R programs is essential to the success and long-term maintenance of the programs. Funding and time to conduct IM&R activities are limited resources that must not be wasted. Methods of increasing efficiency include 1) using in-house staff and resources, interagency collaboration or volunteer labor to complete as much of the IM&R activities as possible, 2) streamlining monitoring and research efforts, to minimize expenses and impact to natural resources, 3) carefully choosing which natural resources to monitor and research, and 4) using scientifically and statistically sound sampling protocols to ensure that the data collected are usable and can be successfully analyzed. Each of these methods is discussed in more detail below.

Objective 1: Complete as much inventory, monitoring, and research as possible using in-house staff and resources, interagency collaboration, or volunteer labor

Actions

1. Hire an experienced ecologist (preferably with botanical and/or entomological background) to act as the Natural Resources Coordinator (NRC).
2. Hire at least one field biologist (preferably with GIS/GPS experience) to aid in field data collection and data entry.
3. Train staff, (NRC, field biologist, rangers) and volunteers in identification of species of concern (e.g., endangered species, invasive species, keystone species), signs of physical resource degradation (e.g., erosion), and use of GIS and GPS.
    a. Hold refresher training yearly and when new members join the natural resources staff, rangers, or Visitor Information Station (VIS) staff.
4. Create a library of books, photo databases, and other materials that can aid in identification of natural resources observed on UH Management Areas.
5. Create a set of laminated species identification cards with color photos and descriptions, to aid identification in the field. Cards could cover native and invasive species of particular concern,

and be punched for ring binding, for easy use in the field. Update the cards whenever new species are detected or when new, potentially invasive species are identified, such as species found on nearby properties at similar elevations.
   a. Create a set of identification keys to help distinguish between closely related species or those that look similar.
   b. Keep extra copies of the identification cards at the Visitor Information Station and at the Hale Pōhaku dorms for interested visitors and residents.
6. Use volunteers when possible.
   a. All volunteers should receive training to ensure consistency of data.
   b. At least one OMKM employee (NRC, field biologist, VIS staff member, or ranger) should be in the field with volunteer groups at all times to ensure their safety and to supervise data collection.
7. Develop relationships with local experts who can help OMKM Natural Resources staff with difficult species identifications. For example, OMKM could reach a standing agreement with local experts for consulting on an as-needed basis rather than contracting with a team of specialists to conduct every aspect of the monitoring work from fieldwork to data analysis. This may be especially helpful in the case of difficult-to-identify invertebrates.
8. Collaborate with other agencies and institutions, when possible. For example, if the USGS is conducting surveys of invasive invertebrates on Mauna Kea, contribute funding or personnel-time to aid in data collection, in exchange for having some of the collection occur at Hale Pōhaku and MKSR. In some cases, simply requesting that UH Management Areas be included in surveys may be all that is needed.
9. Support faculty and students at UH and other institutions who are interested in conducting monitoring and research activities.
10. Develop partnerships with the local, national, and international scientific communities that can leverage OMKM funds with support from research funding institutions (e.g., National Science Foundation (NSF), National Aeronautics and Space Administration (NASA)).

Objective 2: Streamline monitoring and research efforts, to minimize expenses and impacts to natural resources

Actions

1. Combine monitoring efforts in more remote locations. For example, if a trip is arranged for an archaeologist or geologist to visit remote sites in the MKSR, have the biological team go along as well or have the other scientist collect data and information. In addition, combine monitoring efforts for plants, invertebrates, and vertebrates in remote locations, rather than conducting these surveys separately.
2. When outside help is needed, hire consulting teams that can provide expertise on multiple groups of organisms. It will be more cost-effective to hire a team that can survey for plants, vertebrates, and invertebrates at the same time than to contract for each of these surveys separately.
3. Take advantage of opportunistic sightings of rare species. For example, Hawaiian Petrel and Hawaiian hoary bats are unlikely to be seen during a survey that is conducted over one or two days. If rangers, the NRC, and field biologists are trained to recognize these species, their presence can be recorded if they are observed.
   a. When collecting opportunistic data, record the time of day, date of observation, name of observer, and any notes, and record the location with a GPS (or if GPS is not available at time of observation, mark the area and return with GPS).
   b. Enter this data into the GIS database within one to two days of collection.
4. Collaborate and communicate with other agencies in data collection. Share information on new threats or other issues observed in the field as soon as possible. This will allow a more

coordinated and rapid response to new ecological problems, and, ultimately, lower management costs.

5. Use data collected by other agencies or facilities whenever possible, for example, data collected by the astronomy observatories, DLNR, and Mauna Loa Observatory.

Objective 3: Carefully choose natural resources to inventory, monitor and research

Actions

1. Conduct broad baseline inventories on a 20 year basis, and limit yearly biological monitoring surveys to selected representative resources and groups, including:
    a. Rare and legally protected species (Threatened & Endangered species, Species of Concern)
    b. Selected invasive species (or groups of species) known to, or suspected to, impact native communities (e.g., invasive grasses, predatory arthropods, feral ungulates).
2. Reduce sampling frequency to every two to five years for those resources that are unlikely to change over the period of one year (e.g., adult māmane trees).
3. Limit measurements of physical resources to those that are most representative of ecosystem health or that are most likely to demonstrate changes (e.g., water quality, soil erosion rates, rainfall, temperature).
4. Reduce data collection needs where possible.
    a. Determine what resources are being monitored by other agencies responsible for land management on Mauna Kea and elsewhere on the Island of Hawai'i. Coordinate with these agencies to collect and share data using similar techniques for comparable results.
    b. Use data collected by other personnel, agencies, or groups to greatest extent possible (for example, data for temperature, wind speed, particulates, and aerosols are collected at the summit by the observatories).

Objective 4: Use scientifically and statistically sound sampling protocol to ensure that the data collected is usable and can be successfully analyzed

Actions

1. Follow the recommendations for monitoring protocols in NPS guidance on sample design (McDonald and Geissler 2004).[20]
    a. Use probability sampling. Divide the entire management area into sampling units. Within the sampling units, randomly locate sampling plots or, for transects, start points.
    b. Inferences (on community composition or resource condition) can be made only about areas included in sampling; therefore, if remote areas are not included in the sampling design, no inferences can be drawn about these areas.
    c. Avoid using "representative sites" selected by experts or field technicians, as these selections may be biased in some way; for example toward sites with easy access or sites with exceptional diversity.
    d. The sampling effort should be spread uniformly over entire management area, but additional effort may be put into sampling areas of special interest.
    e. Simple random sampling without stratification (division of the management area into a grid) is not recommended because it may miss important areas.
    f. Stratification should not be done by vegetation communities, as these may shift over time, and the boundaries are often blurry. Areas of special interest should be delineated

[20] Available online at http://science.nature.nps.gov/im/monitor/SamplingDesign.cfm

by physical characteristics such as terrain, elevation, or other features unlikely to change rapidly. Elevation would be a good choice for Mauna Kea.

g. Use permanent plots for monitoring. This will allow managers to identify changes over time, and will preclude problems caused by naturally occurring variation between plots.
h. Optimize sample sizes to obtain the information desired. This requires an understanding of how much change needs to be detected and the variability of resources across space and time. The smaller the change needing detection or the greater the variability across space and time, the more samples that need be taken. Of course, sample size must be balanced with the availability of time and personnel. As a rough guide, NPS recommends a minimum sample size of six plots (per resource or community measured; e.g., māmane woodlands).
i. View the sample locations on a map using GPS and GIS technology, to ensure that adequate representation and coverage of natural resources is being achieved by the sampling protocol.
j. It is not necessary to visit all selected monitoring sites every year. Sampling protocols can be designed to cover a greater area by using rotating sampling locations (see Section 4.1.2.2 for an example).
k. Attempt to sample the different resources in same sample areas (e.g., vegetation, birds, mammals and invertebrates, and abiotic factors), in the same locations or in closely spaced sites, so relationships between these resources can be investigated.

2. Use labor-saving techniques during fieldwork whenever possible and economically feasible. Two such techniques are remote sensing and aerial photography.
3. Consult a statistician before finalizing the sampling design to ensure that monitoring protocols are statistically sound.[21]
4. Doing a test run (or runs) before establishing permanent long-term monitoring or research protocols will help determine how many samples are needed and will allow the NRC to address any problems discovered in the sampling design. This will improve the overall quality of the data collected and ensure that flaws in the sampling design do not render data unusable. This may delay the start of the monitoring or research program but in the long term, it will improve the quality of the data collected.

4.1.3.2 Measuring Progress

Goal IMR-5: Measure progress towards performance goal of preserving, protecting, and restoring Mauna Kea ecosystems

The main purpose of the inventory, monitoring, and research programs is to provide quality data for use in tracking and understanding the status of the natural resources on UH Management Areas. The IM&R programs will accomplish this if data collection methodology is consistent from year to year; data entry and analysis is conducted in a careful manner; and the data is preserved and protected from loss (e.g., from fire, flood, and eventual wear and tear on electronic equipment). This section addresses the basic activities that will enable OMKM to measure progress towards meeting management goals. Specific monitoring and research efforts needed to determine the success of individual management actions are provided in the appropriate component plans (see Section 4.2, Threat Prevention and Control) and below, in Section 4.1.4.

[21] Occasionally it will not be possible to conduct research projects or monitoring activities in such a manner that allows for multiple plots, and therefore statistical analysis of results (for example, monitoring or research conducted on a single isolated population of an endangered plant). In these cases, this limitation should be recognized up front and clearly stated in all reports, proposals, etc.

Objective 1: Collect the right data and ensure data quality

Actions

1. When developing management actions, include a means to measure progress towards the management goal, such as monitoring site conditions regularly. The frequency of monitoring efforts will depend on the nature of the project and how rapidly the resource being managed is expected to respond.
    a. Examples of these are provided in the various component plans (e.g., Section 4.2, Threat Prevention and Control; Section 4.3, Natural Resources Preservation, Enhancement, and Restoration).
2. Each year, devise a list of questions to be answered by the monitoring and research activities covered during that time period.
    a. A running checklist of all monitoring requirements should be developed by the OMKM NRC. The list should include general trend-monitoring goals as well as a list of monitoring goals specific to projects, as described in Item 1, above.
3. Determine if monitoring and research methodologies, and the natural resources selected for monitoring, can provide the data needed to answer the questions posed by the monitoring and research programs.
    a. Consult with statisticians and local experts, if needed.
    b. If it is determined that the methods used, or the resources selected for monitoring, are not appropriate to answer questions, revise methodology, add additional monitoring activities, or begin monitoring of additional resources.
4. Develop and carry out inventory, monitoring, and research programs.
5. Follow protocols for proper data management, including Quality Assurance/Quality Control (QA/QC).
6. Ensure that natural resources staff has proper training in data collection, management, and analysis.

Objective 2: Analyze data to identify trends in natural resources status and to answer specific management questions

Actions

1. Analyze monitoring and research data annually and look for trends that indicate change in the conditions of natural resources. If evidence of degradation of resources is found, examine management activities and determine where management techniques and activities can be improved.
    a. Analyze data with the goal of answering the questions described in Objective 1, above.
2. Review management plan and monitoring and research programs yearly, to determine progress towards management goals.
3. Revise plans as needed, or every five years.
4. Produce "State of the Resources" reports (trend analysis reports) every five years (see Section 4.1.3.3).

4.1.3.3 Communicating and Coordinating

Goal IMR-6. Increase communication, networking and collaborative opportunities, to support natural resource management and protection

Fully developed and implemented IM&R programs will enable OMKM to provide quality information regarding the status of the natural resources on UH Management Areas to interested parties. It will enable OMKM to demonstrate that it is managing its resources; is aware of potential and existing environmental problems; and is responding to the problems using the techniques of adaptive management. In addition, it provides a means to measure progress in achieving management goals in an unbiased, scientific manner. Collaborating with other entities in collecting data, conducting research projects, and implementing management prescriptions, will improve the efficiency, likelihood of success, and applicability of the results of monitoring and research programs.

Objective 1: Produce reports to inform stakeholders, public, and collaborating agencies about the status of the natural resources

Actions

1. Produce annual status report on natural resources. This report should include the results of the current year's monitoring and research efforts, any new developments in status of natural resources or ecosystem health, newly identified data gaps, new recommended management actions, and new collaborations with other agencies and individuals, undertaken during the year.
2. Share the report with collaborating agencies and stakeholders, as appropriate.
3. Provide a summary of the report on OMKM website, and to news agencies, if desired.
4. Every five years, produce a State of the Resources report, detailing changes over time, and responses to management actions.
5. Present the results of various management activities and monitoring program at scientific meetings, especially those involving land managers for other high-elevation areas in the Hawaiian Islands.

Objective 2: Identify opportunities for collaborative data collection and resource management

Actions

1. Communicate and meet with other natural resource management agencies and scientists regularly, to discuss natural resource conditions on Mauna Kea.
    a. Host a Mauna Kea (or high elevation) natural resources management conference, meeting, or work group. Invite all agencies, researchers, and others involved in high elevation natural resources management or research in Hawaiʻi (or elsewhere, if desired). See Section 5 (Implementation and Evaluation Plan) for more information.
2. Work with other agencies, individuals, and programs to identify opportunities for collaboration.
3. Share data with other agencies, and use data collected by other agencies, as appropriate.
4. Develop Memoranda of Understanding (MOUs) with collaborating agencies (as necessary).

4.1.4 Natural Resource Components: Inventory, Monitoring & Research

Data and knowledge gaps about the natural resources on Mauna Kea were identified in Sections 2 and 3. Many of the data gaps can be filled by the collection of the baseline inventory data, or through long-term monitoring. Other data/knowledge gaps will require additional research efforts to fill. This section provides a review of the data gaps concerning the various natural resources on UH Management Areas, and describes the inventory, monitoring, and research activities needed to address these data gaps.

Many of the knowledge gaps and monitoring and research questions in this section are about ecosystem functions, and therefore relate to complex interactions among several types of natural resources, abiotic and biotic. However, since most people still tend to think about resources in general, easily defined categories (geological processes, climate, air, water, soil, plants, invertebrates, mammals, birds, etc.) rather than in terms of interactions among these resources, this section is organized around the resource categories, similar to Section 2 of this NRMP. Generally, the category under which a monitoring or research question is cataloged will be the resource that is either being managed, or is being acted on or affected by the other resources. For example, the impact of mammalian predators on native birds at Hale Pōhaku would be categorized under Birds rather than Mammals. However, research on the diets of rats found at Hale Pōhaku would be categorized under Mammals as the rats are eating more than just bird eggs, and in this case the goal is to better manage (control) the rats through understanding their behavior and impacts at Hale Pōhaku. In some cases, cross-references to specific research projects are made under more than one category when a research project could clearly fall under either category. For the most part, research into the impacts of human use (e.g., recreation, astronomy, cultural activities) on Mauna Kea is included under the natural resource thought to be most impacted by the use activity. However, data gaps and IM&R activities investigating impacts of human use are also discussed in Section 4.1.4.10.

For each of the natural resources categories, a short summary of the data gaps is provided, and a corresponding table identifies how the data gaps can be filled (baseline inventory, long-term monitoring, or research). Following that, information on IM&R program needs is discussed. Individual research protocols have not been developed, as all research needs have not yet been identified through a baseline inventory.

Inventory, monitoring, and research activities were prioritized based on current knowledge of resource condition/status, immediacy of need for management activities, legal status (e.g., if they contained threatened and endangered (T&E) species), and discussions with OMKM Environment Committee, local experts, and stakeholders. Although they are prioritized according to High, Medium, and Low, there are no resources included here that are considered unimportant. In other words, a Low priority does not indicate that the resource should be ignored or is unimportant to ecosystem functioning. It just means that there are other resources that should receive higher priority attention. Priorities for long-term monitoring and research are likely to change after the results of the baseline inventory become available.

The prioritization of activities within a program is relative only to other activities in the program. Prioritization does not carry across programs. For example, monitoring of plant communities is prioritized as high in the Monitoring program, but it does not necessarily outrank baseline inventory of mammalian predators, which is prioritized as medium in the Baseline Inventories program). The overall priority of programs (IM&R) is as follows: Baseline inventories are considered top priority (high), monitoring medium priority, and research low priority. In other words, the baseline inventories should be conducted before beginning monitoring programs. However, in practicality, funding may limit conducting all baseline inventories at once. If this is the case, it is in the best interest of OMKM to begin long-term monitoring of resources in the year following completion of the baseline inventory, regardless of whether all baseline inventories have been completed.

Factors other than priority may also play into when a project is undertaken. For example, a project that is Low priority, but is inexpensive and easy to accomplish, may fit in nicely with a High or Medium priority project and provide additional useful information. When possible, projects that complement each other are cross-referenced so that consideration may be given to undertaking them simultaneously.

The following information is provided as a resource for the NRC, and it is not the intention of this NRMP that all of the following inventory, monitoring and research activities be undertaken by OMKM. Due to staffing and funding constraints, it is recognized that only a small subset of these inventory, monitoring, and research activities will be undertaken.

4.1.4.1 Geology

4.1.4.1.1 Data Gaps

The geology of Mauna Kea has been surveyed and mapped numerous times (Baldwin 1915; Jaggar 1925; Wentworth and Powers 1943; Macdonald and Abbott 1970; Porter 1972b; Wood 1980; Woodcock 1980; Wolfe et al. 1997; Guinness et al. 2003; Porter 2005). The OMKM GIS contains the primary maps delineating geological features of the summit region of Mauna Kea in digital format and hardcopy. Wolfe and Wise have mapped the geology of Mauna Kea, including land within MKSR, and this base map is available digitally (see Figure 2.1-2).[22] Lockwood (2000) characterized and mapped geologically unique features (see Figure 2.1-8).[23] High resolution aerial photos are valuable components of GIS being used for land management. Subsequent photos, over time, can be analyzed to show changes to surface features, potentially prompting management action. A high resolution 2004 air photograph of the MKSR area is available and can be used as base reference image. Additional spatial data may be added over time to the OMKM GIS to illustrate other geologic information. Two main repositories for data available through the US Geological Survey include a listing of *USGS Geologic and Thematic Maps of the Hawaiian Islands* and the *Hawai'i Bibliographic Data Base*, a comprehensive bibliography on the volcanological history of the Hawaiian Island chain.[24]

Table 4.1-3. Geologic data gaps and actions to fill them

Action	Data Gap Filled	Notes
Baseline Inventory	- Database of geologic features at MKSR and Hale Pōhaku	- Base maps of this information are available. Geology maps will show geospatial distribution and contain descriptions of rock types and features.
Long-term Monitoring	- Detection of changes to geologic features through natural and anthropogenic forces	- Ground-based surveys combined with photo interpretation of remotely sensed imagery will allow detection of changes.
Research Projects	- Documentation and evaluation of the subsurface structure and lithology of summit cinder cones	- Further investigation of cinder cone lithology will provide structure information that will assist in understanding subsurface movement of water.

22 Portions of the "Geologic map of the south flank and summit of Mauna Kea Volcano, Hawaii (scale 1:24,000)" by E.W. Wolfe, W.S. Wise, and J.P. Lockwood, including the area of the MKSR, have been converted to digital format and are part of the OMKM GIS. The area of Hale Pōhaku is not included in the currently available digital data.

23 This map has been converted to digital format as part of this project and submitted to OMKM.

24 http://hvo.wr.usgs.gov/products/maplist.html; http://hvo.wr.usgs.gov/products/database.html

4.1.4.1.2 Baseline Inventory

Priority: Medium

Objectives: The objective of cataloguing existing information on geological resources into a GIS database is to:

1. Provide a map that describes the surface features, identifies those that are unique geologically and warrant protection, and identifies potential areas of concern.
2. Provide a physical baseline for use in biological habitat assessment.

Locations/Resources Included: Geologic features within the summit region of Mauna Kea and Hale Pōhaku boundaries (e.g., glacial features, cinder cones, material of different volcanic series (Hamakua and Laphoehoe), cinder vs. lava, and locations of hydrothermal alteration).

Techniques: Compile existing GIS maps of geological features into OMKM GIS, including information submitted as part of this report. Develop new digital maps, by digitizing hard copy maps and associating descriptive text, and compile existing digital maps showing the presence and distribution of geological resources and incorporate them into the OMKM GIS (see Section 4.1.4.1.1). Use photo interpretation and field-based knowledge of OMKM Rangers to identify access points and impact areas that may affect geological resource areas of concern (e.g., roads, trails, landscape scars, known areas of impact to geological features).[25] Resulting data should be entered into the OMKM GIS.

4.1.4.1.3 Monitoring

Priority: Low

Objectives: The objective of monitoring the geologic features is to:

1. Detect any changes to the geologic environment over time and provide data to inform management decisions
    a. Natural changes[26]
    b. Human-induced changes (e.g., road building, trails)

Locations/Resources Included: All geologic features found within the summit region of Mauna Kea and Hale Pōhaku boundaries (e.g., glacial features, cinder cones, and locations of hydrothermal alteration).

Frequency: Monitoring, through aerial photo interpretation should occur every five years.[27] Opportunistic monitoring can be used to document changes to geological resources as they are detected.

Techniques: Two types of monitoring will provide the information needed to assess the condition of geologic resources over time. The first will utilize remotely sensed images captured from fixed wing or satellite platforms. This monitoring will require comparison of features identified on a baseline image

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[25] Photo interpretation and documenting of problem areas by OMKM Rangers (and possibly others), who have extensive on-the-ground knowledge of the resources is a cost-effective way to initially identify potential areas of concern. A field survey of the entire MKSR would be time-consuming and expensive.

[26] Natural changes to the geologic features of Mauna Kea have occurred either very slowly with the passing of time or extremely quickly following events such as a volcanic eruption. Future changes to these features will likely follow this same pattern.

[27] This will require the acquisition of aerial imagery as it becomes available. In addition to paying for imagery, partnerships and collaborative work may also result in the ability of OMKM to obtain free or share cost.

with those on subsequent images. For the large spatial area of the MKSR, this approach is cost-effective and it reduces potential impacts from ground-based surveying. The second technique is a ground-based method employing observations made by OMKM Rangers or staff familiar with features of concern that are within the high travel zones where the probability of resource impact from human activities are greater. Observations will be geospatially delineated using either a global positioning system (GPS), or by identifying the features or areas of interest on the high resolution ortho-rectified air photograph. This technique will include establishing photo-point monitoring of features. Delineated areas of concern from both techniques will be tagged with field notes and other information that describes or quantifies the feature of interest.

4.1.4.1.4 Research

Priority: Low[28]

Although much is known regarding the geology and formation of Mauna Kea, new questions continually surface. Geologic research has the potential for testing hypotheses and answering questions that cannot be inferred through monitoring. However, much of the potential information that could be learned is not required to manage the resources. From a research perspective, identifying the lithology of the cinder cones in the summit region is somewhat of a prerequisite for understanding how water that infiltrates the cones moves beneath the surface. It would also assist geologists and hydrologists in their understanding of the relationship between the hydrology of the summit region and the aquifers and streams of the larger Mauna Kea region. Further investigation of cinder cones may provide a more detailed understanding of how they were built, whether or not their lithology has any bearing on summit hydrogeology, and the limits of their structural integrity. Core samples are required for this type of investigation, to better understand lithology, hydraulic connectivity and flow paths.[29] In the event core sampling is not possible, ground penetrating radar, electrical sounding techniques, and acoustic methods could also be applied to provide useful, if incomplete data.

Questions:

1. What is the inner structure of individual cinder cones? What are the discrete layers composed of and what are their approximate layer depths?
2. Are there consistencies in how the material has been laid down between different cinder cones?
3. For each cinder cone, what are the physical characteristics of the different materials forming the bulk of the cone?

Research Projects:

1. Substrate analysis at varying depths in construction areas
2. Geological analysis at varying depths in construction areas

[28] This type of investigation may warrant higher priority if new projects are proposed for the summit region.

[29] A potential limitation to this project or similar projects that result in disturbance to subsurface resources is the sensitivity required when conducting these types of activities. It is possible that this type of research would not be permitted due to cultural considerations or concerns about disturbance to natural resources resulting from the study. Relevant data could be gathered during any permitted construction activities.

4.1.4.2 Surficial Features and Soils[30]

4.1.4.2.1 Data Gaps

Baseline soil maps have been developed by the Natural Resources Conservation Service (NRCS), and are available in hard copy and digital format.[31] See Section 2.1.2 for more information. There has been no quantitative or qualitative information collected on the causes and impacts of erosion or on areas impacted from concentrated storm water runoff.[32] A systematic inventory and assessment of areas with accelerated erosion has not been conducted. Impacts include, but are not limited to, irretrievable loss of soil resources, potential to damage road or parking areas, and potential safety hazards. There are numerous locations such as along trails, and at the edges of parking areas where accelerated erosion is occurring. An inventory and assessment of erosion sources and impacts is needed.

Table 4.1-4. Surficial features and soils data gaps and actions to fill them

Action	Data Gap Filled	Notes
Baseline Inventory	- Database of hiking and off-road vehicle trail distribution and physical condition - Database of erosion at storm water drainages - Database of soils	- The initial baseline surveys and analyses will help clarify and prioritize future monitoring and management efforts (remediation, monitoring, or no action needed) by identifying problem areas. GIS database will facilitate on-going management.
Long-term Monitoring	- Detection of sites with accelerated erosion (new or increasing) - Detection of changes to physical parameters of drainage-related erosion at locations identified through baseline and at new locations	- Long-term monitoring will allow for adaptive management (e.g., response to changes in conditions, evaluate effectiveness of management efforts).
Research Projects	- Investigate treatments and management actions to remediate accelerated erosion.	- Will provide information on techniques and methods to implement

4.1.4.2.2 Baseline Inventory

Priority: High

Objectives: The objectives of the baseline inventory of surficial features and soil resources are to:

1. Identify and record distribution of soil types across UH Management Areas
2. Identify locations and cause of accelerated erosion sites, and other sites with surface disturbance.
    a. Hiking and off-road vehicle trails
    b. Summit Access Road (unpaved section)
    c. Storm-water drainage infrastructure
3. Catalogue geospatial locations and associated notes into GIS.

Locations/Resources Included: Document accelerated erosion at Hale Pōhaku and the MKSR, with a focus on trails, roadways and land adjacent to building and parking areas.

[30] Potential contamination of substrate as a result of releases of foreign substances are covered in conjunction with potential impacts to surface and groundwater in Section 4.1.4.3.

[31] http://www.ctahr.hawaii.edu/soilsurvey/Hawaii/hawaii.htm

[32] Erosion is a natural process. This section addresses accelerated erosion brought on by changes in the runoff regime or ground cover due to human or activity or factors such as invasive species.

Techniques: Conduct an erosion assessment to identify locations and causes of accelerated erosion, and make recommendations to correct problems.[33] The assessment should also summarize the inventoried sites and prioritize them for treatments. All sites should be catalogued into GIS and tagged with supporting documentation.

4.1.4.2.3 Monitoring

Priority: Medium

Objectives: The objectives of monitoring surficial features and soils are to:

1. Detect adverse changes to surface conditions induced by erosion or other actions in order to identify new sites and assess changes to inventoried sites.
2. Provide consistent documentation of how areas are used, who uses them and associated impacts and/or changes to the resources over time.
3. Maintain GIS database to support inventory and monitoring.
4. Evaluate efficacy of treatments and management actions that may be implemented to control erosion or reduce impacts from storm water runoff on surficial features.

Locations/Resources Included: Hale Pōhaku and the MKSR, with focus on trails, roadways and land adjacent to building and parking areas.

Frequency: Yearly, along hiking trails and roads, and sites associated with storm water drainages. Validation monitoring should occur at construction sites to ensure the best management practices are effective and implemented per construction schedules and permit requirements.

Techniques: Conduct monitoring of surficial features and soil resources at hiking trails and off-road vehicle trails using a combination of visual inspections and identification approaches and quantitative methods such as measuring area of impact. Monitoring should be robust enough to detect significant change in trail attributes from previous monitoring results. Conduct monitoring of erosion associated with storm water drainages using a site survey and photo monitoring protocol. Extent of drainage system should be captured during assessment walks with GPS. Assessment should be compared to previous monitoring assessment and changes documented to determine level of need for remediation, continued monitoring, or no action. Compile all monitoring results into GIS.

[33] Recommended solutions are part of Threat Prevention and Control, Section 4.2.

4.1.4.2.4 Research

Priority: Medium

The focus of surficial feature and soils research will be to investigate the effectiveness of treatments and management actions to remediate accelerated erosion implemented as part of the Threat Prevention and Control Program (see Section 4.2.3.4). Identifying which methodologies work best in the high-elevation, arid conditions of the Mauna Kea summit region will facilitate continued implementation of successful erosion control activities. In addition, research can be conducted on identifying the impacts of some of the less obvious contributors to erosion (e.g., invasive plants, feral ungulates) in order to provide additional justification for control of these threats.

Questions:

1. What erosion control methodologies are most effective to reduce various types of accelerated erosion?
2. Are invasive plant species or feral ungulates contributing significantly to accelerated erosion?

Research Projects:

1. Determine which erosion control methodologies are most effective for different types of erosion. This will be achieved through trial of a range of methodologies and long-term monitoring of their success or failure.
2. Determine the impact of invasive plant species and feral ungulates on substrate and potential contributions to erosion. Coordinate with other research on impacts of these threats on vegetation resources (see Sections 4.1.4.6.4.2 and 4.1.4.9.4).

4.1.4.3 Hydrology

4.1.4.3.1 Data Gaps

The hydrology of Mauna Kea encompasses the occurrence, distribution, source, movement and properties of water in its liquid, solid, and gaseous phases. However, as described in Section 2.1.3, the hydrology of the summit region of Mauna Kea has not been thoroughly investigated.[34] The main data gaps include

1. Hydrologic connection and contribution of recharge from lands within the summit region of Mauna Kea to underlying aquifers. While it has been suggested that rainfall and snow contribute some amount of water to the water budget of Mauna Kea (Woodcock 1980; Ehlmann et al. 2005), it is unknown whether or not water from the summit region is hydraulically connected to the aquifers and streams beneath and down slope of the summit area. Flow paths between summit water contributions and lower-elevation seeps and springs are thought to exist (Bryan 1939; Woodcock 1980).
2. Contribution of past and potential contaminant discharges (intentional wastewater and unintentional spills) from summit facilities to Lake Waiau, lower elevation seeps and springs, and aquifers. See Sections 3.1.1.2.6 and 3.1.1.2.7.
3. Hydrology of Lake Waiau, including its water quality and its water budget.

[34] Lake Waiau is located within the Mauna Kea Ice Age NAR, managed by DLNR. As described in Section 2.1, any analysis of the hydrology of the summit region of Mauna Kea must include consideration of Lake Waiau. Any inventory, monitoring and research projects that include Lake Waiau will need to be coordinated with and permitted by DLNR NARS. Ensuring cultural concerns are addressed is a primary concern for any data collection activities.

Future hydro-geologic investigations will most likely be limited by several factors including cost, cultural considerations, and level of environmental disturbance. However, continued data collection and recording of precipitation from rainfall and snow, along with expanding meteorological sampling to include snow pack depth and snow water equivalent will provide researchers with key information on water inputs.

Table 4.1-5. Hydrological data gaps and actions to fill them

Action	Data Gap Filled	Notes
Baseline Inventory	- Baseline water quality and morphology of Lake Waiau. - Location of all seeps and springs and collection of hydrology data (e.g., flow and quality) within MKSR and Hale Pōhaku including Liloe Spring, Waihu Spring and Hopukani Springs.[35] - Assay of substrate at cesspool and septic tank leach fields for chemical and biologic constituents that have been and may have been discharged.	- Baseline data regarding water quality of Lake Waiau are needed to effectively manage these resources. - The extent of active seeps and springs across MKSR is currently unknown. The locations and condition of hydrologic features will be entered as layers into GIS. - Provide data on the concentration and presence of water quality parameters collected.
Long-term Monitoring	- Water quality of Lake Waiau. - Morphological characteristics of Lake Waiau. - Water quality of specific springs and seeps.	- Data on water quality will assist in the adaptive management process. Changes in water quality may correlate to activities in MKSR
Research Projects	- Conduct hydro-geologic investigation to determine fate and transport of water inputs from MKSR to aquifers - Continued investigation of hydrologic connectivity of water contributions and Lake Waiau and location, discharge volumes, and water quality of specific seeps and springs in Pohakalua Gulch.	- The literature currently contains evidence to support subsurface conduit networks between Lake Waiau and lower elevation seep discharge sites; continuing this and similar research may help understand existing hydrology without instituting invasive coring procedures.

4.1.4.3.2 Baseline Inventory

Priority: Low (water quality and morphology of Lake Waiau); Low (mapping seeps and springs in Hale Pōhaku and MKSR); Medium (assay of substrate at observatory cesspools and septic leach fields)

Objectives: The objectives of the baseline inventory are to

1. Establish a baseline water quality and bathymetry map of Lake Waiau.
2. Map, in GIS, the location and estimate of discharge of all springs and seep outlets at Hale Pōhaku and within the MKSR and collect water samples for baseline water quality.
3. Determine the presence of potential contaminants.

Locations/Resources Included: Water quality monitoring should occur at Lake Waiau and at all seep outlets and springs found within MKSR boundaries (including Liloe Spring, Waihu Spring and Hopukani Springs). Physical condition and morphology should be documented for Lake Waiau. Substrate assays should occur at observatories cesspools and septic tank leach fields.

Techniques:
Lake Waiau: Collect baseline data using water quality monitoring and visual assessment protocols for lakes (Hoffman et al. 2005). Water quality analysis parameters should include at minimum: chemical (isotope analysis, metals, phosphorus, nitrogen, pharmaceutical by-products); physical (temperature, pH,

[35] Although these water bodies are not within the MKSR, they are included to help address concerns that human use of the summit area of Mauna Kea is impacting water resources below the MKSR boundary.

dissolved oxygen, total dissolved solids, conductivity, optical clarity); and biological (bacteria, chlorophyll-a).[36] Physical parameters of Lake Waiau measured and inventoried should include surface area, bed topography, water depth, and presence or absence of vegetation or debris in and around the lake.

Seeps and Springs: Identify and map unknown springs and seeps through field work (requires walking gulches and investigating areas). Discharge measurements and water quality samples should be taken to quantify flow volume and quality. Discharge can be measured by collecting water into a container of known volume and recording the time it takes to fill. Water quality analysis parameters should include at minimum: pH, salinity, visual turbidity and color assessment, and tests for phosphorous and nitrogen as indicators for human impact.

Substrate Assays: Conduct laboratory analysis for chemical and biological constituents that are known to be in waste effluent. Acquisition of samples to obtain baseline data for locations of known or suspected effluent discharges or spills must be conducted by a licensed hazardous waste professional following Phase II Environmental Site Assessment protocol. Results of initial sample analyses will determine how to proceed further.

All baseline data should be compiled into GIS.

4.1.4.3.3 Monitoring

Priority: Low[37]

Objectives: The objectives of hydrological monitoring activities include:

1. Detecting changes in basic parameters for the purpose of assessing morphology and water quality over time
   i. Lake Waiau
   ii. At seeps and springs
2. Detecting threats to water quality including
   i. Wastewater and effluent leaks and/or spills
3. Provide information on hydro-geologic processes
4. Maintain GIS database to support inventory and monitoring

Locations/Resources Included: Water quality monitoring should occur at Lake Waiau and at seeps and springs of interest (including Liloe Spring, Waihu Spring and Hopukani Spring).[38] Physical characteristics should be collected as part of the baseline inventory of Lake Waiau.

Frequency: Semi-annually (wet and dry season) for water quality and at two year intervals for physical characteristics and morphology of Lake Waiau. Water quality and discharge monitoring at specific seep and spring sites should occur annually at the end of winter.

Techniques: Continue data acquisition with same protocols used to acquire baseline data. Adjust protocols and methodologies as needed. Analysis of samples should be replicable and consistent. Analysis of samples must be conducted using methods that result in reporting levels with sufficient precision so

[36] These parameters have been included to cover the range of inputs into the lake, including potential human impact.

[37] Priority may change if contaminants are found in Lake Waiau during baseline inventory.

[38] Reduce the number of sites to be monitored by analyzing baseline data. Accessing all seeps and springs every year may prove more invasive and destructive than necessary.

that changes between subsequent samples can be detected. All monitoring data should be compiled into GIS.

4.1.4.3.4 Research

Priority: High

Due to a variety of reasons, including no regulatory requirements to do so, the hydro-geology of Mauna Kea's summit region has not been investigated. Simple one dimensional modeling for very limited areas has been conducted. In order to understand how land uses in the summit area affect or do not affect water resources beneath and downslope of the MKSR, it is recommended that a robust multi-dimensional hydro-geologic investigation be conducted.

Questions:

1. How much water that reaches the aquifers and streams is from rain and snow that falls across the MKSR?
2. What is the fate of potential contaminants contained in runoff and waste effluent discharged across the MKSR?

Research Projects:

1. Hydro-geologic investigation[39]

4.1.4.4 Climate and Weather

4.1.4.4.1 Data Gaps

Meteorological data have been collected at the summit by observatory facilities since at least 1961 to help the observatories forecast future weather conditions (Businger et al. 2008).[40] Precipitation data was collected at Hale Pōhaku consistently between 1971 and 2000 and meteorological data is currently being collected and streamed real-time to the Mauna Kea Weather Center website.[41] The contribution of precipitation from snowfall has only been collected within the past three years at one summit location, the Subaru Observatory. Precipitation and other meteorological variables have not been collected for areas across MKSR except for those locations indentified above, nor have any snowpack depth measurements and subsequent calculation of snow water equivalent been collected. Presently, there are large spatial gaps between the data collected at Hale Pōhaku and at the observatories. Information on the amount and distribution of snow may also provide valuable information about the response of the wēkiu bug to presence or absence of snow, as well as identify precipitation inputs from snowfall. For natural resource management it is important to monitor and record weather conditions at representative locations in order to quantify one of the drivers in the unique Mauna Kea ecosystem, identify long- and short-term trends, provide reliable climate data to other researchers, and to participate in larger scale climate monitoring and modeling efforts. At present no single database houses the meteorological data collected by the observatories.

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[39] A specific experimental design containing hypotheses, methods, and equations would have to be developed.

[40] http://mkwc.ifa.hawaii.edu/archive/index.cgi

[41] Archived precipitation data can be found at: http://www.wrcc.dri.edu/summary/Climsmhi.html

Table 4.1-6. Climate and weather data gaps and actions to fill them

Action	Data Gap Filled	Notes
Baseline Inventory	- Geospatial meteorological data and estimates of evaporation - Contribution of precipitation from snowfall	- Compiling and analyzing existing weather and climate data will provide managers information on whether or not current data is sufficient to establish baseline for all areas within the MKSR and if additional sampling stations are needed. - Collecting snow pack depth data at MKSR will ensure that an accurate water budget can be calculated for the summit region.
Long-term Monitoring	- Long-term collection of meteorological variables - Data on contribution of snowfall to precipitation input, achieved by installing snow course with sampling instruments	- Data can be used for statistical analysis and filling in spatial gaps by continuing sampling and expanding station network. - Long-term climate monitoring will provide data that may be used in global climate change analysis for Mauna Kea. - Data will enable tracking changes and drawing correlations within the abiotic and biotic environments (i.e., higher temperatures and reduced volumes at seep discharge sites). - Potential for collaboration (e.g., other agencies collecting the same data at similar locations, researchers needing data for analysis).
Research Projects[42]	- Establishment of long-term weather stations for use in global climate analysis - Use of data collected at high elevation stations as both input to, and to validation of, efficacy of climate change forecast models	- Continue current climate and weather research and modeling efforts to support specific research being undertaken at the mountain (i.e., wēiku bug food source modeling). Model wind patterns to determine where aeolian drift comes from and where it is deposited on the summit. Model effects of climate change on wind patterns to determine whether climate change will impact wēkiu bug distribution at the summit. - Tracking changes in the inversion layer width and elevation will allow natural resource managers to study potential linkages between the inversion layer and its affect on meteorological variables that effect ecosystem functions.[43]

[42] It is not the intention of this plan that OMKM conduct long-term global climate change research or develop climate change models. However, the data collected from weather stations can be provided to experts for use in climate change studies. In return, OMKM can use information provided by the experts on climate trends to determine potential management implications.

[43] Information on inversion layer width and elevation would be obtained from climate experts and would not be tracked by OMKM.

4.1.4.4.2 Baseline Inventory

Priority: Medium

Objectives: The objective of compiling existing data on weather and climate parameters at Hale Pōhaku and MKSR is to provide a baseline for trend analysis, monitoring and comparison to future data sets.

Locations/Resources Included: At MKSR baseline data parameters should include: temperature, rainfall, relative humidity, wind-speed and direction, barometric pressure, solar radiation, snowfall and snowpack depth. At Hale Pōhaku baseline data parameters should include: temperature, rainfall, relative humidity, wind-speed and direction, barometric pressure, and solar radiation.

Techniques: Observatories and Hale Pōhaku should continue to use their current protocols for sampling frequency and collection of meteorological variables. In addition, weather stations should be installed at the lower boundary of the MKSR, on the east and west sides of the mountain.[44] All data should be streamed via a wireless network to Hale Pōhaku for display and logging. Compile and analyze data collected for each station for the period of record at both the observatory weather stations and at the Hale Pōhaku station using basic statistical methodologies. The data should be compiled in a master geo-database. For both locations, estimates of evaporation should be developed for monthly intervals and included in the databases.[45]

4.1.4.4.3 Monitoring

Priority: Medium

Objectives: The objectives of climate and weather monitoring are to

1. Detect changes in the subalpine and alpine climate on Mauna Kea
2. Collect weather and climate data to allow for analysis of impacts of climatic factors (such as rainfall) on health and functioning of biotic resources
3. Continue and improve upon snow fall monitoring and modeling program to support wēkiu bug research and accurate calculation of summit water budget
4. Provide data for public/scientific research use.

Locations/Resources Included: At MKSR data parameters should include: temperature, rainfall, relative humidity, pan-evaporation, wind-speed and direction, barometric pressure, solar radiation, snowfall, and snowpack depth. At Hale Pōhaku data parameters should include: temperature, rainfall, relative humidity, pan-evaporation, wind-speed and direction, barometric pressure, and solar radiation.

Frequency: Observatories and Hale Pōhaku should continue to use their current protocols for sampling frequency and collection of meteorological variables. All variables should be sampled at a minimum of 15 minute intervals. Data on snow should be collected annually during the snow season.

Techniques: Continue data acquisition using same collection procedure used to acquire baseline data. Snow course instruments (automated equipment that measures and records snow depth and snow water

[44] This will allow capture of information and fill in spatial gaps. Station data can be used to support other studies (e.g., meteorological, biological).

[45] Evapotranspiration is commonly estimated indirectly using one of three methods: water balance, hydro-meteorological equations, or energy budget. Alternatively, the State of Hawai'i has developed evaporation curves that can be used.

equivalent) should be deployed across the summit area of the MKSR at the beginning of each snow season and removed upon snow melt. Data should be statistically summarized annually.

4.1.4.4.4 Research

Priority: Medium

While it is generally agreed that anthropogenic impacts are contributing to global climate increases, the effects to the climatic regime of the Hawaiian Islands can only be postulated. Mauna Kea provides a unique platform for testing hypotheses and assessing meso-scale changes to atmospheric attributes. Research into how shifts in global weather patterns may impact the persistence and elevation of trade wind inversion are of specific interest due in part to controls the inversion places on precipitation frequency and its magnitude across the MKSR.

It has been suggested that wind patterns play a significant role in maintaining arthropod communities at the summit of Mauna Kea (Howarth and Stone 1982; Howarth et al. 1999; Englund et al. 2002; Porter and Englund 2006). Global climate change has the potential to impact the ecology of arthropod communities through changes in local wind vectors on MKSR. It is known that the summit area aeolian ecosystem is a function of wind, and changes to the wind, in both its magnitude and direction can potentially have an adverse impact on native arthropods. Changes to wind vectors could be induced by large scale atmospheric forcing induced either by climate change or locally by obstructions such as buildings. How these potential changes alter the transport and deposition of wind transported food sources across the summit area is unknown. Research into these potential changes may provide biologists with information on how to better manage the summit arthropod communities.

Questions:

1. Where does the aeolian drift (food sources for the summit arthropod communities) come from?
    a. How does the wind flow up Mauna Kea?
    b. How do observatories and buildings alter wind patterns at the summit?
2. Will shifts in global scale weather patterns alter the persistence and elevation of the tradewind inversion? How will these changes affect other meteorological variables across the MKSR?

Research Projects:

1. Conduct wind flow studies and models to determine sources of aeolian drift at summit.
2. Conduct airflow analysis. Conant et al. (2004) recommend field studies of impacts of buildings on aeolian drift and moisture through deployment of an array of moisture sensors, sediment collectors, and seed traps (to capture aeolian drift).
3. Model windflow patterns under various climate change regimes to determine impact of climate change on aeolian ecosystems.
4. Develop (or support development) of climate change models of high elevation areas in the Hawaiian Islands. Collect and analyze climate data for both MKSR and Hale Pōhaku.
5. Model climate change and vegetation response for subalpine and alpine regions.

4.1.4.5 Air Quality and Sonic Environment

4.1.4.5.1 Data Gaps

Air Quality: Some astronomy facilities at the Mauna Kea summit are sampling the air for a range of variables including particulates. The size of dust particles generated from crushed cinders and other crushed volcanic derived material is unknown. Relative contributions of dust to the airshed around Hale

Pōhaku and the MKSR from sources such as foot traffic, wind blowing over exposed surfaces, and from vehicles have not been quantified. However, it is generally agreed that most dust introduced into the airshed is generated off the unpaved section of the Summit Access Road. The time dust remains in suspension, its distance of spread, and its fallout distribution have not been investigated. No studies have been conducted on the potential adverse impacts on biological resources, physical processes, human health, and vehicles that arise from dust generated by the road surfaces or from other, non-road surfaces affected by human disturbance. However, it is speculated that adverse impacts are occurring and the degree of the impacts is the real unknown. Dust generation by vehicles and construction equipment has been postulated as a potential threat to wēkiu bug habitat (Howarth and Stone 1982).

Sonic Environment: It is generally assumed that current ambient background noise levels are low (see Section 2.1.5); however there has been no monitoring of noise levels nor has a baseline for ambient background noise level been established.

Table 4.1-7. Air Quality and Sonic Environment data gaps and actions to fill them

Action	Data Gap Filled	Notes
Baseline Inventory	- Identify and map dust fall out areas - Compile existing particulate data from observatories - Obtain ambient background noise baseline at Hale Pōhaku and MKSR	- Identification of areas where dust settles will assist in identifying what resources are impacted, and if the impacts are significant. - Deposition of dust may be linked to environmental impacts on arthropod populations and biological health. - Obtaining an ambient background noise baseline will provide information on the conditions at the time of the baseline survey against which future monitoring results can be measured.
Long-term Monitoring	- Assess impact of dust fall out on resources - Detect changes in air-borne dust parameters at Hale Pōhaku and MKSR - Detect changes in ambient background noise levels over time at Hale Pōhaku and MKSR	- Assessment of dust fall out locations will enable natural resource managers to determine if dust is having an impact on natural resources. - Long-term monitoring of specific air quality and background noise levels parameters will allow for tracking the effects of changes seen at the MKSR such as an increase or decrease in visitor density and associated changes in both volume of particulates generated and changes in ambient background noise levels. - Potential to collaborate with other agencies collecting similar data (e.g., Mauna Loa Observatory).
Research Projects	- Compile and analyze air-borne dust particulate data from existing MKSR database for particulates between 1-1000 microns in size - Conduct chemical analysis of dust and dust pockets within dust fall out areas to determine potential contribution of dust to the presence and/or potential for nutrient cycling in support of biological communities.	- Research into the types, constituents, and volumes of air-borne particulates found within the air of Hale Pōhaku and MKSR may potentially help identify whether or not on-site dust generation is impacting human or ecosystem health. If there appears to be significant impact from dust generation, then various management solutions (paving roads, limiting vehicle travel) can be evaluated.

4.1.4.5.2 Baseline Inventory

Priority: Medium (air quality); Low (noise)

Objectives: The objectives of establishing a baseline for air-borne particulates and noise levels are to:

1. Identify locations where dust settling is occurring and assess impacts to resources
2. Provide data on current ambient background noise levels for use in detecting and measuring changes

Locations/Resources Included: The air quality assessment should be focused along the Summit Access Road and areas where dust is blown to, generally upslope and downwind. Ambient noise levels should be collected at areas frequented by visitors, and around observatories.

Techniques: Use visual methods and record locations on a map where dust is observed to generate and settle. A dust dye tracer may be used to facilitate this effort. Compile particulate data collected by observatories into geo-database GIS. Baseline ambient noise can be sampled at frequented visitor sites and at various locations in the MKSR using a mobile sound level meter. Sampling locations should be recorded using GPS and samples should be collected on a day and at times that are representative of normal conditions. All results for both efforts should be compiled into a GIS database.

4.1.4.5.3 Monitoring

Priority: Medium (air quality); Low (noise)

Objectives: The objectives of air quality and sonic environment monitoring are to

1. Detect changes in the concentration of air-borne particulates and assess areas of dust impacts
2. Evaluate if treatments to control dust generation from road surfaces are effective
3. Monitor trends in noise level over time to ensure that ambient levels are not significantly elevated
4. Identify sources of air-borne particulates and noise
5. Allow for potential correlation between changes in natural resource attributes (e.g., increased generation of dust, decreased arthropod populations) and human activity level over time
6. Provide data for public and scientific research use.

Locations/Resources Included: Air-borne particulate concentration and sonic environment monitoring activities should be conducted at both Hale Pōhaku and the MKSR at the same sites used for baseline monitoring.

Frequency: A ground based assessment of sources and the fall out areas should occur at least annually, and possibly more frequently if treatments to control dust are implemented. Continuous collection of particulates at selected observatories should continue and be shared with OMKM. Sampling ambient noise using a sound level meter should occur quarterly.

Techniques: Methods used to collect and compile baseline data should be replicated for both air quality and sonic environment. Data should be analyzed using standard statistical approaches and both positive or negative trends estimated. Apply adaptive management techniques should current collection procedures be found inadequate. Monitoring activities should be rigorous enough to detect significant changes from previous monitoring events.

4.1.4.5.4 Research

Priority: Medium

At this time no noise-related research is being recommended. The focus of air quality research will be to investigate the effectiveness of treatments and management actions to remediate generation of fugitive dust implemented as part of the Threat Prevention and Control Program (see Section 4.2.3.2). Identifying which methodologies work best in the high-elevation, arid conditions of the Mauna Kea summit region will facilitate continued implementation of successful dust abatement control activities. In addition, research can be conducted on identifying the impacts of some of the less significant contributors to dust (e.g., trails) in order to provide additional justification for control of this threat. Further research can include studies to determine if there are human health risks associated with prolonged dust exposure, if dust fallout is adversely impacting biological resources, and where particulates are generated.

Questions:

1. What types of particulates are in the air at MKSR and Hale Pōhaku?
2. Where are the particulates coming from?
3. Are the levels of dust-sized air-borne particulates currently present within the air shed potentially harmful to human health?
4. Are dust-sized particulates negatively impacting the health of the local biological communities?
5. Are there chemical constituents of the dust that may be adding to the nutrient load of Mauna Kea's upper elevation soils?

Research Projects:

1. Conduct literature search to determine impacts of certain air quality parameters on human health.
2. Conduct literature search to determine impacts of certain air quality parameters on lichens and mosses.
3. Investigate potential linkages between dust-sized, air-borne particulates and local biotic health (e.g., covering leaves and reduction of photosynthesis, clogging of cinder substrate, reduction of available wēkiu bug habitat).

4.1.4.6 Plants

4.1.4.6.1 Data Gaps

No quantitative studies of plant communities have been conducted at Hale Pōhaku, the Summit Access Road, or MKSR. Several qualitative (presence/absence) surveys have been conducted at Hale Pōhaku (Gerrish 1979; Char 1985, 1990, 1999a; Pacific Analytics 2004) and MKSR (Smith et al. 1982; Char 1999b), but all were limited in scope or area covered. The last surveys that involved more than a brief examination of field conditions were conducted at Hale Pōhaku in 1990 and at MKSR in 1982. Smith et al. (1982) surveyed only the plant species found above 13,000 ft (3,960 m) and only in areas considered for future telescope construction (as described in the 1982 Master Plan). No botanical surveys of any sort have been conducted along the Summit Access Road between Hale Pōhaku and MKSR.

Information is lacking on the abundance, distribution, and diversity of both invasive species and protected and rare native species in the UH Management Areas. There are isolated populations of some endangered and threatened species on the properties, but the number of protected species and their locations and population sizes are generally unknown. For example, the Mauna Kea silversword was recently discovered in the MKSR (Nagata 2007; Tomlinson 2007), despite not having been recorded there in previous Environmental Impact Statements or in the Master Plan. Additionally, Char (1985) found the threatened species Hawaiian catchfly (*Silene hawaiiensis*) at Hale Pōhaku in 1985, but does not mention this species again in her 1990 or 1999a reports. Its status at Hale Pōhaku is unknown.

Table 4.1-8. Plant data gaps and actions to fill them

Action	Data Gap Filled	Notes
Baseline Inventory	- Composition of plant community - Boundaries of various plant communities (e.g., māmane woodlands, alpine shrublands) - Native species diversity, distribution and abundance - Protected (T&E) species location and abundance - Invasive species distribution, abundance, and concentrations	- The initial baseline plant survey will help clarify and prioritize future monitoring and management efforts by identifying problem areas or areas of special interest (e.g., high native diversity).
Long-term Monitoring	- Changes in community composition - Changes in community boundaries (e.g., movement of communities up or down slope in response to global climate change, reductions in range) - Changes in native species diversity, distribution, and abundance - Changes in invasive species diversity, distribution and abundance - Changes in health and reproductive status of keystone species (e.g., māmane) and T&E species (e.g., silversword). - Response of plant communities to management efforts - Early detection of new invasive species - Identification of any alarming (or promising) trends in native and invasive plant abundances, distribution, or other factors	- Long-term monitoring will allow for adaptive management (e.g., response to changes in conditions, determination of effectiveness of management efforts).
Research Projects	- Determine impediments to recovery of native plant species of concern	- To be done if native plant communities are declining, or are not recovering where restoration efforts are being made.
	- Test control techniques for invasive species	- The best control method to use for a given invasive species may differ between locations (due to such factors as differences in rainfall or interactions with other invasive species), and it may be necessary to do trial runs for a variety of techniques to find the best for the site.
	- Determine response of native plants/animals to changes in abundance of invasive plants	- To be done both through research projects and through long-term monitoring.

4.1.4.6.2 Baseline Inventory

Priority: High (T&E species, invasive species, māmane woodlands, alpine stone desert); Medium (subalpine and alpine shrublands and grasslands)

Objectives: The objectives of the vegetation baseline inventory are to

1. Map the extent, diversity, and composition of all plant communities on UH Management Areas
2. Locate populations of rare or protected (Threatened, Endangered, Candidate) species
3. Determine the locations and severity of invasive plant infestations on UH Management Areas.

Locations and Resources Included: All vegetation communities found at Hale Pōhaku and MKSR, with special emphasis on māmane woodlands and alpine stone desert lichen and moss communities.

Techniques: Vascular plants: Use NPS Pacific Islands Network monitoring protocols (Jacobi et al. 2007). Check for updates to the NPS monitoring protocols. Field data collection on vegetation communities should be accomplished through nested rectangular plots.[46] Aerial photos or remote sensing may be useful for conducting aerial surveys for isolated plant communities. Ground-truthing of aerial survey results (to be done in more easily accessible areas) will be necessary before utilizing these techniques extensively in order to determine whether it is successful in detecting vegetation in the alpine zone. Lichens and Mosses: No NPS protocols are available for inventory or monitoring of lichens and mosses. See Kanda and Inoue (1994), Matthes et al. (2000), and Eldridge et al. (2003) for survey techniques.

4.1.4.6.3 Monitoring

Priority: High (T&E species, invasive species, māmane woodlands, alpine stone desert); Medium (subalpine and alpine shrublands and grasslands)

Objectives: The objectives of the monitoring program for the **native vegetation** community are to

1. Determine changes over time in
    a. Community composition
    b. Location and extent on UH Management Areas
    c. Plant density (woodlands and shrublands) or percentage cover (grasslands)
    d. Diversity
2. Determine the health and reproductive status of keystone species (e.g., māmane trees)
    a. Flower & fruit production[47]
    b. Health of individual plants (senescing, healthy)
    c. Recruitment[48]
3. Track rare or protected (T&E) species populations (e.g., Mauna Kea silversword)
    a. Reproduction and recruitment
    b. Changes in population sizes
    c. Threats
4. Detect threats
    a. Invasive species (e.g., browsing by feral ungulates, invasions by non-native plants)
    b. Encroachment (e.g., development or habitat alteration caused by human uses)
    c. Abiotic threats such as climate change or pollution
    d. Other (e.g., over-collection, trampling, fire)
5. Monitor responses to any management activities, including habitat restoration projects

The objectives of the **invasive vegetation** monitoring program are to

1. Monitor established species
    a. Detect new populations
    b. Detect the expansion or contraction of ranges

[46] In vegetation surveys, the vegetation plot is often divided up into subplots of varying sizes. Small plants and ground cover are measured within a small subplot while trees are measured in a larger subplot. The data gathered from these subplots are then used to estimate plant density and abundance in the entire vegetation plot. This reduces the time needed to record conditions at the site, as there can be many thousands of small plants within a vegetation plot.

[47] Flower and fruit production will provide information on the reproductive status of the plant itself, as well as provide an index of food availability for animal species that depend on the fruits and flowers (such as the Palila).

[48] Recruitment is the entry of new individuals into a population by reproduction or immigration.

   c. Prioritize species for control, based on expansion rates, life history, and modes of dispersal, invasiveness, vectors, and location on UH Management Areas
   d. Monitor response to control projects
2. Early detection of new species
   a. Develop list of known invasive plant species found in Hawai'i that are not currently on UH Management Areas but that are thought to pose a threat to subalpine or alpine communities
   b. Work with other agencies and experts to determine the locations of new populations of potentially invasive plants that are near to, but not on, UH Management Areas
   c. Detect incipient populations of invasive plants on UH Management Areas before populations explode
   d. Determine the locations and sizes of new populations on UH Management Areas
   e. Prioritize species for control, based on life history, dispersal modes, rate of spread, vectors, and location on UH Management Areas
   f. Enable rapid response to incipient populations (control or remove as soon as detected)
3. Monitor response to control projects.

Locations and Resources Included: All vegetation communities at Hale Pōhaku and MKSR should be monitored, if possible. These include the māmane woodlands and subalpine grasslands and shrublands, at Hale Pōhaku, and alpine shrublands, grasslands, and stone desert (lichen and moss communities) at MKSR. If funding is not available for monitoring all vegetation communities, priority should go to māmane woodlands at Hale Pōhaku and lichen and moss communities in the alpine stone desert, in MKSR. All populations of T&E species found on the properties during the baseline inventory (or at other times) should be monitored. Invasive plant populations should be monitored across Hale Pōhaku and MKSR, with priority given to developed and high-use areas such as the VIS and dormatories at Hale Pōhaku and the Summit Access Road. Invasive plant species to monitor include established species such as mullein, fireweed, evening primrose, and telegraph weed, and potential new invaders such as fountain grass.

Frequency: Yearly, with a rotating plot visitation schedule as described in Section 4.1.2.2. Monitoring of restoration or control projects should occur quarterly for at least one year, and then annually thereafter. Monitoring results should be reviewed annually and a "Vegetation Community Trends Report" should be produced every five years (as part of the State of the Resources report). Monitor māmane woodlands during flowering and fruiting seasons, to detect changes in flower and fruit abundances. Monitoring for incipient populations of invasive species in developed areas should occur quarterly (see Section 4.2, Threat Prevention and Control).

Techniques: Vascular Plants: Use NPS Pacific Network vegetation monitoring protocol (Jacobi et al. 2007). Use nested rectangular plots for collection of data in the field, as described in the baseline inventory. The plot locations will be permanent and will be the same as (or a subset of) those used in the baseline inventory. Aerial photographs or remote sensing (e.g., Light Detection and Ranging (LIDAR)) may be used to monitor plant populations in remote areas of MKSR if this technique proves successful in the baseline inventory. However, currently this technique cannot be used to determine the health and reproductive status of individual plants, so field visits to locations of T&E species will still be necessary. If threats to native plant populations are detected through monitoring, initiate threat control actions as described in Section 4.2, Threat Prevention and Control. Methods for prioritizing additional monitoring and control efforts for invasive plants are provided in Section 4.2. Lichens and Mosses: No NPS protocols are available for monitoring of lichens and mosses. Utilize techniques presented in Kanda and Inoue (1994), Matthes et al. (2000), and Eldridge et al. (2003).

4.1.4.6.4 Research

Basic information about the distribution and composition of plant communities on Mauna Kea will be addressed as part of the baseline inventory and long-term monitoring. However, there remain some gaps in the data regarding the management of native and invasive plant communities. These will require directed research. Additional questions will arise after the initial baseline inventory and during long-term monitoring, some of which will need to be addressed through research projects. Some of the research projects described below may already be in progress, or may have been completed for other high-elevation areas in Hawai'i. The NRC should conduct a thorough literature review and interview local experts prior to conducting any of these studies.

4.1.4.6.4.1 Native Plant Research

Priority: Medium

Native plant populations are declining on Mauna Kea, due to high levels of herbivory by introduced mammals (mouflon, sheep, and perhaps rats and mice) and invertebrates (slugs, snails, insects); climate change (increased drought and temperatures); interactions with invasive plants (competition for limiting resources such as water and soil nutrients, as well as simple displacement by more vigorously growing invasive plants); and habitat degradation and loss through development, use of areas for parking lots, off-road driving and hiking, and the increased frequency of fires. The initial baseline inventory and long-term monitoring activities on UH Management Areas will help determine the status and trends of native plant communities. However, there are some aspects of the survival of native plant communities that can be directly addressed only through research. These research projects can be completed for any native plant species of concern that appears to be declining or that fails to increase in abundance after management actions are taken. Therefore, the questions posed below are general and not species specific.

One species, the Mauna Kea silversword (*Argyroxiphium sandwicense* ssp. *sandwicense*) is already known to face challenges to its recovery. Steve Bergfeld and Jay Hatayama (DLNR DOFAW), and Rob Robichaux (University of Arizona) are collaborating to aid the recovery of this endangered species. Any research conducted on the silversword should be coordinated with DOFAW. Natural resource managers at DOFAW are interested in collaboration with OMKM in managing silversword populations on UH Management Areas (Jacobi et al. 2007; Bergfeld 2008).

Questions:

1. What are the current impediments to recovery of native plant species of concern?
    a. Pollination: are there sufficient pollinators, and are plants being cross-pollinated?
    b. Seed Production and Dispersal: Is seed production sufficient? Are seeds viable, and are they being dispersed?
    c. Seedling Germination: Are seedlings able to germinate and survive in current climatic conditions? What are the impediments to germination?
    d. Seedling Growth and Survival: Are seedlings surviving to grow to maturity? What are the impediments to maturation? Are the seedlings being consumed by herbivores before they can reach maturity?
    e. Survival and reproduction of adult plants: What is impacting the survival of mature plants? Are they being eaten by herbivores such as feral ungulates or introduced insects? Are they being out-competed by invasive plants?
2. Do native plant populations respond to restoration efforts, including herbivore exclosures and invasive species control? What are the impediments to successful restoration projects at Hale Pōhaku and in the MKSR?

3. Are changes in climate (rainfall, temperature, snowfall) impacting the native plant communities? This is a question that may be addressed in part through long-term monitoring.

Research Projects:

1. Study pollinator abundance and diversity at Hale Pōhaku and lower regions of MKSR. Determine which insects are pollinating which species, and how large an area individual pollinators cover.
2. Study seed set and dispersal in species of concern to determine if the plants are producing enough viable seed, and whether it is dispersing far enough from the parent plants to establish new populations.
3. Seed germination and seedling survival studies. Determine survival rates of seedlings in the field, and compare to those in other areas of Mauna Kea. Determine what factors are impacting the survival of seedlings. Are they getting enough water? Are herbivores eating the seedlings before they can become established? This study could include multiple factors, such as treatment plots that are fenced or screened to keep out herbivores, treatment plots that receive water, treatment plots that have both screening and water, and control plots.
4. Determine impacts of invasive plants on the survival and reproduction of native plants. This project is discussed below in Section 4.1.4.6.4.2.
5. Whenever possible, restoration projects should be conducted in the form of small, replicated research experiments, to determine which restoration techniques are successful. Once the techniques have been honed, large-scale restoration projects can take place. This is discussed in more detail in Section 4.3, Natural Resource Preservation and Restoration.

4.1.4.6.4.2 Invasive Plant Research

Priority: High

Invasive plants are becoming more abundant in the subalpine and even alpine ecosystems of Mauna Kea. Control or elimination of populations of invasive plants is desirable, particularly in areas of high native plant diversity. Areas that have been completely taken over by invasive plants can be restored through active control of the invasive species and planting of native species. Control efforts will need to continue until the native species become sufficiently established, and in some cases, in perpetuity. Thus, control efforts should be undertaken carefully and managers must determine which methods are best before attempting control on a large scale.

Questions:

1. Which invasive plants pose the greatest threat to native plant communities and should, therefore, be controlled?
2. What are the best control methods for invasive plants at Hale Pōhaku and the lower regions of MKSR?
3. What is the best time of year or the best climactic conditions in which to conduct invasive species control efforts?
4. Does control of one invasive species cause increases in another invasive species?
5. Which human activities at UH Management Areas affect spread of invasive plants and what changes in management offer the greatest return in limiting invasive species expansion.?

Research Projects:

1. Determine which invasive plants are impacting native plant communities the most. This will be most easily achieved through long-term monitoring and through communication with other scientists and land managers. The NRC may prioritize invasive plants through review of rates of spread and corresponding changes in native plants communities in newly invaded areas.

2. Determine the best control methods for individual invasive species. The best method to use for a given species may differ between locations (due to factors such as differences in rainfall and interactions with other invasive species), and it may be necessary to do trial runs for a variety of techniques to find the best strategy for each site. Some of this information may already be available in the scientific literature, but trial runs are still preferable to ensure that techniques will work at UH Management Areas and to avoid spending money on large control efforts that don't work.
3. Determine the best time of year (or stage in the plant lifecycle) to control invasive plant species. Some species might be vulnerable during drought conditions and thus easier to control during drier times of year. Others may be more vulnerable during wetter seasons when they are actively growing. Usually, it is preferable to control an invasive plant before it goes to seed so that seeds are not spread in the area where control actions are taking place.
4. Determine effects of control efforts for one species on population trends for other invasive species. Control of one invasive species can lead to population explosions of other invasive species (Zavaleta 2002).
5. Study the distribution and densities of invasive plants to determine if human activities are increasing the spread of these plants. For example, if movement upslope appears to follow trails or roads (rather than random directions or the predominant wind-flow patterns), then it is likely that seeds are being spread by human movement. Understanding the role of humans in the spread of invasive plants will help determine the most effective control and prevention activities for these species.

4.1.4.7 Invertebrates

4.1.4.7.1 Data Gaps

Most of the research and monitoring of invertebrates completed to date on UH Management Areas has focused on the developed areas of the summit, specifically, on the wēkiu bug. Very little information is available on the other arthropods found at the summit, and almost no information is available about arthropod communities at Hale Pōhaku, along the Summit Access Road, and in the MKSR below the summit. There have been no comprehensive invertebrate surveys conducted at Hale Pōhaku or the Summit Access Road, and no surveys for important invertebrates such as native snails, bees, or moths. Very little is known about the native moths, centipedes, or spider species that inhabit the summit. Two comprehensive qualitative arthropod surveys have been conducted at the summit (Howarth and Stone 1982; Howarth et al. 1999). Both of these surveys covered limited areas, but produced a good list of species found in the community (species composition, but not population densities). Since then, research into the status and biology of the wēkiu bug has continued (Englund et al. 2002; Englund et al. 2005; Englund et al. 2006; Englund et al. 2007; Eiben 2008). Relatively little information is available on the density, distribution, and effects of established invasive invertebrate species on the properties. In 2007-2008, Bishop Museum entomologists conducted a survey for invasive arthropod species along the Summit Access Road, from Hale Pōhaku to the summit, with a focus on developed areas, and on certain undeveloped cinder cones within the MKSR (Englund et al. 2009). This study provided a list of non-native species present and information on distribution of certain species. It is unknown whether these invasive species are impacting native species on the mountain.

Table 4.1-9. Invertebrate data gaps and actions to fill them

Action	Data Gap Filled	Notes
Baseline Inventory	- Invertebrate community composition - Native species diversity, distribution and abundance - Rare and protected species location and abundance - Invasive species distribution, abundance, and concentrations - Identification of sites, species, & groups for long-term monitoring.[49]	- This baseline inventory will serve as an update to the 1982 and1999 surveys conducted at the summit, and will expand the area covered to include Hale Pōhaku and the Summit Access Road. - Focus will be on selected groups (arthropods, snails), as survey for all types of invertebrates would be prohibitively expensive and time consuming.
Long-term Monitoring	- Changes in community composition - Changes in native species diversity, distribution, and abundance - Changes in invasive species distribution and abundance - Response of rare species (such as wēkiu bug) to management efforts - Identification of any alarming (or promising) trends in abundances and distributions of native and invasive invertebrates.	- Long-term monitoring will allow for adaptive management (e.g., response to changes in conditions, determination of effectiveness of management efforts). - Long-term monitoring will focus on rare or protected native species, keystone species, and harmful invasive species.
Research Projects	- Wēkiu bug life history	- Currently underway (Eiben 2008).
	- Wēkiu bug response to habitat alteration	- To be conducted before implementing any large-scale wēkiu habitat restoration plans.
	- Habitat requirements of native arthropods. - Response of native arthropods to natural changes in environmental conditions	- More information on habitat requirements of native arthropods, and their responses to environmental gradients would improve manager's ability to protect core habitat.
	- Impact of invasive arthropods on native species	- If it is determined that native invertebrate populations are declining, research may be conducted to determine whether established invasive arthropods are impacting native species; for example, whether invasive spiders at the summit are impacting wēkiu bug populations.
	- Test control techniques for invasive species (if successful control methods are not already established for high elevation areas)	- To be conducted if invasive invertebrate species are discovered on the properties.
	- Determine response of native invertebrates to invasive invertebrate control projects	
	- Determine response of native invertebrates (primarily pollinators, moths) to changes in abundance of invasive and native plants	- To be done both in conjunction with any restoration of māmane woodlands or other restoration or invasive plant control projects.

[49] The wēkiu bug monitoring program has been underway since 1997, although it has only recently refined its monitoring techniques to the point where data may considered comparable between years. Monitoring locations and frequency were decided by the Wēkiu Bug Working Group in 2008.

4.1.4.7.2 Baseline Inventory

Priority: High: (native pollinators at Hale Pōhaku, summit arthropods, invasive species); Medium (snails, alpine arthropods below summit); Low (Other native subalpine arthropods)

Objectives: The objectives of the invertebrate baseline inventory are to

1. Map the extent, diversity, and composition of select invertebrate communities on UH Management Areas
    a. Hale Pōhaku: Native pollinators (bees & moths), snails, invasive species
    b. MKSR: Arthropods and invasive species at the summit; alpine arthropods (below the summit)
2. Locate populations of rare or protected (Threatened, Endangered, Candidate) species[50]
3. Determine locations and severity of invasive arthropod infestations on UH Management Areas, with the focus on Hale Pōhaku, Summit Access Road, and the summit, near developed areas.
4. Identify sites and species and groups of invertebrates to include in long-term monitoring efforts.

Locations and Resources Included: Inventory arthropod and snail communities in all habitat types found at Hale Pōhaku and MKSR, with special emphasis on māmane woodlands and alpine stone desert (summit) communities. Wēkiu bug baseline inventory locations should include, at minimum, the five survey areas identified by the Wēkiu Bug Working Group and Bishop Museum staff (see Locations and Resources under Monitoring, below).

Techniques: Arthropods: NPS has not yet established protocols for inventories of terrestrial invertebrates, but a variety of methodologies are available for general arthropod biodiversity sampling and monitoring. Additional information on developing a terrestrial arthropod monitoring program is provided in Rohr et al. (2007). If NPS terrestrial arthropod monitoring protocols for either subalpine or alpine regions, or Hawai'i, do not become available by the time of baseline inventory, use the monitoring protocol for terrestrial arthropods available through the Ecological Monitoring and Assessment Network, of Environment Canada (an entity of the Canadian Government) (Finnamore et al. 2002) for invertebrate communities not previously surveyed (all Hale Pōhaku communities, and alpine communities below the summit). These protocols recommend several methodologies similar to those used by Bishop Museum for recent surveys of invasive arthropod species on Mauna Kea. It is also recommended that the Environment Canada protocols be used to conduct baseline inventory of summit arthropod communities. However, as there have been ongoing studies of the wēkiu bug at the summit for over 10 years, integrating the sampling techniques developed specifically for the wēkiu bug by Bishop Museum into the arthropod monitoring protocols is recommended for continuity of data. A combination of ethylene glycol death traps and live trapping is recommended, because arthropods such as the lycosid spiders can enter the live traps, eat the wēkiu bugs and other arthropods within, and leave again, skewing trap results.

Snails: Snail survey techniques should follow those developed by Cowie et al. (1995) for surveying snails in montane habitats on the Island of Hawai'i.

[50] Habitat use and distribution of the wēkiu bug has already been well documented on the summit, but will be updated and refined by the baseline inventory. This objective refers primarily to any other rare or protected species discovered during the baseline inventory.

4.1.4.7.3 Monitoring

Priority: High

Objectives: Monitoring program objectives for terrestrial macroinvertebrate community (insects, spiders, snails) include

1. Determine changes over time in
    a. Community composition
    b. Location and extent on UH Management Areas
    c. Relative abundance of macroinvertebrates in traps and bait stations[51]
    d. Community diversity
    e. Population size or density of selected rare species
2. Detect threats
3. Monitor response to management actions, including habitat restoration projects.

Monitoring program objectives for invasive invertebrates include

1. Monitor established species
    a. Detect new populations
    b. Detect expansion and contraction of ranges
    c. Detect increases or decreases in population sizes or densities (relative abundance at bait stations and traps may also be used)
    d. Prioritize species for control based on threat to native community, potential for successful control, rate of population growth, and location on UH Management Areas
    e. Monitor response to control projects.
2. Detect arrival of new species
    a. Develop list of known invasive invertebrate species found in Hawaiʻi that are not currently on UH Management Areas but that are thought to pose a threat to subalpine or alpine communities
    b. Collaborate with other agencies and experts to determine locations of new populations of invasive species that are near, but not on, UH Management Areas
    c. Detect new invasive invertebrates (incipient populations) on UH Management Areas before population explosion
    d. Determine location and size of new populations on UH Management Areas
    e. Prioritize species for control based on potential threat to native communities, rate of spread, and location on UH Management Areas
    f. Enable rapid response to incipient populations (control or remove as soon as detected)
    g. Monitor response to control projects.

Locations and Resources Included: Because of the time and labor intensive methodologies used in invertebrates surveys, such as sorting and identifying invertebrates collected in traps, invertebrate monitoring activities should focus on selected populations of native and invasive arthropods (and snails, if present). These communities will be determined by the results of the baseline inventory, but should include, at minimum, the native pollinators (bees and moths) at Hale Pōhaku, the wēkiu bug and Lycosid spider at the summit, invasive predators (yellowjackets, ants, and spiders) across all UH Management Areas, and any additional rare or protected species discovered in the baseline inventory. Invasive arthropod monitoring should focus on developed areas at Hale Pōhaku and MKSR and on the Summit

[51] Estimating population sizes is notoriously difficult for many invertebrates. Therefore comparing relative trap capture rates over time is one of the most effective methods for tracking changes in invertebrate populations. For this to work, trapping must be conducted under similar conditions (season, time, weather conditions) during each monitoring period.

Access Road. Monitoring of wēkiu bugs should be conducted annually at the five locations decided upon by the Wēkiu Bug Working Group: pu'u's south and north of the Very Long Baseline Array (VLBA), around the VLBA parking lot, Pu'u Hau Kea, Pu'u Hau Oki, and Pu'u Wēkiu (Preston 2008), and at any additional areas identified as being worthwhile during the baseline inventory.

Frequency: Yearly for general community monitoring, using rotating plot visitation as described in Section 4.1.2.2. Monthly sampling for invasive arthropods, by NRC and VIS staff, at VIS and the observatories . Quarterly sampling for arthropod restoration or control projects for, at minimum, one year, and yearly following that.

Techniques: Arthropods: Use Environment Canada protocols, as described under baseline inventory above. Incorporate Bishop Museum protocols for wēkiu bug monitoring to ensure continuity with previously collected wēkiu bug data. Monthly invasive species screening will be conducted at VIS, near garbage cans and restrooms along Summit Access Road, and near observatories. The screening will entail putting out ant bait traps[52] of two types: canned cat food, for protein loving ants, and honey or sugar solution for sugar loving ants, and by hanging yellowjacket traps (Sea Bright Yellowjacket Inns baited with Heptyl Butyrate) (Montgomery 2008). The ant baits will be collected after 24 hours. For yellowjacket monitoring, follow the protocol described in *Management Strategies for Western Yellowjackets in Hawaii* (Gruner and Foote 2000). Traps will be changed as necessary to ensure integrity and freshness of bait. Other invasive species will be detected during annual invertebrate community monitoring efforts, and additional monthly sampling for invasive species at Hale Pōhaku can be added to monitoring efforts if new invasive species threats are identified. Identification of incipient invasive species to monitor for, and prioritization of invasive species for control activities are discussed in Section 4.2, Threat Prevention and Control.

Snails: No standardized techniques exist for monitoring snail populations (Rundell 2008). Use snail survey techniques developed by Cowie et al. (1995) for montane habitats in Hawai'i.

4.1.4.7.4 Research

Priority: High

Very little is known about the invertebrate communities at Hale Pōhaku and in the alpine zone below the summit of Mauna Kea. The baseline inventories at Hale Pōhaku and lower regions of the MKSR will identify which species are present, and long-term monitoring will help determine population trends for species of concern. Because so little is known about these invertebrate communities, there are relatively few research projects proposed here for subalpine and alpine invertebrate species, other than those recommended in Section 4.1.4.6.4.1 on pollinator populations.

Although the invertebrate community found on the summit of Mauna Kea has been studied in more detail, there is still much to learn. Most of the focus at the summit has been on the wēkiu bug, and there are several research projects underway to better understand wēkiu bug life history and habitat requirements (See Section 2.2.2.2). Although there have been several studies cataloging the diversity at the summit, very little is known about the life histories of invertebrates other than the wēkiu bug.

[52] The baits should be screened or otherwise protected to keep feral cats or other animals from consuming the cat food.

Questions:

1. What are the habitat, dietary, and reproductive requirements of summit invertebrates other than the wēkiu bug?
2. Are wēkiu bug populations increasing, decreasing, or staying the same?
3. What is the life cycle of the wēkiu bug? Do wēkiu bugs move between populations? What is the relationship between the wēkiu bug and the Mauna Loa bug? (These questions are currently being addressed by Jesse Eiben, University of Hawaiʻi at Mānoa).
4. What are the habitat requirements of wēkiu bugs, where are they currently distributed, and how stable are the populations? (These questions are currently being addressed by researchers at the Bishop Museum).
5. What summit arthropods feed on, or compete with, wēkiu bugs?
6. How do wēkiu bugs respond to habitat alteration, including habitat restoration? (The impact of alteration of wind patterns by development of new facilities and the impacts of dust on wēkiu bugs are addressed in Sections 4.1.4.4 and 4.1.4.5, respectively).
7. How do summit arthropods respond to natural variation in environmental conditions at the summit? How does this influence habitat selection by these species?
8. Are the native arthropod populations at the summit being impacted by the presence of invasive arthropods such as the introduced hunting spider *Meriola arcifera*?
9. What are the best control methods for invasive invertebrates found to be impacting native flora or fauna?
10. Are pollinators at Hale Pōhaku abundant enough to effectively pollinate native plant species? (See Section 4.1.4.6.4.1).
11. Do native invertebrate populations respond to habitat restoration or control of invasive plants? This research would be conducted in conjunction with restoration projects.

Research Projects:

1. Conduct studies of life history, habitat use, and diet of selected summit arthropods such as the Lycosid spider and Agrotis moth. This might be best accomplished by funding graduate students, as is being done for Jesse Eiben's wēkiu bug research at the summit.
2. Conduct population estimate studies of the wēkiu bug. Conant et al. (2004) argue that current estimates of wēkiu bug activity levels are insufficient. They recommend expanding live-trap coverage to provide the increased statistical power needed to examine population trends and seasonal patterns of activity. They also suggest attempting a mark-and-recapture study, and using genetics to determine effective population size (Jesse Eiben is addressing the latter).
3. Continue studies of the life history and habitat-use of wēkiu bugs (Jesse Eiben and Bishop Museum; See Section 2.2.2.2.1).
4. Study food web at the summit of Mauna Kea. Conant et al. (2004) recommend fatty acid stable isotope work for the study of food webs (Conant et al. 2004).
5. Conduct experimental restoration of wēkiu bug habitat to determine if proposed restoration techniques would be successful on a large scale (Pacific Analytics 2000).
6. Conduct studies of response of summit arthropods to natural variation in environmental conditions at the summit.
7. Determine if invasive arthropods are impacting native arthropods at the summit. This is a difficult question to address for already established invasive species, because there are no estimates of arthropod population densities at the summit from before invasive species such as *Meriola arcifera* were accidentally introduced. One way to study the impacts of the invasive species would be to compare native summit arthropod populations in areas with invasive species to those areas that are not yet invaded. This, of course, relies on there being areas that are good native arthropod habitats that are not currently occupied by the invasive species, such as the hunting spider. This situation may not exist at the summit. It would also be difficult to rule out the possibility that habitats not currently occupied by *Meriola arcifera* are suboptimal arthropod

habitats. However, this sort of research could be conducted if, in the future (following the baseline inventory and/or long-term monitoring), a new species of invasive arthropod were discovered at the summit. A study of the diet of *Meriola arcifera* can identify which species are being predated and which are the preferred prey. This alone will not, however, indicate whether there is a true impact on the native arthropods, but it could help determine if wēkiu bug are being predated.

8. Determine the best control methods for invasive invertebrates that are found to be impacting native flora or fauna. Examples of this would be experimental control of yellow jackets or ants, should they be discovered at Hale Pōhaku.
9. Conduct pollination studies for native bees and moths at Hale Pōhaku to determine if they are effective pollinators of native plants (See Section 4.1.4.6.4.1). Determine if any non-native arthropods are filling the role of pollinator at Hale Pōhaku and whether these non-native species prefer native or non-native plant species.
10. Study the response of native invertebrate populations to habitat restoration activities conducted at Hale Pōhaku and MKSR (See Section 4.3, Natural Resource Preservation and Restoration).

4.1.4.8 Birds

4.1.4.8.1 Data Gaps

There have been no quantitative bird surveys conducted in Hale Pōhaku, the Summit Access Road, or the MKSR. Two brief qualitative studies were conducted at Hale Pōhaku in 1979 and 1985 (Stemmerman 1979; Stemmerman Kjargaard 1985), and a very limited survey was conducted in 1988 at the VLBA proposed sites (Kjargaard 1988). Bird surveys are needed primarily at Hale Pōhaku, as relatively few birds venture up into the MKSR. Information on the abundance and distribution of protected species and species of concern (e.g., Palila, Apapane, ʻIʻiwi) is needed for Hale Pōhaku, as well as information on the density and distribution of established invasive bird species and their effects on native communities (in particular native plants and birds).

Table 4.1-10. Bird data gaps and actions to fill them.

Action	Data Gap Filled	Notes
Baseline Inventory	- Bird community composition - Native species diversity, distribution and abundance - Protected species location and abundance - Invasive species distribution, abundance, and concentrations	- Baseline Inventory for birds will occur at Hale Pōhaku and along Summit Access Road, to tree line. - Suspected Hawaiian Petrel burrows observed while conducting other work (such as archaeological, invertebrate, or vegetation studies) in the lower regions of MKSR and along the Summit Access Road should be noted. If any are observed, then a more thorough search for Hawaiian Petrel should be conducted in these areas. - Timing of bird surveys must reflect seasonal fluctuations in their abundances. Many of the nectarivorous birds use only subalpine forest while the māmane trees are flowering. Palila and other seed eating birds are more likely to be found when trees have seedpods. Multiple site visits spread over time will be necessary to accurately survey birds at Hale Pōhaku.

Action	Data Gap Filled	Notes
Long-term Monitoring	- Changes in community composition - Changes in native species diversity, distribution, and abundance - Changes in invasive species distribution and abundance - Response of rare and protected species to management efforts	- Long-term monitoring will allow for adaptive management (e.g., response to changes in conditions, determinations of the effectiveness of management efforts). - Long-term monitoring will focus on all bird species.
Research Projects	- Response of native birds to habitat restoration	- To be done in conjunction with any restoration of māmane woodlands, or other restoration or invasive-plant-control projects. Will involve long-term monitoring.
	- Impact of invasive birds on native communities	- This type of research may be conducted if there are suspected links between the spread of certain invasive plants and non-native birds, etc.
	- Monitoring distribution and abundance of mosquito populations over time to determine if they are increasing in elevation in response to global climate change.	- This work will most likely be accomplished by avian malaria researchers (at USGS or University of Hawai'i). However, OMKM should record and report presence of mosquito at Hale Pōhaku, should it be observed there.

4.1.4.8.2 Baseline Inventory

Priority: High

Objectives: The objectives of the bird inventory include determination of

1. Community composition
2. Species diversity
3. Native and invasive bird abundances
4. Location and extent of native bird species on UH Management Areas
    a. Habitat use
    b. Seasonality
    c. Evidence of breeding (nests, young birds)

Locations and Resources Included: The bird baseline inventory will occur primarily at Hale Pōhaku, with a focus on the māmane woodlands. Surveys for Hawaiian Petrel burrows should be conducted in the lower regions of MKSR. The Hawaiian Petrel surveys can be combined with other field surveys to increase efficiency and reduce costs.

Techniques: Use NPS protocol, which entails variable circular plots spaced 150 m apart (approximately 492 ft) along transects (Camp et al. 2006). Before beginning the inventory, inquire at Hawaii Volcanoes National Park about an updated draft of the monitoring protocol. The timing of bird surveys must reflect fluctuations in their abundances due to seasonal differences in resource availability such as māmane flowers and seedpods. Multiple site visits spread over time will be necessary to accurately survey birds at Hale Pōhaku. For the Hawaiian Petrel, use the visual survey methods provided in Hu et al. (2001).

4.1.4.8.3 Monitoring

Priority: Medium (upgrade to High if native bird species are detected in baseline inventory).

Objectives: The objectives of bird monitoring activities include:

1. Detect changes over time in:
   a. Community composition
   b. Location and extent of bird populations on UH Management Areas
   c. Species abundances
   d. Species diversity
2. Detect threats
3. Record habitat use and duration-of-stay of rare or protected (T&E) species
4. Record all observations (whether opportunistic or during monitoring) of rare and protected species
5. Monitor response of bird community to management activities, including habitat restoration projects.

Objectives of invasive bird monitoring activities include:

1. Monitor established species
   a. Detect new populations
   b. Detect expansion or contraction of ranges
   c. Detect increases or decreases in population sizes or densities
   d. Prioritize species for control based on their threat to native community, rate of population growth, location on UH Management Areas
   e. Monitor response to control projects.
2. Detect arrival of new species
   a. Develop list of known invasive bird species found in Hawai'i that are not currently on UH Management Areas but that are thought to pose a threat to subalpine or alpine communities.
   b. Collaborate with other agencies and experts to determine locations of new populations of invasive birds that are near but not on UH Management Areas.
   c. Detect new invasive birds (incipient populations) on UH Management Areas, before population explosion.
   d. Determine location and size of new populations on UH Management Areas.
   e. Prioritize species for control based on their potential threat to native communities, invasiveness[53], and location on UH Management Areas.
   f. Enable rapid response to incipient populations (control and remove as soon as detected).
   g. Monitor response to control projects.

Locations and Resources Included: Monitoring should occur at Hale Pōhaku and along Summit Access Road, up to the treeline. All bird species should be included. Special effort should be given to monitoring native birds, if any are found. If evidence of Hawaiian Petrel burrows is observed at any time in MKSR, monitoring for these birds should be conducted in MKSR.

Frequency: Yearly with monitoring efforts coinciding with peaks in māmane flowering and fruiting. This will result in two monitoring events per year, with the timing somewhat dependent on abiotic influences (e.g., rainfall and temperature) on māmane tree flower and fruiting. Because the total area included in the

[53] The term invasiveness refers to the ability of a species to spread from its point of introduction into new habitats. It takes into account rate of spread and the ability to inhabit a variety of ecosystems.

bird monitoring program is quite small (approximately 19 acres), this should not result in undue time or effort spent for monitoring bird populations at Hale Pōhaku.

Techniques: Use NPS protocol (variable circular plots placed 150 m apart along transects) (Camp et al. 2006). Inquire at Hawai'i Volcanoes National Park about an updated draft of the monitoring protocol before starting the monitoring. Monitoring of habitat use, duration of stay, and the behavior of native passerines should be done in conjunction with DOFAW.[54] Monitoring of Hawaiian Petrel (if present) should follow Hu et al. (2001). Techniques for identifying incipient invasive species to monitor, and for prioritizing control efforts of invasive species, are presented in Section 4.2, Threat Prevention and Control.

4.1.4.8.4 Research

Priority: Low (upgrade to high if native birds are found to reside at Hale Pōhaku)

Native birds have been observed at Hale Pōhaku in the past, but there is no information on whether native species are using habitats there now. The initial baseline inventory and long-term monitoring will provide information on what bird species now use the subalpine areas at Hale Pōhaku. However, if it is found that there are native birds at Hale Pōhaku, OMKM may wish to determine if these birds are transient visitors or permanent residents, in order to better manage the properties for these species. This can be accomplished only through bird banding and repeated observations over time. Because of the relatively small size of Hale Pōhaku, it would be beneficial to collaborate on bird research projects with adjacent land managers, such as DLNR. Any bird banding or research programs should be cleared and coordinated with DOFAW.[55]

Invasive birds are abundant at Hale Pōhaku, but their numbers, distribution across the habitat, and impact on native and invasive plant communities are unknown.

Questions:
1. If native birds are found at Hale Pōhaku, are they transient visitors or year-round residents?
2. Are invasive mammals (predators or ungulates) impacting native bird communities at Hale Pōhaku?[56]
3. Do native birds respond to habitat restoration at Hale Pōhaku? For example, if the māmane woodlands are restored at Hale Pōhaku, will native birds respond by using the area or by increasing in abundance?
4. What are the impacts of non-native birds on the plant and animal communities at Hale Pōhaku?

Research Projects:
1. Conduct long-term banding and observation of native birds at Hale Pōhaku. Any study of the native birds utilizing UH Management Areas should be coordinated with DOFAW. It may be possible for DOFAW or USGS to conduct the needed studies as part of an expansion of their current activities on Mauna Kea.
2. Measure densities of invasive mammals at Hale Pōhaku to determine whether predator control or ungulate exclosures may be required (See Section 4.1.4.9.4). This may already be completed if

[54] Contact the Forest Birds Project Coordinator (currently David Leonard) at the DOFAW Honolulu office.

[55] Contact the Forest Birds Project Coordinator (currently David Leonard) at the DOFAW Honolulu office.

[56] The impacts of invasive predatory mammals (cats, rats, mongoose) and introduced ungulates (sheep, goats) on native birds have already been well studied in Hawai'i. The purpose of this question is to determine whether populations of non-native mammals are present at Hale Pōhaku in high enough densities to impact native birds that may be found there.

mammal populations are being monitored at Hale Pōhaku as part of the long-term monitoring plan.

3. Include long-term monitoring for birds in any restoration project for māmane woodlands or subalpine shrublands undertaken at Hale Pōhaku. See Section 4.3, Natural Resource Preservation and Restoration.
4. Study the impact of non-native birds on the communities at Hale Pōhaku. Research projects could include:
   a. Seed dispersal by non-native birds (preference for seeds of native vs. invasive plants, whether dispersal by birds increases or decreases germination)
   b. Predation of native arthropods by non-native birds
   c. Predation of māmane seeds by non-native birds
   d. Predation of native birds by non-native birds
   e. Disease prevalence in non-native birds residing at Hale Pōhaku
   f. Residency status of non-native birds (are they transient visitors or do they reside at Hale Pōhaku?).

4.1.4.9 Mammals

4.1.4.9.1 Data Gaps

There have been no quantitative surveys for mammals conducted at Hale Pōhaku, the Summit Access Road, or the MKSR. A brief (qualitative) inspection for mammals was conducted by Stemmerman, in connection with her 1979 bird survey at Hale Pōhaku and 1988 bird survey at the VLBA proposed sites. No trapping or specific efforts to observe mammals (spotlighting, bait stations, or traps) has been conducted on any of the properties. The only native mammal that that may use the subalpine region on Mauna Kea is the ʻopeʻapeʻa (Hawaiian hoary bat, *Lasiurus cinereus semotus)*, a Federally Endangered Species, but no surveys have been conducted for the bat on UH Management Areas. Little information is available regarding density, distribution, and effects of established invasive mammal species on the properties. There is a need for a comprehensive survey of invasive mammal species at Hale Pōhaku and identification of environmental problems they may be causing. Data are available from DLNR on the number of feral sheep, mouflon, and goats shot during semi-annual ungulate control efforts conducted by helicopter over the entire mountain area, from the Mauna Kea Forest Reserve to the summit. These numbers can be used as an index of relative abundance to track changes in ungulate populations over time.

Table 4.1-11. Mammal data gaps and actions to fill them.

Action	Data Gap Filled	Notes
Baseline Inventory	- Invasive species distribution, abundance, and concentrations - Hawaiian hoary bat presence at Hale Pōhaku	- Baseline inventory for mammals will occur at Hale Pōhaku, the Summit Access Road, and the MKSR to approximately 12,800 ft (where grasslands become stone desert and grazers would no longer find sufficient food). - Each mammal group (e.g., cats, feral ungulates, rats and mice, mongoose) will require different survey methodology.
Long-term Monitoring	- Changes in invasive species distribution and abundance - Change in hoary bat use of Hale Pōhaku (if present)	- Long-term monitoring will allow for adaptive management (e.g., response to changes in conditions, determination of effectiveness of management efforts). - Long-term monitoring will focus on all mammal species.

Action	Data Gap Filled	Notes
Research Projects	- Impact of invasive mammals on native communities	- This type of research may be conducted if links are suspected between the spread of certain invasive plants and introduced mammals, or predation of native species by introduced mammals (e.g., feral cats eating birds). Nature of projects to be determined by findings of baseline inventory and long-term monitoring.
	- Other projects to be determined upon assessment of introduced mammal populations at Hale Pōhaku.	- Future versions of this plan may identify specific research projects based on findings of baseline inventory or long-term monitoring. For example, if rats are found to be abundant and are thought to be impacting native communities, the NRC may want to test a variety of control methods for most appropriate method for the site.

4.1.4.9.2 Baseline Inventory

Priority: High (native species, invasive herbivores); Medium (invasive predators and seedeaters)

Objectives: The objectives of mammal monitoring include determining the abundance and distribution of invasive mammals, including herbivores such as sheep, mouflon, and goats; predators such as cats, mongoose, rats, and mice; and, at Hale Pōhaku only, seedeaters such as mice and rats. A survey for the native Hawaiian hoary bat *(Lasiurus cinereus semotus)* should be conducted in the māmane woodlands at Hale Pōhaku, as it is expected to use that area during the winter months (Menard 2001).

Locations and Resources Included:
Hale Pōhaku: Surveys for the native bat and invasive herbivores (sheep, mouflon, and goats), predators (cats, mongoose, rats), and seedeaters (mice and rats) should focus on māmane woodlands.
MSKR: Surveys for herbivores (sheep, mouflon and goats) should be conducted in the alpine shrublands and grasslands in MKSR, while surveys for arthropod predators (mice, rats) should be conducted at the summit and near buildings.

Techniques: Currently there are no completed NPS inventory and monitoring protocols for mammals in Hawai'i; however, field-tested methods exist for each of the various groups of mammals in Hawai'i and elsewhere. Scientific articles and reports documenting various survey methodologies are detailed below and included in OMKM EndNote library. General information on mammal monitoring methods can be found in The Wildlife Society's *Wildlife Management Techniques Manual* (Schemnitz 1980).

Bats: Survey techniques for the Hawaiian hoary bat should follow those in Menard (2001) and Gorresen et al. (2008), and should be conducted during the winter (Dec–March), as bats are more abundant in high elevation areas during this time.

Small mammals: Survey techniques for mammalian predators (cats, rats, mongoose) used in the Palila restoration projects can be found in Banko et al. (2005). Non-lethal tracking tunnels are an easy way to index rodent abundance at a site (Gillies and Williams 2003). This methodology may work as well for and other small mammals, possibly including mongoose. Natural resources managers for the U.S. Army on O'ahu will implement this methodology soon, and it may be useful at Hale Pōhaku (Rohrer 2008). Additional survey methods. currently being used on Kaho'olawe for rats and mice, are also available

(British Columbia Ministry of Environment 1998b; Bruch 2008). Copies of these resources are included in the OMKM EndNote library.

Herbivores: Feral ungulates (sheep, mouflon and goats) are currently controlled by DLNR on all of Mauna Kea, from the boundaries of the Forest Reserve to the summit. Each year, the total number of animals shot is recorded in a report to the Federal Court and DLNR is willing to share this data with OMKM. While it cannot provide absolute population estimates, the shoot data can provide an index of relative abundance. Baseline inventory activities for feral ungulates (primarily sheep and mouflon) on UH Management Areas should consist of ground-based surveys, which can be combined with other survey work and recording locations of herbivory damage to native plants, which can be done as part of the vegetation baseline inventory.

4.1.4.9.3 Monitoring

Priority: Medium

Objectives: The objectives of mammal monitoring include

1. Monitoring established species
    a. Detect new populations
    b. Detect expansion or contraction of ranges
    c. Detect increases or decreases in population sizes or density
    d. Prioritize species for control based on the severity of the threat to native community, the rate of population growth, its location on UH Management Areas
    e. Monitor response to control projects[57]

2. Detect arrivals of new species[58]
    a. Develop a list of known invasive mammal species found in Hawaiʻi that are not currently on UH Management Areas but which are thought to pose a threat to subalpine or alpine communities.
    b. Collaborate with other agencies and experts to determine the locations of new populations of invasive species near, but not on, UH Management Areas.
    c. Detect new invasive vertebrates (incipient populations) on UH Management Areas before population explosion.
    d. Determine location and size of new populations on UH Management Areas.
    e. Prioritize species for control based on the potential threat to native communities, invasiveness, and its location on UH Management Areas.
    f. Enable rapid response to incipient populations (control and remove as soon as detected).
    g. Monitor response to control projects.

Locations and Resources Included:

Hale Pōhaku: Monitoring of bats (if found in baseline survey), herbivores (sheep, mouflon and goats), predators (cats, mongoose, rats), and seedeaters (mice and rats) should focus on māmane woodlands.

[57] Collaboration with managers of adjacent lands would greatly improve the success of any control projects. See Section 4.2, Threat Prevention and Control.

[58] Although it is unlikely that any new species of mammals will be introduced to the Hawaiian Islands, it cannot be completely ruled out. In the event of the establishment of new invasive mammal species in Hawaiʻi, this monitoring protocol should be implemented.

MSKR: Monitoring of herbivores (sheep, mouflon and goats) should be conducted in the alpine shrublands and grasslands in MKSR, while surveys for mice and rats, which prey on arthropods, should be conducted at the summit and near buildings.

Techniques: Currently there is no completed NPS monitoring protocol for mammals in Hawai'i. For bats and small mammals, use the monitoring methodologies discussed above under Baseline Inventory. Monitoring for herbivores (sheep, mouflon, and goats) should complement DNLR aerial monitoring, and should consist of visual observations of animals and recording of location of plant damage. Areas of heavy damage may indicate areas in need of fencing. The DLNR helicopter shoot results can be used to track changes in feral sheep and mouflon abundance. Request a copy of the annual court report from DLNR. Coordinate with DLNR to obtain more precise data, such as the numbers of animals shot in various locations. This would be useful for tracking what proportion of ungulates were found in MKSR as opposed to the Forest Reserve.

4.1.4.9.4 Research

Priority: Medium

Mammals found in the subalpine and alpine zones of Mauna Kea are predominantly invasive species such as goats, sheep, rats, cats, and mongoose that are known to heavily impact native plant and animal communities. The native Hawaiian hoary bat (*Lasiurus cinereus semotus*) can be found in māmane woodlands, but it may not be found at Hale Pōhaku given the low density of trees there. The baseline inventory and long-term monitoring will help determine which mammal species are found on UH Management Areas and their distribution and abundances. If it is found that invasive mammals are abundant on the properties (particularly at Hale Pōhaku), then it will be useful to determine what impact these species are having on the native flora and fauna.

It is already known that non-native ungulates such as sheep and mouflon are damaging vegetation communities in the subalpine and lower alpine regions of Mauna Kea. Research should focus on effective control and mitigation of the damage caused by these mammals, rather than on whether these mammals are damaging vegetation on UH Management Areas.

Questions:

1. Are feral cats, rats, mongoose, and mice impacting the native bird communities at Hale Pōhaku? (This assumes that native birds are currently using Hale Pōhaku.)
2. Do mice and rats occur at the summit and if so, are they impacting native arthropod populations?
3. Are rats and mice impacting native plant communities in the subalpine and alpine zones of Mauna Kea through consumption of seeds and seedlings? In other words, are rodents preventing re-establishment of native species in areas where sheep and mouflon are controlled?
4. Do native plant communities respond to removal (or exclusion) of invasive mammals through increased seed set and plant survival? (See also Section 4.1.4.6.4.1).

Research Projects:

1. Study the diets of mammalian predators at Hale Pōhaku.
2. Study the behavior and diets of mice and rats at summit.
3. Conduct seed predation studies and rodent control projects to determine if rats and mice are playing a significant role in reducing the reproductive success of native plants. Rats are known seed predators in dry forests on Hawai'i (Cabin et al. 2000; Chimera 2004).

4.1.4.10 Human Use

4.1.4.10.1 Data Gaps

The impacts of human presence at MKSR and Hale Pōhaku (astronomy facilities, scientific research, tourism, recreation, and cultural use) on subalpine and alpine natural resources are not fully understood. In part this results from the absence of monitoring of the ecological conditions at the site, and therefore no analysis of relationships between human use levels and factors such as erosion, pollution, spread of invasive plants, and habitat loss. Data has been collected on the number and type of vehicles traveling up the mountain, as well as the number of visitors and trail use, on a daily basis since June 2001 (see Section 3.1.3). However, as no data exists on the changes of the status of natural resources over the same time period, OMKM is not currently able to use visitor data for natural resource management decision making. Continued collection of human use data, combined with the long-term monitoring of biological and physical resources on UH Management Areas will address this data gap. Human use issues are also addressed in Section 4.2, Threat Prevention and Control and Section 4.4, Education and Outreach.

Table 4.1-12. Human use data gaps and actions to fill them.

Action	Data Gap Filled	Notes
Baseline Inventory	- Human use impacts on natural resources - Distribution across properties - Number and type of visitors - Number of hikers - Number and type of vehicles - Number of hunters and animals taken - Cultural visitors/cultural events - Distribution and amount of trash - Locations of obvious damage to landscape/ecosystem caused by human use	- The baseline inventory will be a continuation of the data already collected at UH Management Areas, with an additional spatial (GIS) component
Long-term Monitoring	- Similar to Baseline Inventory - Record locations and concentrations of human use on properties with GIS (trail locations, visitor hotpots) - Record locations of significant human use issues such as car accidents or trail erosion	- Long-term monitoring will be a continuation of current monitoring of human use, with the added spatial (GIS) component
Research Projects	- Impact of human use levels on spread of invasive species	- This type of research may be conducted if there are suspected links between spread of certain invasive plants and human uses such as hiking. Nature of projects to be determined by findings of baseline inventory and long-term monitoring.

4.1.4.10.2 Baseline Inventory

Priority: High

Objectives: The objectives of the human use baseline inventory activities include:

1. Determination of location of damage to natural resources caused by human use
2. Quantification of human use levels (continuation of current data collection efforts):
    a. Number of visitors by type
    b. Number of hikers by trail
    c. Number of vehicles by type
    d. Number of hunters, location, and number of animals taken
    e. Cultural visitors/cultural events

f. Distribution and amount of trash
g. Location of, and natural resource damage caused by, car accidents or other major disturbances

Locations/Resources Included: MKSR, Summit Access Road, and Hale Pōhaku.

Techniques: Record ecosystem damage caused by human uses in a GIS database (e.g., point location, type of damage, date).[59] Data can be collected opportunistically or while conducting other baseline inventory surveys. Continue current methodology (OMKM Ranger Reports, see Section 3.1.3) to track visitor usage, including entry into Access database (see Section 4.5).

4.1.4.10.3 Monitoring

Priority: High

Objectives: The objectives of human use monitoring activities include:

1. Track visitor use/recreation uses to detect impact of increased usage on natural resources
    a. Number of visitors by type
    b. Number of hikers by trail
    c. Number of vehicles by type
    d. Number of hunters, location, and number of animals taken
    e. Cultural visitors/cultural events
    f. Distribution and amount of trash
    g. Location and natural resource damage caused by car accidents or other major disturbances

Locations/Resources Included: Hale Pōhaku, Summit Access Road, and MKSR with focus on developed areas, roads, trails, and parking lots.

Frequency: Yearly summaries (based on daily ranger reports), and opportunistic monitoring for infrequent events such as car accidents.

Techniques: Similar to baseline. Enter data into Access database and GIS database and run summary reports on visitor use. Visitor surveys can also be used to collect data on activities and use.

Visitor numbers/recreational use tracking:

1. Hale Pōhaku:
    a. Number of visitors to VIS (Estimates are currently made by VIS staff. Improved data could result from a visitor orientation and registration program. Counts could be summarized from commercial tour operators.)
    b. Number of hikers on trails and trails used (OMKM Ranger Reports)
    c. Off-road vehicle use (OMKM Ranger Reports)
    d. Hunting (OMKM Ranger Reports, DOFAW data)
2. MKSR:
    a. Vehicle traffic to summit (OMKM Ranger Reports)
    b. Number of visitors to observatories (OMKM Ranger Reports. Could obtain data on summit tours from VIS program)
    c. Number of hikers and trail usage (OMKM Ranger Reports)

[59] Determine which specific spatial data layers should be developed based on collected information.

d. Hunting (OMKM Ranger Reports, DOFAW data)
e. Cultural use (OMKM Ranger Reports)
f. Distribution and amounts of trash (OMKM Ranger Reports. Could collect data with GPS if significant amounts following winter season)

4.1.4.10.4 Research

The majority of research questions related to human uses have been addressed in other sections. For example, the impact of dust generation by vehicles traveling on the Summit Access Road is addressed in Section 4.1.4.5; the fate of contaminants released on the summit is addressed in Sections 4.1.4.2 and 4.1.4.3; and the impact of human use on spread of invasive species is addressed in Sections 4.1.4.6 through 4.1.4.9.

4.1.4.11 Landscape Level

4.1.4.11.1 Data Gaps

It is easy to observe and react to large-scale short-term changes to an ecosystem. However, the cumulative impact of many small perturbations to ecosystems that occur through human use and the effects of biotic and abiotic threats such as invasive species and climate change are not obvious unless studied on a landscape scale. There is very little information available on landscape-level changes to Mauna Kea ecosystems. Analysis of threats such as habitat loss or alteration, fires, and distribution of invasive species on the landscape level can provide better management guidance than simply studying these impacts on a small scale. In addition, as natural resource attributes are altered, changes in the viewshed could result. Viewshed conditions will also be altered as a result of changes to the existing facility footprint on the mountain (e.g., decommissioning, new development), including building shape, size, and color or physical condition and shape of cinder features following removal of a building.

Table 4.1-13. Landscape level data gaps and actions to fill them.

Action	Data Gap Filled	Notes

Baseline Inventory	- Landscape level impacts
	  - Fire (Frequency and Distribution)
	  - Land cover and use
	  - Viewscapes
		- The baseline inventory will be a continuation of the data already collected at UH Management Areas, with an additional spatial (GIS) component.

Long-term Monitoring	- Similar to Baseline Inventory - Detect changes in landscape level impacts such as fire, land cover/use, and viewscapes	- Use spatial (GIS) component to monitor long-term landscape level impacts.
Research Projects	- Long-term changes in fire frequency and distribution - Landscape-level changes of plant communities resulting from historical introduction of feral ungulates and invasive plant species	- Changes in plant community composition and global climate change will likely impact fire frequency and distribution. - Using historical data it may be possible to map previous plant community distributions in the subalpine and alpine ecosystems. Once feral ungulate control is achieved it will then be possible to determine if vegetation is returning to historical range. This can also help identify sites for future restoration projects.

4.1.4.11.2 Baseline Inventory

Priority: Medium

Objectives: The objectives of the landscape level baseline inventory activities include:

1. Quantification of landscape level impacts:
    a. Fire (frequency, fuel loads, location, extent)
    b. Land cover and uses
    c. Viewscape
    d. Plant community distribution

Locations/Resources Included: MKSR and Hale Pōhaku

Techniques: The baseline survey will be used to create a GIS map layer showing current conditions – locations of recent fires, land cover types (e.g., grasslands, buildings, parking lots, roads), and three dimensional rendering of current viewscapes.

4.1.4.11.3 Monitoring

Priority: Medium

Objectives: The objectives of landscape level monitoring activities include:

1. Detect landscape/ecosystem level changes in
    a. Fire frequency and location
    b. Land cover and uses (e.g., native plant communities, bare land, invasive plant communities, buildings, parking lots, roads, trails, cultural sites)
    c. Viewscape
    d. Plant community distribution

Locations/Resources Included: Hale Pōhaku and MKSR with focus on developed areas, roads, trails, and parking lots.

Frequency: Yearly updates, and opportunistic monitoring for infrequent events such as fire.

Techniques:

1. Opportunistically record locations and extent of fires and enter into GIS database to determine if the VIS/sub-alpine region is under threat.
2. Create annual updates to GIS map layers of UH Management Areas to document changes and detect undesirable changes to land cover and uses and allow for mitigation or habitat restoration. Activities at Hale Pōhaku should focus on detecting reduction/fragmentation of māmane woodlands. Activities at MKSR should focus on detecting loss of wēkiu bug habitat at the summit, and disturbance of high diversity lichen communities.
3. Update viewscape models when any changes to viewscape occur (such as development of new facility, or removal of old facility, development of new trails or removal of established trails). Some viewscape modeling will be conducted as part of preparation of project planning for proposed projects to assess potential impacts to the viewshed.

4.1.4.11.4 Research

Priority: Medium

The majority of research questions related to landscape level changes have been addressed in other sections. Landscape level research projects that would be useful for management of UH Management Areas include:

1. Historical and current distribution, frequency, and intensity of fires in the subalpine zone. This will help determine whether fires are increasing due to the presence of invasive grasses, and whether fire is a concern in the subalpine zone at Hale Pōhaku.
2. Changes in plant community distribution caused by feral ungulates (using historical information as well as current plant community composition and distribution).
    a. Landscape level analysis of changes in plant community distribution once feral ungulate control is achieved on the mountain. (This project can only be completed once the DLNR fence is repaired and maintained). This project can help identify areas that may benefit from restoration efforts, or invasive species control.
3. Landscape level changes in vegetation community composition and distribution on Mauna Kea, due to environmental factors such as global climate change. This project may include analysis of factors blocking natural migration of species in response to changing environmental factors.

Table 4.1-14. Summary of Baseline Inventory and Monitoring of Mauna Kea's Natural Resources

Resource	Priority HP	Priority MKSR	Baseline Inventory[60]	Monitoring Objectives	Monitoring Techniques	Monitoring Frequency	Action[61]
Physical: Geology							
Geologic Features	N/A	Med	Compile existing geologic maps into GIS[62]	Determine changes over time in physical features (natural, human-induced)	Interpretation of remote-sensed images; ground survey where feasible with photo journal; delineate areas of concern within GIS	Image interpretation: every 5 years; Opportunistic	See Preservation, Enhancement and Restoration, Section 4.3
Physical: Surficial Features and Soils							
Trails, Roadways, Parking Areas, Open Spaces Adjacent to Facilities	High	High	Areas of accelerated erosion along - hiking trails - off-road vehicle trails - Summit Access Road Compile into GIS	1. Detect adverse changes to ground surface induced by erosion on existing or new trails	Visual inspections supplemented with quantitative methods (i.e., measuring trail width) and photo journal	Annually; Opportunistically	See Threat Prevention and Control, Section 4.2 See Preservation, Enhancement and Restoration, Section 4.3
				2. Conduct effectiveness monitoring of any restoration or erosion control projects	Visual inspection of area with photo journal, and quantify changes using techniques to be determined	Annually; Opportunistically	See Preservation, Enhancement and Restoration, Section 4.3
	High	High	Areas of accelerated erosion along storm water drainage infrastructure	1. Detect changes in erosion attributes along stormwater drainage infrastructure: - headcutting into mountain, under and/or around drainage pipe/culvert	Visual inspections, quantitative data collection (i.e., measuring headcut gully depth) and photo journal	Annually	See Threat Prevention and Control, Section 4.2. See Preservation, Enhancement and Restoration, Section 4.3
				2. Map extent of drainage system	Walk system network and record extent with GPS	Once and again as system is altered	See Preservation, Enhancement and Restoration, Section 4.3

[60] To the extent possible, the location and condition of each resource element should be mapped and inventoried.

[61] Contains recommended actions, or references to component plans where management actions to address the objective are described.

[62] Map would include volcanic and glacial features contained on USGS maps, and other reference materials

Resource	Priority HP	Priority MKSR	Baseline Inventory[60]	Monitoring Objectives	Monitoring Techniques	Monitoring Frequency	Monitoring Action[61]
				3. Conduct effectiveness monitoring of any restoration or erosion control projects	Visual inspection of area with photo journal and quantify changes using techniques to be determined	Before, at least once during and then semi-annually following completion of project	See Preservation, Enhancement and Restoration, Section 4.3
Soils	High	High	Soil types	N/A	N/A	N/A	N/A
Physical: Hydrology							
Lake Waiau	N/A	Low	Water quality and morphology	1. Detect changes to - Water quality - Morphology	Use NPS Protocol (Hoffman et al. 2005); adjust as needed	Semi-annually for water quality and every two years for morphology	See Threat Prevention and Control, Section 4.2
				2. Detect threats to water quality	Data analysis of water quality samples	Annually; Opportunistic	See Threat Prevention and Control, Section 4.2
Seeps and Streams	N/A	Low	Location Water quality and discharge rate	1. Detect changes in basic parameters - Water quality - Morphology	Use standard NPS and USGS protocols; adjust as needed	Annually at the end of winter	See Threat Prevention and Control, Section 4.2
				2. Detect threats to water quality	Data analysis of water quality samples	Annually; Opportunistic	See Threat Prevention and Control, Section 4.2
Septic Systems	Med	Med	Assay of substrate at cesspool and septic tank leach fields	N/A	N/A	N/A	N/A
Physical: Climate and Weather							
Meteorological Variables	Med	Med	Meteorological variables to include: temperature, rainfall, relative humidity, wind-speed and direction, barometric pressure, and solar radiation	Detect changes in climate Provide data for use in public / scientific research	Weather stations - automated, real time download	Sampling frequency: every 15 minutes Data analysis frequency: annually	Annual report summarizing data
	N/A	Med	Snow pack depth and amount and distribution of snowfall	Snow fall monitoring program to support wēkiu bug research and accurate calculation of summit water budget	Snow course sampling protocol, automated, real time download	Sampling frequency: every 15 minutes Data analysis frequency: annually	Annual report summarizing data
Physical: Air Quality and Sonic Environment							

Resource	Priority HP	Priority MKSR	Baseline Inventory[60]	Monitoring Objectives	Monitoring Techniques	Monitoring Frequency	Monitoring Action[61]
Air-Borne Particulates	Med	Med	Identify and map location of dust generation and fall out areas and impacts to resources	Continue impact assessment of dust fall out on resources within mapped fall out areas	Protocol developed by NRC – visual assessment using GPS and/or dye tracer	Annually; possibly more frequently if treatments to reduce dust are implemented	See Threat Prevention and Control, Section 4.2
				Effectiveness monitoring of treatments to control dust generation from road surfaces	Protocol developed by NRC; Analyze data using standard statistical approaches	Annually, and as determined by OMKM and MKSS	See Threat Prevention and Control, Section 4.2 MKSS/OMKM to discuss results and decide action
			Compile existing particulate data from observatories	Detect changes in the concentration of air-borne particulates	Obtain on-going data from observatories; Analyze data using standard statistical approaches	Continuous	See Threat Prevention and Control, Section 4.2
Ambient Background Noise	Low	Low	Level of ambient background noise	Monitor trends in ambient background noise levels	Use sound level meter	Quarterly	See Threat Prevention and Control, Section 4.2
Biological: Plants							
Alpine stone desert (lichens and mosses)	N/A	High	Community composition, distribution, boundaries, density and diversity	1. Determine changes over time in: - community composition - location/extent - plant density or percent cover - diversity	Lichens and mosses: See Kanda and Inoue (1994), Matthes et al. (2000), and Eldridge et al. (2003) Vascular plants: Use NPS Protocol (Jacobi et al. 2007)	Annually with Five Year Status Report Conduct monitoring during flowering and fruiting seasons	See Preservation, Enhancement and Restoration, Section 4.3 If threats are detected, see Threat Prevention and Control, Section 4.2
Alpine grasslands	N/A	Med					
Alpine shrublands	N/A	Med		2. Monitor health and reproductive status of keystone species			
Māmane woodlands	High	N/A					
Subalpine shrublands	Med	N/A		3. Detect threats			
Subalpine grasslands	Med	N/A		4. Monitor response to any habitat restoration projects	Use NPS Protocol (Jacobi et al. 2007)	Quarterly after completion of restoration projects	See Preservation, Enhancement and Restoration, Section 4.3

Resource	Priority HP	Priority MKSR	Baseline Inventory[60]	Monitoring Objectives	Monitoring Techniques	Monitoring Frequency	Monitoring Action[61]
T&E Species[63]	High	High	T&E species location, abundance, and population sizes	1. Locate and track health of populations of rare or protected species	Use NPS Protocol (Jacobi et al. 2007)	Annually with Five Year Trend Reports	If problems detected, see Research (4.1.4.5.4); Threat Prevention and Control (4.2); and Preservation, Enhancement and Restoration (4.3).
				2. Detect changes over time in population sizes			
				3. Monitor reproductive success			
				4. Detect threats			
				5. Monitor response to any restoration projects	Use NPS Protocol (Jacobi et al. 2007)	Quarterly after completion of restoration projects	See Preservation, Enhancement and Restoration, Section 4.3.
Invasive Plants: Established Species	High	High	Community composition, distribution and density of established species: - Mullein - Fireweed - Telegraph weed - Evening primrose - Hairy cat's ear	1. Detect new populations of established invasives	Use NPS Protocol (Jacobi et al. 2007)	Annually with Five Year Trend Report	See Threat Prevention and Control, Section 4.2
				2. Prioritize species for control based on: - expansion rates - life history - dispersal modes - invasiveness - vectors of spread - location on UH Management Areas	Review literature, discuss with BIISC[64] members and experts		
				3. Detect expansion or contraction of ranges	Use NPS Protocol (Jacobi et al. 2007)		
				4. Monitor response to control projects		Quarterly following control project	See Threat Prevention and Control, Section 4.2

63 Mauna Kea silversword and any T&E species encountered during baseline

64 BIISC = Big Island Invasive Species Committee

Resource	Priority HP	Priority MKSR	Baseline Inventory[60]	Monitoring Objectives	Monitoring Techniques	Monitoring Frequency	Action[61]
Invasive Plants: Incipient Species	High	High	Community composition, distribution of new species: - Grasses (Fountain grass) - Herbs - Shrubs	1. Develop list of known invasive plant species found in Hawaii that are not currently on UH Management Areas but thought to pose a threat to subalpine or alpine communities 2. Work with other agencies and experts to determine locations of new populations of potentially invasive plants (near but not on UH Management Areas)	Attend BIISC meetings, review literature, meet with neighboring land managers to discuss invasive species	Annually	See Threat Prevention and Control, Section 4.2
				3. Detect incipient populations of invasive plants on UH Management Areas (prior to population explosion).	See Threats Section 4.2	Quarterly	See Threat Prevention and Control, Section 4.2 if new species detected
				4. Determine location and size of new populations on UH Management Areas	Use NPS Protocol (Jacobi et al. 2007)	Annually and as detected	
				5. Prioritize species for control based on life history, dispersal modes, invasiveness, vectors of spread, and location on UH Management Areas	Review literature, discuss with BIISC members	As detected	See Threat Prevention and Control, Section 4.2
				6. Enable rapid response to incipient populations	See Threats Section 4.2	As detected	Control/remove as soon as detected. See Threat Prevention and Control, Section 4.2
				7. Monitor response to control projects	Use NPS Protocol (Jacobi et al. 2007)	Quarterly after completion of control projects	See Threat Prevention and Control, Section 4.2
Biological: Invertebrates							
Snails	Med	N/A	Community composition, distribution and abundance Location of any T&E species	1. Determine changes over time in: - community composition - location/extent on UH Management Areas - abundances - diversity 2. Detect threats	See Cowie et al. (1995) for snail monitoring techniques.	Annually with Five Year Trend Reports (if detected in Baseline Inventory).	See Threat Prevention and Control, Section 4.2

Resource	Priority HP	Priority MKSR	Baseline Inventory[60]	Monitoring Objectives	Monitoring Techniques	Monitoring Frequency	Action[61]
Terrestrial Arthropods: Subalpine Pollinators and Summit Arthropods	High	High	Community composition, distribution and abundances Determine locations of monitoring efforts. Record location of any T&E species	1. Determine changes over time in: - community composition - location/extent on UH Management Areas - abundances - diversity	See Finnamore et al. (2002) and Rohr et al. (2007) for arthropod monitoring techniques	Annually with Five Year Trends Report	See Threat Prevention and Control, Section 4.2
Terrestrial Arthropods: Alpine species below summit	N/A	Med		2. Detect threats			
Terrestrial Arthropods: Other subalpine species	Low	N/A		3. Monitor response to restoration efforts	See Finnamore et al. (2002) and Rohr et al. (2007)	Annually	See Preservation, Enhancement and Restoration, Section 4.3
Terrestrial Arthropods: Invasive Species	High	High	Location and abundance, with focus on Hale Pōhaku, Access Road, and Summit	1. Detect: - New populations - Expansion/contraction of ranges - Changes in abundances	See Finnamore et al. (2002), Gruner and Foote (2000) and Rohr et al. (2007)	Annually (with monthly sampling at Hale Pōhaku)	See Threat Prevention and Control, Section 4.2
				2. Prioritize species for control	Review literature, discuss with BIISC members and experts	Annually	
				3. Monitor response to control projects	See Finnamore et al. (2002), Gruner and Foote (2000) and Rohr et al. (2007)	Quarterly	
Terrestrial Arthropods: Incipient Species	High	High	Location and abundance of new species: - Yellowjackets - Ants - Alpine predators	1. Develop list of known invasive invertebrate species found in Hawaii that are not currently on UH Management Areas but thought to pose a threat to subalpine or alpine communities	Attend BIISC meetings, review literature, meet with neighboring land managers to discuss invasive species, consult with experts	Annually (with monthly sampling efforts at Hale Pōhaku)	See Threat Prevention and Control, Section 4.2
				2. Work with other agencies and experts to determine locations of new populations of potentially invasive invertebrates (near but not on UH Management Areas)			

Resource	Priority HP	Priority MKSR	Baseline Inventory[60]	Monitoring Objectives	Monitoring Techniques	Monitoring Frequency	Monitoring Action[61]
				3. Detect incipient populations of invasive invertebrates on UH Management Areas (prior to population explosion)	See Threat Prevention and Control, Section 4.2	Monthly at HP and observatories	See Threat Prevention and Control, Section 4.2 if new species detected
				4. Determine location and size of new populations on UH Management Areas	See Finnamore et al. (2002) and Rohr et al. (2007)	As detected	
				5. Prioritize species for control based on life history, dispersal modes, invasiveness, vectors of spread, and location on UH Management Areas	Review literature, discuss with BIISC members and experts	As detected	Create priority list, estimate costs for control, obtain funding
				6. Enable rapid response to incipient populations	See Threat Prevention and Control, Section 4.2	As detected	Control/remove as soon as detected. See Threat Prevention and Control, Section 4.2
				7. Monitor response to control projects	See Finnamore et al. (2002) and Rohr et al. (2007)	Quarterly after completion of control projects	See Threat Prevention and Control, Section 4.2
Biological: Birds							
Bird Community (Hale Pōhaku to tree line)	High	N/A	Determine: - Community composition - Distribution - Species diversity - Abundances - Location and extent of native bird species o Habitat use o Seasonality o Evidence of breeding	1. Determine changes over time in: - Community composition - Location/extent on UH Management Areas - Abundances - Species diversity	Use NPS Protocol: Variable Circular Plots (Camp et al. 2006)	Annually with Five Year Trend Report Review monitoring results annually	If threats detected, see Threat Prevention and Control, Section 4.2
				2. Detect threats			
				3. Record habitat use and duration of stay (native species)	Contact DOFAW and USGS		
				4. Record all observations of rare and T&E species	NPS protocol and opportunistic observations	During monitoring efforts or opportunistic	Update GIS database
				5. Monitor response to any habitat restoration projects	Use NPS Protocol (Camp et al. 2006).	Quarterly for first year after completion of restoration projects, then annually	See Preservation, Enhancement and Restoration, Section 4.3

Resource	Priority HP	Priority MKSR	Baseline Inventory[60]	Monitoring Objectives	Monitoring Techniques	Monitoring Frequency	Monitoring Action[61]
Hawaiian Petrel	High	High	Burrow locations Presence of species	1. If detected, monitor as described above in Bird Community	Visual inspection for burrows (Hu et al. 2001)	Annually	If detected, follow monitoring recommendations in Hu et al. (2001)
Invasive Birds: Established Species	High	N/A	Distribution, abundance, and concentrations	1. Detect: - New populations - Expansion/contraction of ranges - Changes in abundances	Use NPS Protocol (Camp et al. 2006)	Annually	
				2. Prioritize species for control	Discuss with local experts, review literature	Annually	See Threat Prevention and Control, Section 4.2
				3. Monitor response to control projects	Use NPS Protocol (Camp et al. 2006)	Quarterly for first year then annually	See Threat Prevention and Control, Section 4.2
Invasive Birds: Incipient Species	High	N/A	Distribution, abundance, and concentrations	1. Develop list of known invasive bird species found in Hawaii that are not currently on UH Management Areas but thought to pose a threat to subalpine or alpine communities	Attend BIISC meetings, review literature, meet with neighboring land managers to discuss invasive species, consult with experts	Annually	See Threat Prevention and Control, Section 4.2
				2. Work with other agencies and experts to determine locations of new populations of potentially invasive birds (near but not on UH Management Areas)			
				3. Detect incipient populations of invasive birds on UH Management Areas (prior to population explosion)	See Threats Section 4.2	Annually and opportunistically	See Threat Prevention and Control, Section 4.2 if new species detected
				4. Determine location and size of new populations on UH Management Areas	Use NPS protocol (Camp et al. 2006)	As detected	
				5. Prioritize species for control based on potential threat to native communities	Review literature, discuss with experts	As detected	Create priority list, estimate costs, and obtain funding
				6. Enable rapid response to incipient populations	See Threat Prevention and Control, Section 4.2	As detected	Control/remove as soon as detected See Threat Prevention and Control, Section 4.2

Resource	Priority HP	Priority MKSR	Baseline Inventory[60]	Monitoring Objectives	Monitoring Techniques	Monitoring Frequency	Monitoring Action[61]
				7. Monitor response to control projects	Use NPS Protocol (Camp et al. 2006)	Quarterly after completion of control projects for first year, then annually	See Threat Prevention and Control, Section 4.2
Biological: Mammals							
Herbivores (sheep, mouflon, goats)	High	High (below summit)	Distribution and abundance up to approx. 12,800 ft elevation	1. Detect: - New populations - Expansion/contraction of ranges - Changes in abundances	Herbivores: Work with DLNR-DOFAW Small mammals: See Schemnitz (1980), British Columbia Ministry of Environment (1998b, a), Gillies and Williams (2003), and Banko et al. (2005)	Annually	See Threat Prevention and Control, Section 4.2
Bird Predators (cats, rats, mongoose)[65]	Med	N/A	Distribution and abundance to treeline	2. Prioritize species for control	Prioritization: Review literature, consult with experts	Annually	Develop priority list, estimate cost, obtain funding
Arthropod Predators (rats, mice)	Low	High	Distribution and abundance at summit	3. Monitor response to control projects	See Schemnitz (1980), British Columbia Ministry of Environment (1998b, a), Gillies and Williams (2003), and Banko et al. (2005)	Quarterly for first year then annually	See Threat Prevention and Control, Section 4.2
Seed Predators (rats, mice)	Med	N/A	Distribution and abundance to treeline and at locations of T&E plant species				
Hawaiian hoary bat	High	N/A	Presence, distribution, abundance, seasonality	1. If detected during baseline survey, monitor for: - Changes in population size - Expansion/contraction of ranges - Changes in abundances	Work with USGS See Menard (2001) and Gorresen (2008) for techniques	Annually if detected during baseline inventory Five year trend report	If threats detected, see Threat Prevention and Control, Section 4.2
				2. Detect threats			
Human Use							

[65] Inventory and Monitoring of bird predators should be classified as High Priority if native bird species are detected at Hale Pōhaku.

Resource	Priority		Baseline Inventory[60]	Monitoring			
	HP	MKSR		Objectives	Techniques	Frequency	Action[61]
Human Activity	High	High	Human use impacts on natural resources: - Distribution of human activity across properties - Number and type of visitors Number of hikers - Number and type of vehicles - Number of hunters and animals taken - Cultural visitors/cultural events - Distribution and amount of solid waste - Locations of obvious damage to landscapes and ecosystems caused by human use	1. Record locations and concentrations of human use at Hale Pōhaku and within MKSR properties	Ranger reports; volunteer estimates; physical presence of someone recording activity at specific locations	Daily; as situations occur	If threats detected, see Threat Prevention and Control, Section 4.2
				2. Record locations of significant human use issues - car accidents - trail erosion	Ranger reports; field surveys	Daily; as situations occur	If threats detected, see Threat Prevention and Control, Section 4.2
Landscapes	Med	Med	Landscape level impacts - Fire (distribution) - Land cover and uses - Viewscapes - Plant community distributions	Detect landscape/ecosystem level changes in - Fire frequency and location - Land cover and uses - Viewscapes - Plant community distributions	Record location of fires using GIS Update OMKM GIS annually with land cover and uses data, and vegetation monitoring data	Annual updates Opportunistic collection of fire data	See Threat Prevention and Control, Section 4.2 and Preservation, Enhancement and Restoration, Section 4.3

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[66] Copies of protocols can be found in the OMKM library.

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4.2 Threat Prevention and Control Component Plan

4.2.1 Introduction

Threats to natural resources on UH Management Areas were identified and discussed in Section 2.1, 2.2, and 3.2, and are summarized below in Table 4.2-1. In addition, inventory, monitoring, and research projects to be conducted on UH Management Areas will clarify how significant these threats are and identify any new threats (see Section 4.1). Once a threat has been detected, the Natural Resources Coordinator (NRC) must determine the appropriate course of action. Some threats will be minor and require no response, while others will be so large as to be out of the scope of response by the Office of Mauna Kea Management (OMKM). For threats between these extremes, threat management is an option. A major responsibility of the NRC will be to determine the magnitude of these threats and to prioritize threat management activities.

Natural resource managers have three general tools at their disposal to deal with threats to natural resources: prevention, detection, and control. To be carried out properly, prevention, detection and control activities need to be carefully planned and must receive sufficient funding. Prevention includes activities that deter the threat from occurring or that keep existing threats from becoming more destructive. Detection includes activities that help managers locate new threats or become aware of changes in the magnitude of previously identified threats. Detection activities may be conducted as part of the regular monitoring of natural resources (Section 4.1), or through special detection efforts. Control includes activities that either eliminate the threat or reduce its impact. Prevention is the preferred method of response. Controlling a threat is often more difficult and expensive than preventing it.

Table 4.2-1. Threats to Mauna Kea High Elevation Natural Resources

Resource	Threat	Section
Habitat	Habitat alteration and loss	- Physical Resources: 2.1.2.5 and 2.1.3.6 - Plants: 2.2.1.3.1 and 2.2.1.3.5 - Invertebrates: 2.2.2.3.1 - Birds: 2.2.3.3.1 - Sources/Pathways of disturbance: 3.2.1, 3.2.8
Air	Air pollution	- Physical Resources: 2.1.5 - Plants: 2.2.1.3.5 - Invertebrates: 2.2.2.3.1 - Sources/Pathways of disturbance: 3.2.2
Water	Groundwater contamination	- Physical Resources: 2.1.3 - Hazardous Materials: 3.1.1.2.7 - Sources/Pathways of disturbance: 3.2.3
Soil	Soil contamination	- Physical Resources: 2.1.3 - Hazardous Materials: 3.1.1.2.7 - Sources/Pathways of disturbance: 3.2.3
	Erosion	- Physical Resources: 2.1.2 - Sources/Pathways of disturbance: 3.2.4
	Solid waste	- Physical Resources: 2.1.6 - Sources/Pathways of disturbance: 3.2.5
Auditory Environment	Noise	- Physical Resources: 2.1.5 - Sources/Pathways of disturbance: 3.2.6
Flora and Fauna	Invasive species	– Plants: 2.2.1.3 – Invertebrates: 2.2.2.1.2, 2.2.2.2.2 and 2.2.2.3 – Birds: 2.2.3.1.3, 2.2.3.2.2, and 2.2.3.3.2 - Mammals: 2.2.4.1.2, 2.2.4.2.2, and 2.2.4.2 - Pathways: 3.2.8

Resource	Threat	Section
	Population decline and loss of diversity	- Plants: 2.2.1.3 - Invertebrates: 2.2.2.3 - Birds: 2.2.3.3 - Mammals (native bat): 2.2.4.3 - Impacts to native plant and animal communities through human uses and activities: 3.2
	Scientific research and sample collection	- Physical Resources: 2.1.1.6, 3.2.1 - Invertebrates: 2.2.2.2.3 - Sources/Pathways of disturbance: 3.2.9
	Fire	- Plants: 2.2.1.3.2 - Birds: 2.2.3.1.1 - Sources/Pathways of disturbance: 3.2.10
	Climate change	- Plants: 2.2.1.3.6 - Invertebrates: 2.2.2.3.4 - Birds: 2.2.3.3.4 - Sources/Pathways of disturbance: 3.2.11

4.2.1.1 Threat Prevention and Control Program Goals

The overarching goal of this Threat Prevention and Control Component Plan is to protect the natural resources on UH Management Areas from being degraded by human activities and related natural forces. The specific goals addressed by the component plan are summarized below. Management objectives and actions to aid in reaching these goals are discussed under each goal.

	Program Goals	Section
Goal TPC-1	Provide early warning of undesirable changes to Mauna Kea's high-elevation ecosystems	4.2.2
Goal TPC-2	Minimize habitat alteration and disturbance	4.2.3.1
Goal TPC-3	Maintain high level of air quality	4.2.3.2
Goal TPC-4	Prevent migration of contaminants to the environment	4.2.3.3
Goal TPC-5	Minimize accelerated erosion	4.2.3.4
Goal TPC-6	Reduce impacts of solid waste	4.2.3.5
Goal TPC-7	Maintain current levels of background noise	4.2.3.6
Goal TPC-8	Prevent establishment of new invasive species and control established invasive species	4.2.3.7
Goal TPC-9	Maintain native plant and animal populations and biological diversity	4.2.3.8
Goal TPC-10	Limit impacts to natural resources from scientific research and sample collection	4.2.3.9
Goal TPC-11	Prevent fires	4.2.3.10
Goal TPC-12	Manage ecosystems to allow for response to climate change	4.2.3.11

4.2.1.2 Reporting Needs

Annual reporting on the Threat Prevention and Control Program is necessary for evaluating the effectiveness of threat prevention and control activities, documenting threat response activities, and enabling planning of future threat response activities. It is recommended that the annual report contain the following items:

1. Summary of the condition of natural resources on UH Management Areas (to be based on results of inventory, monitoring, and/or research activities).

2. Threats detected, their severity, and resources impacted.
3. Prioritization of threat response activities for the year being reported on, including a summary of how activities were prioritized.
4. Threat prevention, detection, and control activities carried out. For each one, detail
    a. Description of activity, including methodology.
        i. For more complex projects that require detailed description of the methodology, a separate protocol document should be developed prior to carrying out the activity. See Section 4.1 for more information on developing protocols.
        ii. Detection activities that are part of the annual monitoring efforts carried out in the monitoring program need only be listed and not described in detail, since they will be addressed in detail in the Annual Monitoring Report (see Section 4.1).
    b. Date started.
    c. Date of completion or expected completion (as dictated by funding or estimated, based on the rate of progress).
    d. Cost of project, and any expected ongoing expenditures.
    e. Outcomes of the threat prevention, detection, and control activities carried out.
        i. If unknown, state what activities are needed to determine outcome (e.g., continue monitoring, conduct research, or wait and see).
        ii. Analysis of the success of the activity.
            1. Use the goals set forth in project protocols and/or in the Threat Prevention and Control Components listed in Section 4.2.3.
5. Further prevention, detection, and control activities needed.
    a. Identify through results of current activities, or through knowledge of needs for the particular threat response activity.
    b. Organize by priority, or the type of threat addressed.
6. Summary of the results of the Threat Prevention and Control Program.

4.2.2 Detection of Undesirable Changes to the Ecosystem

Goal TPC-1: Provide early warning of undesirable changes to Mauna Kea's high-elevation ecosystems.

Early detection of undesirable changes will allow development of effective mitigation measures and reduce the overall cost of management by catching the problem before it becomes uncontrollable. Routine monitoring (on a one- to five-year basis) of abiotic conditions and biotic communities on UH Management Areas will, for the most part, help achieve the goal of detecting undesirable changes to Mauna Kea high-elevation ecosystems. The two objectives of this goal are to detect and respond to 1) short-term and 2) long-term changes to UH Management Area lands. The actions necessary to meet these objectives must be dynamic and adaptive and are described below.

Some threats, such as arrival of new invasive species, require special effort and increased vigilance to detect. In the case of these threats, it is desirable for OMKM to be made aware of the problem early on, to allow for rapid response and coordination with other land managers in the region. It is more cost effective to respond to invasive species while their populations are small or localized, and the probability of successful eradiation is higher. Detecting new populations of invasive species requires frequent monitoring of high traffic areas of the UH Management Areas. The development of the Invasive Species Monitoring and Rapid Response Program is discussed further in Section 4.2.3.7.

Geospatial software such as a Geographic Information System (GIS) is an important management tool to aid in prevention, detection, and control of threats to natural resources on Mauna Kea. Compilation of data and detection of ecosystem trends can be facilitated by using GIS to quantify contraction or expansion of habitats or changes of physiographic variables over time. It is recommended that methodologies to achieve the actions presented below incorporate a geospatial database and maps (see Section 4.5).

Objective 1: Detect short-term, undesirable changes to high-elevation ecosystems

This objective can be met through the annual monitoring efforts conducted as part of the Inventory, Monitoring and Research Component Plan (Section 4.1), as well as through general observations made by rangers and other field staff. The benefit of collecting data annually is that sudden or unexpected changes can be detected early on, and in some cases, responded to soon enough to reduce the overall extent of damage. However, it is important to keep in mind that natural variation in resources may mask some changes, making a situation seem better or worse than it is, and that long-term monitoring may be necessary to determine the real trends. For example, a decrease in an insect population one year may be followed by an increase in the following year without any intervention. The NRC must use his or her scientific knowledge of the resource in question, and other expert opinion if necessary, to decide whether immediate management actions are needed, or if further monitoring is called for.

Actions

1. Conduct annual monitoring efforts as described in Section 4.1.
2. Conduct annual photo-monitoring in high traffic and sensitive areas[1] to allow for comparison over time.
3. The NRC and field biologist(s) should spend enough time in the field to recognize negative changes to the system, such as sudden die-back of plants in a localized area, excessive erosion, or evidence of fire.
4. Analyze monitoring data to detect annual changes in condition of resources, such as declining populations and increased erosion rates.
5. Develop management actions in response to sudden changes in the natural resources that are not explained by natural variation (e.g., stemming from fire, disease, increased predation, large erosion events).
    a. Many management responses to potential or currently known threats to the ecosystem are described below, in Section 4.2.3.
6. Communicate and collaborate with other land managers when the problem crosses administrative boundaries.

[1] A sensitive area is an area that is deemed in need of protection. Sensitive areas may include areas with a rare, Threatened, or Endangered species; a unique native community; or physical resources. Sensitive areas may also be areas prone to disturbance such as erosion or crushing of cinder.

Objective 2: Detect long-term, undesirable changes to high-elevation ecosystems

The effects of slow-acting but powerful forces, such as global climate change, on ecosystem processes cannot easily be detected in the short term, in part because the changes are often hard to distinguish from natural variability. Long-term monitoring will be necessary to detect ecosystem-level changes brought about by such threats as climate change, air pollution, and increased visitation rates to the summit. The only way to detect and respond to changes brought about by these forces is through regular collection of comparable data, including abiotic and biotic factors, and analyses for trends over time.

Actions

1. Collect annual data on abiotic variables, such as rainfall, temperature, air quality, and water quality.
2. Collect annual data on native plant and animal communities, including densities, population sizes, and age distribution, as appropriate.
3. Determine current population ranges or elevational extent. Compare to previous years to detect shifts in boundaries, including movement of populations up or down slope and other contraction or expansion of ranges.
4. Compile annual abiotic and biotic data in GIS.
5. At five-year intervals, conduct serial data correlation analysis between abiotic and biotic variables, to assess relationships between the variables and to detect spatial and temporal trends. Prepare a report identifying any observed trends.
6. Communicate and collaborate with state and federal agencies, and local experts, regarding observed changes to other high-elevation ecosystems in the Hawaiian Islands.
7. Use adaptive management to respond to negative changes.

4.2.3 Management Actions to Address Threat Prevention and Control

The following sections describe management actions to deal with potential and actual threats to natural resources found on UH Management Areas, as identified in Sections 2, 3, and 4.1 of this Natural Resource Management Plan. Other threats may be identified in the future, and this section should be updated every five years to address new threats and make necessary changes in management responses to established threats. Some of these threats are currently known to be impacting the natural resources, while others are not currently known to be a major source of impact (potential threats). The potential threats are included because they were deemed to be probable source of impacts in the future.

An indication of the current threat level is presented at the beginning of each of the following Threat Prevention and Control subsections. For simplicity, the threats are identified as High, Medium, Low, and Unknown. The threat level is an indication of the current danger posed by this threat to the natural resources on UH Management Areas and the urgency of management response to the problem. For example, a threat level of High indicates that the threat is potentially severe and should be dealt with rapidly, if possible. A threat level of Unknown indicates that there is not enough information on the threat to give it a priority. Following every use of Unknown is a ranking of High, Medium, or Low, in parentheses, indicating the priority assigned to determining the level of the threat. For example, Unknown (High) indicates that the current threat level is unknown, but that finding out is of high priority, because the threat is considered likely to have significant negative impacts on natural resources. The threat level is based on our current understanding of the conditions on Mauna Kea and can (and most likely will) change once the baseline inventory is conducted. Threat levels will likely change again as personnel analyze status and trend data on the Mauna Kea's natural resources collected during the natural resource monitoring program (see Section 4.1). Because time and budget constraints will most likely preclude managing all threats at once, these threat levels are to be used simply as way of prioritizing management actions.

Each threat prevention and control subsection presents the source of the threat, potential management responses, priority[2], and an estimated relative cost. Where numerous potential actions are identified, the actions are presented in table format. For many threats, a variety of management actions are presented. It is not the intent of this plan that all of these be implemented, but rather the best actions be chosen depending on the management priorities, situation, availability of funding, and the results of the baseline inventory and long-term monitoring. These management actions are intended to be recommendations only. If a recommendation is implemented and it results in an action that would require ground disturbance or alteration of the existing environment, a separate environmental analysis will be conducted in compliance with existing State law. In some cases, an activity may address more than one threat. For example, an activity that may accomplish the goal of reducing habitat disturbance may at the same time accomplish other management goals such as minimizing erosion or reducing the spread of invasive species. When there is overlap, the corresponding subsection is identified.

4.2.3.1 Habitat Alteration

Threat Level: Hale Pōhaku: Medium; MKSR: Medium.

Habitat alteration and disturbance results in the loss of unique natural physical resources and threatens native plant and animal communities by directly removing or destroying their physical habitat, or by degrading it to the extent that it stresses the native species. A common type of habitat alteration in the UH Management Areas is cinder disturbance. Cinder disturbance includes any activity that reduces cinder particle size by mechanical impact. When cinder is crushed, biotic habitats can be impacted through loss of physical structure and the deposition of dust particulates on their surfaces. Visual impacts associated with cinder disturbance include changes in air quality due to the generation of dust-sized particles that are prone to entrainment by wind, and etched pathways visible from both short and long distances. Areas with vehicular access may be susceptible to increased cinder disturbance. Secondary adverse impacts include potential to increase erosion rates (see Section 4.2.3.4) and impacts to the viewplane.

The principal causes of habitat alteration on Mauna Kea have been the construction and demolition of buildings and infrastructure such as roads, parking lots; installation and maintenance of utilities; conversion of native plant communities to agricultural fields or grasslands for livestock grazing at lower elevations; and the spread of invasive species. Invasive species are currently a major source of habitat degradation in the subalpine ecosystems, and place significant stress on Mauna Kea's native flora and fauna. Invasive species are discussed in their own section below (Section 4.2.3.7). For UH Management Areas, the main sources of habitat alteration and cinder disturbance (other than invasive species) include construction and maintenance of infrastructure, road grading, recreational use (e.g., off-road vehicles, hiking, snow play, hunting), and to a much lesser extent cultural practitioners and scientific inquiry.[3]

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[2] The management actions are prioritized similarly to the threat levels as High, Medium, Low, and Evaluate. A high rank indicates that this action would afford the highest level of resource protection, and/or is perceived as being an important management action given the current understanding of natural resources on UH Management Areas. Evaluate indicates that there needs be further investigation into the benefits and costs of the proposed action, either because the action is complex or expensive, or because not enough information is known about the status of the resource or potential impacts of the management action.

[3] Scientific inquiry here implies mainly field-based studies (geology, biology). Development of new telescope facilities is considered under construction and development.

The impacts and sources of habitat alteration and disturbance are discussed further in the following sections of the NRMP:

- Impacts
  - Physical Resources: 2.1.2.5, 2.1.3.6
  - Plants: 2.2.1.3.1, 2.2.1.3.5
  - Invertebrates: 2.2.2.3.1
  - Birds: 2.2.3.3.1
- Sources/pathways of disturbance: 3.2.1, 3.2.8

Goal TPC-2: Minimize habitat alteration and disturbance

The goal of minimizing natural habitat loss due to human use and activities on UH Management Areas can be accomplished by the objectives of 1) preventing unnecessary habitat alteration and disturbance, 2) detecting new habitat disturbance, and 3) repairing damaged habitats.

Objective 1: Prevent unnecessary habitat alteration and disturbance

Human uses and activities that cause physical habitat alteration or that are likely to transport invasive species should be managed to minimize impacts. This can be accomplished by restricting access to sensitive habitats, and by planning future projects to reduce their footprint.

A first step in minimizing habitat disturbance is to identify sensitive areas on UH Management Areas. Sensitive areas may include cultural resources, unique geological features, and habitat for important, rare, threatened or endangered native species, including the wēkiu bug, Mauna Kea silversword, and māmane. Information obtained through baseline inventory and monitoring can be used to identify and map sensitive areas. Data should be entered into a GIS database for analysis and to create maps identifying highly sensitive areas and designating them either off-limits or for limited use, to limit infrastructure development and reduce visitation to these areas. Detailed information on locations of endangered species or protected cultural resources will be available only for OMKM staff or rangers, to be shared with regulatory agencies as appropriate. For more information, see Sections 4.1, Inventory, Monitoring, and Research and 4.5, Information Management.

Minimizing alteration of ground features will also protect the natural beauty of Mauna Kea. Other than construction, the primary impacts to the mountain's viewplane in both undeveloped and frequented areas are existing trails, new trails or shortcuts created by hikers, and tracks made by off-road vehicles. Educating visitors about the sacredness of the mountain and how to act with respect is the best method of preventing additional and unwanted impacts. Approaches to educating visitors may include adding informational signage at trailheads, at picnic areas and at frequently used off-road areas such as turnouts and through increased use of such media as brochures, video, and sign-in sheets at the VIS (see Section 4.4, Education and Outreach).

With a continued human presence at the UH Management Areas, a minimal level of habitat alteration and cinder disturbance is unavoidable. Therefore, threat prevention and control measures should be focused mainly on areas identified as "high-impact" (e.g., building sites, trails, picnic areas, road) and areas that have sensitive habitat (e.g., summits of pu'u). Table 4.2-2 lists sources of habitat disturbance on Mauna Kea, management actions to reduce impacts from these sources, the priority of the action, and relative cost of conducting the action.

Table 4.2-2. Management Actions to Minimize Habitat Disturbance

Management Action	Priority	Cost
Construction & development		
Limit number of new telescope projects or other infrastructure at the summit using guidelines of the 2000 Master Plan.	High	Low
Using guidelines of the 2000 Master Plan, reuse previously developed sites in preference to developing new sites, and to the extent possible, restrict new activities to previously disturbed areas.	High	Low[4]
Site new projects to minimize disturbance of sensitive and key habitats. This will require an understanding of the location of sensitive habitats that can only be gained through detailed baseline inventories of potential construction sites.	High	Low[5]
Require all new projects to conduct baseline surveys of quality similar to those conducted during the site wide baseline inventory by OMKM (see Section 4.1). It is recommended that the survey area cover the entire area of the footprint of the building, staging areas, and other structures (parking lot, road) plus a buffer of 1640 ft (500 m), and include rare and protected species (e.g., wēkiu bug, silversword), unique communities (e.g., lichen/moss communities at the summit), vegetation communities, and unique physical resources.	High	Low[6]
Use geo-spatial analysis capabilities of GIS to map and catalogue estimated potential habitat loss and areas of habitat disturbance from new construction. This action should be conducted during project design and presented in the project's environmental documentation.	High	None[7]
Prohibit development of any undeveloped nunatak (previously unglaciated summit of pu'u) to prevent loss of wēkiu bug habitat. (See Section 2.2.2.2.1 for more information).	High	None
Protect habitat of the indigenous lichen *Pseudephebe pubescens*. Potential telescope sites located on or near "Intensively Studied Areas 2, 3, and 4" (see Figure 2.2-9) should be inventoried to determine whether construction will impact any populations of this species (Smith et al. 1982).	High	Low
Minimize habitat disturbance by placing structures and roadways on the ash or colluvial fields and avoiding the placement of structures where they will block the normal wind flow or sunlight to the lichen colonies or ferns (Char 1999).	High	Low
Require contractors to use best management practices to reduce overall impact of new construction projects.	High	None[8]
Minimize displacement of cinder during construction to the extent possible. Require that cinder be stockpiled in a predetermined location rather than be simply pushed out of the way, down slope. This stockpiled cinder can be used for future restoration projects. Use barriers to contain cinder (Pacific Analytics 2000). Barriers must be sturdy and able to withstand 100-mile per hour winds.	High	None
Prohibit any side-casting of cinder or other materials into wēkiu bug habitat (Pacific Analytics 2000).	High	None

[4] OMKM may have some costs associated with coordinating transfer of a facility from one entity to another.

[5] Most of the cost will be incurred by the developer, although OMKM may have some costs related to review of environmental analysis documents and project plans.

[6] Cost to be borne by petitioner.

[7] Cost to be borne by petitioner.

[8] Cost to be borne by petitioner.

Management Action	Priority	Cost
Road grading		
Pave Summit Access Road. This will eliminate disturbance to roadside vegetation due to movement of cinder during road grading. This will also help reduce dust generation (Section 4.2.3.2).	Evaluate[9]	High[10]
Off-road vehicles		
Continue to prohibit off-road vehicle use and strengthen measures to deter off-road vehicle use (e.g., block or eliminate evidence of any off-road vehicle trails) in the UH Management Areas. This will also help eliminate dust generation (Section 4.2.3.2), erosion (Section 4.2.3.4), and the spread of invasive weed species (Section 4.2.3.7).	High (if found)	Variable[11]
Restrict off-road vehicle use at Hale Pōhaku to established 4WD roads, by blocking or eliminating evidence of unofficial off-road vehicle trails. Place signs to designate entrances to authorized roads.	High (if found)	Variable
Vehicle Accidents		
Conduct road safety inspection by transportation engineer and implement recommendations (e.g., guard rails).	Medium[12]	High
Include information on safe driving on the Summit Access Road in the visitor orientation video.	High	Low
Require all OMKM and telescope staff to attend a basic instructional program on safe vehicle use.	Medium	Low
Hiking		
Define trail network. Trails should provide access to scenic vistas and areas of unique resources and be located to minimize disturbance to sensitive resources. Delineate trail network in OMKM GIS (see Section 4.5). Maintaining a trail network will also help reduce erosion (Section 4.2.3.4) and the spread of invasive weed species (Section 4.2.3.7).[13]	Medium	Medium
Clearly mark trailhead locations with signs containing: - Trail name - Trail length (in miles and kilometers) - Level of difficulty - Any significant elevation change - Potential hazards - What to bring (e.g., water) - Hiking protocol (stay on designated path; wear covered shoes; no littering; do not remove anything).	High	Medium
Provide educational materials including a map of the trail network and information discussing the negative impacts of off-trail hiking. Require visitors to attend an orientation to the mountain that includes discussion of the unique physical and biological features and cultural issues.	High	Low
Delineate trails with local materials such as large rocks or cinder, to keep hikers on the trail.	High	Low
Remove unwanted trails (i.e., those not conforming to standards or that access sensitive resources) by blocking access, posting signs, and restoring alignment to pre-disturbed condition.	High	Variable

[9] The term "Evaluate" indicates that an in-depth cost-benefit evaluation of this option is needed. OMKM should consult with stakeholders to evaluate feasibility of paving the unpaved portion of the road.

[10] It may be possible to get new construction projects and established observatories to contribute to road paving fund. Paving the road will substantially reduce wear and tear on vehicles accessing the summit and eliminate the need for road grading, which currently occurs three times per week.

[11] Cost will depend on the number of off-road vehicle trails discovered.

[12] This priority may be upgraded to "High" if human safety issues are taken into account.

[13] The State Historic Preservation Division (SHPD) would need to be consulted for activities or improvements that may impact known historic or pre-contact trails.

Maintain trails using trail design-and-build standards to minimize cinder disturbance and erosion and improve safety.[14]	High	Medium
Continue ranger patrols to help reduce off-trail hiking.	High	Medium
Snow Play		
Define snow play areas on GIS maps and for distribution to visitors. Install signage that identifies snow play areas, warns of potential injuries, and that recreationists assume all responsibility.[15]	Medium	Low
Develop a shuttle system to be used during snow play, to reduce the number of vehicles traveling to the summit.	Evaluate[16]	High
Scientific Studies		
Require that all research proposals be reviewed and approved to assess potential impacts to resources. Review to be conducted by NRC and/or OMKM Environment Committee.	High	Low
Require projects that disturb natural habitat to be conducted in non-sensitive areas whenever possible (excluding mitigation projects).	High	None
Require research projects to return sites to original (or improved) condition at end of project, if habitat is disturbed. Projects with planned habitat disturbance should be required to prepare and submit a post-research restoration plans for sites and access routes, prior to conducting research.	High	None
Request that researchers who must return on multiple occasions to areas without established trails use a different route each time and, when possible, walk on boulders and rocks to reduce cinder crushing.	High	None
Cultural Practitioners		
Most cultural practitioners leave few permanent traces of their activities. Reduce impact of cultural activities by requesting that practitioners planning to build shrines or conduct other potential habitat disturbing activities provide OMKM with information on location of activity. Cultural and environmental concerns would need to be evaluated.	Low	Low

Objective 2: Detect new habitat disturbance

Detection of habitat alteration and disturbance can be accomplished primarily through baseline inventory and monitoring, as described in Section 4.1, and in particular Section 4.1.4.2. Habitat alteration caused by the spread of invasive species is addressed below, in Section 4.2.3.7. Annual monitoring activities can be supplemented by opportunistic observations of disturbance by the NRC, field crews, Visitor Information Station (VIS) staff, OMKM Rangers, and the general public. Observations of damage should be recorded (by OMKM staff) on standardized data sheets (location, Global Positioning System (GPS) coordinates, type of damage, extent of damage) and should be regularly entered into the GIS database. Recording the locations of habitat disturbance and alteration will help identify which areas need habitat restoration or repair. Areas of frequent disturbance or persistent or worsening damage should be given high priority for management actions.

[14] Trail maintenance will depend on type of impact. *Trail shortcut*: Re-align trail at the problem section, cover up evidence of the unwanted trail, and place a barrier (e.g., rocks, cinder) to discourage access to unwanted trail. *Trails with steep slope and potential safety hazard*: Install steps and appropriately colored handrails to offer visitors a steady footholds and handholds while minimizing further degradation of the trail and adjacent natural resources. *Trails with excessive erosion or severe degradation*: Protect using bio-degradable erosion matting or protective trail puncheons.

[15] Permit snow play only in areas where activity will not adversely impact sensitive resources. On cinder cones, snow play will cease when snow pack at a representative location is eight inches (203 mm) or less.

[16] The term "Evaluate" indicates that an in-depth cost-benefit evaluation of this option is needed

Objective 3: Repair degraded habitats

The primary reasons to repair degraded habitat are to improve its quality for use by native flora and fauna and to mitigate viewplane impacts. This section provides management activities that can be used to mitigate viewplane impacts, including repairing damaged trails or "erasing" evidence of shortcuts. Restoration of ecosystems to protect native flora and fauna is discussed in Section 4.3.

Removing evidence of disturbance and incorporating physical barriers to prohibit access are two methods that will help discourage future disturbance. It should be recognized however, that attempts at mitigation themselves may contribute to disturbance, and repair efforts should be carefully planned so that they do not contribute to the problem. Repair efforts should be concentrated at locations that are considered severely impacted, are easily accessed, and can be seen by visitors. Repairing sites of disturbed cinder can be done by raking cinder from the immediate vicinity to cover bare areas and achieve a 'natural' look. Need and cost will determine what type of barrier will adequately deter people from entering an area under repair. Monitoring the area for both restabilization of the natural environment and maintenance of any erected barrier will ensure that the intended repairs will be successful.

4.2.3.2 Air Pollution

Threat Level: Hale Pōhaku: Low; MKSR: Low

The airshed above and around Mauna Kea is known for its clarity, due in part to the lack of aerosols and other particles. Degradation of air quality at the UH Management Areas is thought to come mainly from human activities and includes vehicle exhaust and fugitive dust from activities conducted on unpaved surfaces, such as vehicle travel, road grading, and construction. Potential threats to the natural environment from these emissions and fugitive dust include

- Decreased surface albedo and associated increased rate of snow melt at higher elevations (dust)
- Disruptions to photosynthesis by vascular plants due to dust fall out (dust)
- Reduced health within the lichen and moss communities (emissions)
- Potential impacts on wēkiu bug habitat (dust)
- Reduced clarity of view for both the human eye and for astronomical technologies (emissions and dust)
- Safety concerns (dust)

The sources and impacts of air pollution are discussed further in the following sections of this NRMP:

- Impacts
  - Physical Resources: 2.1.5
  - Plants: 2.2.1.3.5
  - Invertebrates: 2.2.2.3.1
- Sources/pathways of disturbance: 3.2.2

Goal TPC-3: Maintain high level of air quality

The goal of maintaining a high level of air quality on UH Management Areas can be met by: 1) detecting changes to local air quality; and 2) minimizing local generation of air pollution.

Objective 1: Detect changes to local air quality

While some of the likely sources of air pollutants generated off the UH Management Areas have been identified (see Section 3.2.2), how much they are contributing is unknown. In order to meet the goal of maintaining a high level of air quality, it is necessary that current baseline conditions be described (see Section 4.1.4.5). Ideally, this analysis should identify all air pollutants, correlate current types with sources, and quantify relative contribution. Identification of changes in the air quality will be accomplished through the Inventory, Monitoring, and Research Program (Section 4.1). The chronic threat to air quality can be reduced by implementing management actions to control the pollutant generators that are having the greatest impact.

Objective 2: Minimize local generation of air pollution

The main methods of minimizing local contributions of fugitive dust and vehicle emissions will be controlling the amount of dust generated from unpaved roads by reducing the need for grading and limiting vehicle travel. Visitation rates to the summit have been increasing over time, and are expected to continue to increase over time, especially once the Saddle Road improvements are completed. Thus, the contribution to air pollution by vehicles travelling to the summit is expected to continue to rise.

Paving the remainder of the Summit Access Road (~ four miles) would permanently eliminate most of the fugitive dust generated by grading and vehicle traffic. It would also reduce the wear and tear on vehicles that travel the road.[17] Dust control sprays (tacifiers) are another, short-term way to reduce dust on unpaved roads, but it is likely that any commercially available product would have to be applied frequently, which over time would be expensive. Another option to reduce dust generation is to reduce vehicle trips by encouraging observatory personnel to carpool and by having visitors travel to the summit area in an authorized and permitted shuttle. All contractors should be required to implement best management practices during construction, whether or not the work requires a permit. Table 4.2-3 lists the sources of air pollution on UH Management Areas, management activities that can help reduce these impacts, the priority of the management action, and its relative cost.

Table 4.2-3. Management Actions to Minimize Air Pollution

Management Action	Priority MKSR	Priority HP	Cost
Observatory & support operations			
Encourage reduction of vehicle trips through carpooling and consolidation of support services trips (e.g., water deliveries, waste removal).[18]	High	High	Low

[17] There is some concern that paving the road may lead to increased accidents due to increased vehicle speed and an increase in the number of vehicles on the road. Installing speed bumps or other speed control measures may help control vehicle speed on this portion of the road. However, the potential increase in vehicle traffic needs to be taken into consideration when deciding whether to pave the road.

[18] Recommended no matter which dust abatement recommendation is followed. Carpooling will also reduce fuel consumption and wear and tear on vehicles.

Management Action	Priority MKSR	Priority HP	Cost
Construction & development			
Require contractors to use best management practices for dust control.	High	High	Included in construction cost
Road grading & vehicle travel			
Pave road. This will help reduce dust generation and distribution (see Section 4.2.3.1).	Evaluate[19]	N/A	High
Apply dust control spray to unpaved portion of the Summit Access Road and unpaved parking lots.	High	Medium	High (over time)
Discontinue vehicle traffic to summit and replace with shuttle system, as described in 2000 Master Plan (University of Hawaii 2000).[20]	Evaluate[21]	N/A	High

4.2.3.3 Escape and Migration of Potential Contaminants

Threat Level: Hale Pōhaku: Low; MKSR: Medium

Observatory facilities and support operations housing any potentially hazardous materials are required by law to have spill response and associated safe handling protocols in place. Situations in which a potential release might occur include discharge of liquid waste from septic tanks and cesspools, malfunction of sewage pipes, transport of sewage and hazardous materials, activities requiring the handling of potential contaminants, and vehicle use. Threats to the natural environment due to escape and possible subsequent migration of contaminants vary depending upon the type of contaminant, release volume, and location. The fate and transport of byproducts and potentially hazardous materials used on Mauna Kea have not been determined, and an assessment of the potential risks following a release has not been developed. Recognizing that most of these activities are not OMKM's responsibility, natural resource management staff nonetheless must be aware of materials being stored, used, and transported, to assist them in responding to potential contaminant releases and minimizing impacts to natural and cultural resources.

The sources and impacts of substrate and groundwater contamination are discussed further in the following sections of the NRMP:

- Impacts
  - Physical Resources: 2.1.3
  - Hazardous Materials: 3.1.1.2.7
- Sources/pathways of disturbance: 3.2.3

[19] The impact of dust from vehicle travel and road grading activities on natural resources is unknown at this time, and is worth investigating.

[20] Conant et al. (2004) recommend that the shuttle system first be tested by requiring that all astronomy-related traffic use the shuttle service. If that proves successful, the next step would be to use the service to bring visitors (tourists) to the summit. A small fee could be charged for shuttle service. Traditional cultural practitioners could be exempt from the fee and could choose not to use the shuttle service (Conant et al. 2004).

[21] The term "Evaluate" indicates that an in-depth cost-benefit evaluation of this option is needed.

Goal TPC-4: Prevent migration of contaminants to the environment

Objectives in meeting the goal of preventing migration of contaminants to the environment include: 1) creating and maintaining an information database on contaminants; 2) maintaining a risk assessment and spill response plan; and 3) supporting on-going efforts to minimize use and transport of potential contaminants. Implementation of the recommended management actions will reduce risks associated with contaminant release and migration.

Objective 1: Create and maintain an information database on contaminants

A database listing types, quantities, uses, and transport of potential contaminants in the UH Management Areas will provide a centralized repository for managers. Although the primary contributors to this database will be the observatory facilities and the Mauna Kea Observatories Support Services (MKSS), having this database accessible to the natural resources staff will improve overall coordination and incident response. The database should be updated regularly, as new materials are introduced, as materials are removed from use, and when volumes of materials change significantly. The database will permit risk assessments to be completed for each potential scenario (see Objective 2 below) and facilitate management to adequately and efficiently address situations of contaminant release and potential migration. A great deal of information on contaminant use and storage at the summit has already been compiled in various project specific EISs, making the job of gathering this information easier. The database could be stored at MKSS but should be easily accessible by OMKM and the observatories (via internet or other computer based access).

Incorporate the following information on potential contaminants into a geo-spatial database:

- Type of potential contaminants used and stored on OMKM property
- Location, quantity, and type of use
- Location and quantity of stored unused material
- Location and quantity of stored waste product
- Spill history (substance, amount, location, response)
- Contact information for the party with information regarding storage, handling, and disposal of potential contaminants at each facility
- Date of most current handling protocol for each facility
- Date of data collection
- Person/entity collecting data

Objective 2: Maintain risk assessment and spill response plans

Risk assessment and spill response planning provides a measure of safety for human health and for the protection of the cultural and natural resources of Mauna Kea. Although the observatories have individual spill response plans, such plans are lacking for other transporters or users, such as those that might result from vehicle accidents. Such spill-response plans are needed to ensure safe and timely responses to non-observatory spills. The first step in preparing response plans is to develop risk assessments for the range of potential spill scenarios. The assessments should document the types of potential releases, where they might occur, and their potential impacts. Assessments should also be updated regularly, to include changes to current activities or new activities involving potential environmental contaminants. Risk assessments and spill response plans can be developed by MKSS, OMKM, or as a collaborative effort between the two entities.

Risk assessments should consider and incorporate the following:

- Identification and evaluation of activities that could cause the release of hazardous substances into the environment
- How the level of activity would increase the risk of potential hazardous waste releases
- Type and quantity of substances used or transported as part of the activity
- Locations of potential releases
- Potential impacts of releases on the natural and cultural environments

Spill plans should consider and incorporate the following:

- Emergency contacts both on-site and at off-site locations
- Locations where releases are most likely to occur and access and escape routes for personnel, equipment, and transported wastes
- Level of response that might be required, based on the type and quantity of materials
- Response protocols, based on Phase I Hazardous Spill Response
- Standard reporting mechanism for spills (e.g., appropriate agencies, OMKM, geo-spatial database)
- Having staff (MKSS, OMKM Rangers) trained in Phase I Hazardous Spill Response, with at least one trained person on the mountain at all times.[22] Training should address:
  - Providing for visitor safety and crowd control
  - Ensuring the integrity of the immediately surrounding natural and cultural resources, to the extent possible
  - Supporting the clean-up of minor spills along the summit road
  - Alerting certified spill response crews and requesting assistance with large spills or any release of potential contaminants associated with astronomy facilities and their operations or release of sewage

Risk assessments and spill response plans should be developed for the following materials and locations:

Material or Substance	Hale Pōhaku	MKSR	Summit Road
Any material considered a potential contaminant	X	X	X
Sewage	X	X	–
Portable toilets, chemical and sewage solids	–	X	X

[22] As the support system for the observatories, MKSS has on-site staff, while OMKM Rangers are usually the 'first responders' to accidents or vehicle-related spills along the Summit Access Road.

Objective 3: Minimize use and transport of potential contaminants

Observatory facilities and MKSS should be encouraged to reduce the need for potential contaminants. Newer technologies may continue to make this more feasible. Currently hazardous waste removal activities are often coordinated between multiple observatories (Koehler 2008). Coordinating trips saves money and reduces both the risk associated with transport of materials and the contributions of emissions and dust to the environment. Efforts to reduce and combine the number of vehicle trips transporting potential contaminants should be continued.

Table 4.2-4. Management Actions to Minimize Potential Contaminants

Management Action	Priority MKSR	Priority HP	Cost
Vehicle travel			
Ensure that roads are well maintained and properly signed.	High	High	Medium
Maintain spill response materials in Ranger staff vehicles.[23]	High	High	Low
Observatory & support operations			
Recommend minimal on-site storage of potential contaminants.	High	High	Low
Create geo-spatial database of all potential contaminants used and stored at Mauna Kea.[24]	High	High	Low
Maintain communication between OMKM, MKSS, IfA, and associated astronomical facilities regarding use, storage, transport and spill response.	High	High	Low
Transport of hazardous materials			
Coordinate deliveries and waste removal between multiple facilities.	Medium	Low	Low
Sewage generation			
Ensure that sewage treatment systems adhere to manufacturer's maintenance and clean-out schedules (see Section 3.1.1.2.6).	High	High	Low
Require all proposed structures that have restroom facilities or wastewater disposal to use closed contained systems to prevent discharge of effluent.[25]	High	High	High

4.2.3.4 Stormwater Runoff and Erosion

Threat Level: Hale Pōhaku: Medium; MKSR: Low

Erosion is a process whereby soil particles are detached and transported. Meteorological processes and human activity influence both erosion rates and the degree of their impact. Acceleration of erosion from human activities is usually the result of the discharge of storm water runoff onto exposed surfaces, and due to alteration of the ground surface. During preparation of this report, our observations are that accelerated erosion is occurring in areas adjacent to facilities and roadways. Implementing erosion control best management practices at the identified accelerated erosion locations will reduce the impact to resources.

[23] Details would be developed in the spill response plan.

[24] MKSS could maintain the database. Database should be shared with OMKM and observatories.

[25] Can be accomplished using evaporative decomposing units. Similar recommendation can be made for the retrofit of existing facilities.

Locations associated with an elevated risk of accelerated erosion include

- Frequently used trails (both at the trail head and along trail itself; see Section 4.2.3.1)
- Roadside parking at Hale Pōhaku
- Public access areas at Hale Pōhaku
- Within and immediately surrounding unhardened, open-ditch drainages along the Summit Access Road
- At the mouths of culverts along the Summit Access Road and at Hale Pōhaku
- Within drainages, immediately below culverts
- At unhardened turn-arounds and parking locations along the Summit Access Road
- Building-generated runoff

The sources and impacts of erosion are discussed further in the following sections of the NRMP:

- Impacts
  - Physical Resources: 2.1.2
- Sources/pathways of disturbance: 3.2.4

Goal TPC-5: Minimize accelerated erosion

The objectives for minimizing accelerated erosion on UH Management Areas include: 1) identifying locations associated with accelerated rates of erosion, and 2) generating solution designs to reduce accelerated erosion.

Objective 1: Identify locations of accelerated erosion

Frequent monitoring of high-impact areas is crucial to documenting early signs of degradation that may negatively affect visitor safety or increase the threat to resources. More generally, detecting areas of accelerated erosion will be accomplished through the Inventory, Monitoring, and Research Program (Section 4.1.4.2). Once the location and cause of accelerated erosion have been identified, areas can be prioritized for treatment.

Objective 2: Generate solution designs to reduce accelerated erosion

Because most of the mechanisms associated with accelerated erosion risk at the UH Management Areas are related to infrastructure or human presence and activity, reducing erosion rates will require mitigating the source or treating the eroded site. As part of the erosion assessment conducted in the baseline inventory (see Section 4.1.4.2), recommendations will be developed to prioritize areas for treatment and address the problems. Management actions to mitigate impacts will vary by location and type of erosion-related impact. A majority of the actions are designed to address stormwater drainage, which is known to be the primary eroding agent. Table 4.2-5 lists the sources of accelerated erosion on UH Management Areas, management activities that can help reduce these impacts, the priority of the management action, and its relative cost.

Table 4.2-5. Management Actions to Minimize Accelerated Erosion

Management Action	Priority MKSR	Priority HP	Cost
Infrastructure / Construction & Development[26]			
Regularly maintain unlined open ditch drainages, culvert drainages and sediment basins.	Medium	Medium	Low
Control bank-sloughing and erosion using permanent liners along ditches.	Low	High	Low
Line open ditch drainages with bio-degradable erosion control blanketing and bio-degradable stakes.	N/A	Medium	Medium
Install energy dissipating device at culvert outlet.	Low	High	Medium
Control runoff from hardened areas using energy dissipating devices, infiltration swales and vegetation lining.	Low	Low	Low
Road grading / Vehicle travel			
Pave road [27] and install road drainage best management practices.	High	Medium	High
Secondary roads			
Install best management practices for stormwater runoff.	Medium	Medium	Low

4.2.3.5 Solid Waste

Threat Level: Hale Pōhaku: Medium; MKSR: Medium

Solid waste becomes a threat to the natural environment when improperly disposed of or when left unsecured, especially in the high winds in the summit region. Sources of solid waste include observatories and support facilities (trash), construction (materials), recreational users, and commercial tour groups (litter, snow-play debris), and cultural practitioners (offerings). Impacts from the presence of solid waste at the UH Management Areas include alteration of the viewscape, direct and indirect damage to surfaces, and attraction of invasive species.

The sources and impacts of solid waste are discussed further in the following sections of the NRMP:

- Impacts
  - Physical Resources: 2.1.6
- Sources/pathways of disturbance: 3.2.5

Goal TPC-6: Reduce impacts of solid waste

A primary objective in reducing the negative impacts associated with the presence of solid waste at UH Management Areas is to minimize the potential for solid waste to become fugitive waste.

[26] These are potential management actions that are recommended for implementation. Which ones are used will be determined by the results of the erosion assessment conducted as part of the Inventory, Research and Monitoring Program (Section 4.1.4.2).

[27] This applies to the unpaved portion of the Summit Access Road that lies between Hale Pōhaku and the MKSR.

Objective 1: Minimize fugitive solid waste

The main methods of managing fugitive solid waste will be to reduce source material by educating users of the mountain about the importance of protecting all trash from the wind by disposing of it in proper receptacles or securing it until it can be put in proper containers. Table 4.2-6 lists the sources of fugitive solid waste on UH Management Areas, management activities that can help reduce these impacts, the priority of the management action, and the relative cost.

Table 4.2-6. Management Actions to Minimize Fugitive Solid Waste

Management Action	Priority MKSR	Priority HP	Cost
Observatory & support operations			
Require that all trash cans and dumpsters at UH Management Areas have effective lid closure mechanisms designed to withstand high winds.	High	High	Low
Construction & development			
Require contractors to use best management practices for debris storage and disposal.	High	High	Included w/in SOW
Recreational users & commercial tour groups			
Include information in brochures, orientation video, and signage regarding potential impacts of trash and proper disposal methods. Encourage a pack it in, pack it out ethic.	High	High	Low
Put more trash cans at high-use locations (e.g., VIS, summit parking lots and locations frequented by snow play recreationalists) to reduce the chance of overflow.	High	High	Low
Continue practice of OMKM Rangers removing fugitive solid waste as observed.	High	High	Low
Inspect beds of pick-up trucks and provide trash bags for disposal of loose waste before vehicles ascend to the summit.[28]	High	High	Low
Conduct annual trash inspection and removal in snow play areas at the end of the season.	High	N/A	Medium
Cultural practices			
Include information in brochures, orientation video, and signage regarding potential impacts of cultural offerings.[29]	Low	Low	Low

[28] If some form of managed access is implemented, it may be easier for OMKM personnel to ensure this happens.

[29] Cultural offerings are typically left outside and may be blown away by wind. Besides their potential to become fugitive solid waste, these offerings may also introduce invasive species (see Section 4.2.3.7). Information regarding these threats should be conveyed to visitors so they can make an educated decision when considering leaving an offering.

4.2.3.6 Noise

Threat Level: Hale Pōhaku: Low; MKSR: Low

Ambient noise levels at Mauna Kea are low. The primary receivers that might be disrupted by excessive noise are people on the mountain, (e.g., scientists, cultural practitioners, recreational users). Noise generated by certain activities or systems could also impact biological resources, such as birds. The main activities that produce noise include vehicle travel, observatory operations and construction, mainly by the use of heavy equipment. Noise generated by vehicle travel and observatory operations is on-going, sporadic, and has minimal impact. Construction activities generally generate noise at more acute levels over a short period, and efforts should be made to reduce disruption by, for example, building during specific times and placing large generators within containers. Off-site noise generators include aircraft and live fire at Pōhakuloa Training Area (PTA).

The sources and impacts of noise are discussed further in the following sections of the NRMP:

- Impacts
  - Physical Resources: 2.1.5
- Sources/pathways of disturbance: 3.2.6

Goal TPC-7: Maintain current background noise levels

Maintaining current low ambient noise levels at UH Management Areas can be accomplished by 1) detecting changes to the ambient noise environment and 2) preventing, to the extent possible, increases in noise levels.

Objective 1: Detect changes to ambient noise levels

Detecting changes to the ambient background noise levels at the UH Management Areas will be accomplished through the Inventory, Monitoring, and Research Program (Section 4.1). Analysis of data should take into account short-duration activities at the mountain and off-site, punctuated sounds that may or may not be long-term or chronic.

Objective 2: Prevent increases to ambient noise levels

Any increase in background noise levels at the UH Management Areas will most likely result from changes in human activity: noise generation by aircraft, Army training operations, vehicles, observatory operations, and construction. The main methods of minimizing excessive increases in noise generation will be requiring the consideration of noise impacts during operating activities and educating visitors and the astronomical community about the importance of quiet and reducing the use of or properly muffling loud noise generators in the summit region. Table 4.2-7 lists the sources of noise on UH Management Areas, management activities that can help reduce these impacts, the priority of the management action, and its relative cost.

Table 4.2-7. Management Actions to Minimize Noise

Management Action	Priority MKSR	Priority HP	Cost
Vehicle travel			
Establish and enforce a maximum decibel level for non-construction vehicles.	Medium	Low	Low
Observatory & support operations			
Require evaluation and noise testing for any newly installed, free-standing devices or devices that may be installed on building exteriors.	Medium	Low	Low
Require that permanently installed loud noise contributors such as power generators and compressors be housed in sound-mitigating containers.	High	Medium	Low
Construction & Development			
Require construction projects to use construction equipment and vehicles with proper noise muffling devices.	High	Medium	Low
Recreational users			
Increase information in brochures, orientation video, and signage regarding the importance of low noise levels.	High	High	Low
Off-site noise generators			
Initiate communication with off-site entities that produce potentially disruptive levels of noise, if necessary.	Low	Low	Low

4.2.3.7 Invasive Species

Threat Level: Hale Pōhaku: High; MKSR: Medium

Invasive species damage natural ecosystems and native plant and animal communities, cause economic harm, and can impact human health and well-being (National Invasive Species Council 2008). The most common impacts of invasive plants and animals include habitat alteration; increased erosion and substrate compaction; alteration of hydrology and nutrient cycling; increased frequency and severity of fires; changes in visual attributes; competition with native species for space and resources; introduction and spread of disease; and increased predation and parasitism of native species. Although the harsh conditions in the subalpine and alpine ecosystems of Mauna Kea do prevent establishment of many invasive species, others have taken hold and cause considerable damage. Invasive plants and mammals cause the most damage at Hale Pōhaku. Invasive plants and mammals have also impacted the lower regions of the MKSR. For the summit region, the biggest threat from invasive species is introduction of predacious non-native invertebrates that could impact the unique native aeolian invertebrate community.

Invasive species can arrive at Mauna Kea through a variety of pathways, including natural dispersal (e.g., wind, water, migration), intentional introductions (for biocontrol, hunting, or horticulture), and accidental releases (escaped pets, livestock, and research organisms; pests and weed seeds associated with agricultural and nursery products). Invasive species can be transported onto UH Management Areas by vehicles; by tourists, hikers, hunters and cultural practitioners on equipment, shoes and clothing; construction equipment and materials such as fill; road grading equipment and gravel; scientific equipment and supplies shipped to Hale Pōhaku and the observatories; and visiting scientists and their belongings. Many of the invasive species currently found the UH Management Areas were introduced deliberately for hunting (mouflon), biocontrol (mongoose and several arthropod species), and horticulture or agriculture (the many grass species used for ranching and fountain grass and other showy species used for landscaping). Many of the invasive plants arrived as weed seeds in agricultural feed or as grass seed. Other species, such as the ground hunting spider *Meriola arcifera* probably arrived accidentally on equipment or supplies.

The impacts of invasive species and their pathways for invasion are discussed further in the following sections of the NRMP:

- Impacts
  - Plants: 2.2.1.3
  - Invertebrates: 2.2.2.1.2, 2.2.2.2.2, 2.2.2.3
  - Birds: 2.2.3.1.3, 2.2.3.2.2, 2.2.3.3.2
  - Mammals: 2.2.4.1.2, 2.2.4.2.2, 2.2.4.2
- Pathways: 3.2.8

Goal TPC-8: Prevent establishment of new invasive species and control established invasive species

The goal of the Invasive Species Management Program is to prevent establishment of new harmful invasive species on UH Management Areas, through prevention, detection, and rapid response, and to control currently established invasive species that harm ecosystem function and native species. Four objectives support this goal: 1) prevent the introduction of new invasive species onto UH Management Areas, 2) develop an invasive species monitoring program, 3) develop a rapid response program to eradicate incipient[30] invasive species, and 4) control established invasive species in sensitive areas.

Objective 1: Prevent the introduction of new invasive species onto UH Management Areas

Benjamin Franklin's saying, "An ounce of prevention is worth a pound of cure" is especially applicable to invasive species. It is often extremely difficult, and sometimes impossible, to eradicate[31] an invasive species once it has become established. Efforts to control invasive species are often significantly more costly than prevention activities, and some damage caused by invasions cannot be undone. Prevention often depends on the cooperation (and education) of diverse groups of people, and thus, it is not possible to prevent arrival of all invasive species. Even so, efforts should be made to reduce the influx of invasive species onto UH Management Areas. Prevention of new invasions can be achieved by 1) interception through regulations and inspections, 2) treatment of material suspected to be contaminated with non-native species, and 3) prohibition of particular commodities (Wittenberg and Cock 2001). The most common approach for prevention of new invasions is to target individual species. A more comprehensive approach is to identify major pathways (sources or vectors) of invasive species and to manage the risks

[30] Known invasive species found in Hawai'i that are not currently established on UH Management Areas but that are thought to pose a threat to subalpine or alpine communities

[31] Eradication, when used to refer to the removal of invasive species, means to completely remove or destroy the entire population. Generally it refers to removal of the invasive species from an entire landmass, such as the entire Island of Hawai'i. Eradication is extremely rare in the case of invasive species, and generally occurs only on very small islands and in isolated locations, or with very small populations. The term 'control' is used in a more general sense, to mean removal of an invasive species from a limited area or a reduction of population size to a less damaging level. Although eradication is an excellent goal, control is a more likely outcome for most invasive species removal efforts.

associated with these pathways (Wittenberg and Cock 2001). Whenever possible, preventative activities should be conducted with the cooperation of neighboring land managers and appropriate federal and state agencies with authority, such as U.S. Department of Agriculture (USDA), U.S. Animal and Plant Health Inspection Service (APHIS), USDA Forest Service, Institute of Pacific Islands Forestry (IPIF), and Hawai'i Department of Land and Natural Resources (DLNR), Hawai'i Division of Forestry and Wildlife (DOFAW). Most federal agencies that deal with or manage natural resources in Hawai'i are involved to some degree in invasive species control or prevention. Executive Order 13112 charges all federal departments whose actions may affect the status of invasive species to work together within their authorities to prepare, prevent, and protect resources from harm caused by invasive species to the extent practicable and permitted by law (National Invasive Species Council 2008). Finally, education is a key component to prevention of introduction of new invasive species, and it will be an important tool for helping prevent introductions to UH Management Areas. Education and outreach activities regarding invasive species are discussed below and in Section 4.4.

Table 4.2-8 provides a list of preventative management actions, organized by the various pathways of new invasive species, which can help reduce movement and establishment of invasive species on UH Management Areas. Some preventative actions will occur on UH Management Areas, and others will occur off-property (e.g., in the port of entry, a warehouse). OMKM can implement a subset, or all, of these actions, depending on OMKM's operating budget, the outcomes of the baseline inventory (see Section 4.1), the data gathered during monitoring for invasive species (see Objective 2, below), and community responses to suggested actions. These actions can also be implemented on a trial basis with careful monitoring of efficacy, results and costs. When possible, actions conducted on a trial basis should be treated as research projects (see Section 4.1.2.3), with careful project design and data analysis. It may be beneficial to conduct public outreach and education efforts prior to implementing some of the more restrictive actions below, as they are more likely to be well received if the reason for their enactment is made clear. Following each action is a brief summary of its management priority (low, medium, high) and relative cost (low, medium, high). These prioritizations and cost estimates are based on the current understanding of conditions on UH Management Areas, as well as on general principles associated with preventing establishment of new invasive species. As more information becomes available from baseline inventory and monitoring (see Section 4.1, Inventory, Monitoring and Research), these priorities and estimated relative costs are likely to change.

Table 4.2-8. Management Actions to Help Prevent Establishment of New Invasive Species

Management Action	Priority	Cost
Natural Dispersal		
Work with neighboring land managers to control invasive plants and animals that occur near property borders.	High	Variable[32]
If neighboring land managers are unable/unwilling to control invasive species on their property, establish invasive species control buffers (similar in concept to a fire break) near property boundaries (in areas of infestation) and/or around the border of established invasive species populations. Buffers should be 82 to 164 ft (25 to 50 m) wide whenever possible.	High	High
Remove/control populations of invasive species at the developed areas of Hale Pōhaku and along Summit Access Road to prevent spread into the MKSR.	High	Medium

[32] The cost of controlling invasive species on neighboring properties depends on whether OMKM contributes to the cost of the control activity.

Management Action	Priority	Cost
Fence sensitive areas (such as newly discovered Mauna Kea silversword populations in the MKSR) to keep out feral ungulates. Fencing may also be arranged with DLNR to protect threatened and endangered species (Fretz 2008).	High	High[33]
Intentional Introductions		
Report any observation of intentional introductions to USDA APHIS and DLNR.	High	None
Remove any species or individuals that appear to have been intentionally introduced to UH Management Areas. Follow up with monitoring and further control efforts, if needed. Keep a sample of the organism (or the individual) and obtain proper species identification, if needed.	High	Variable
Educate staff, personnel, and visitors about the uniqueness of Mauna Kea's high-elevation ecosystems and the laws regarding introduction of new species to the Hawaiian Islands.	Medium	Medium
Support new legislation or efforts by other land managers to prevent illegal intentional introductions.	Medium	None
Accidental Introductions		
Require that all landscaping materials be certified weed-free.	High	Low
Use locally grown native plant species for any restoration projects involving outplanting.	High	Low[34]
Minimize importation of road grading and landscaping materials such as gravel from outside the UH Management Areas	High	Low
Prohibit visitors, staff, or observatory personnel from bringing any pets (except dogs) or plant material to Hale Pōhaku or the observatories.	High	Low
Support state and federal legislation that increases inspection of goods at ports of entry.	High	None
Accidental releases on neighboring properties (or elsewhere in the islands) are beyond OMKM's control. However, OMKM could invite neighboring landowners to agree to enact the same standards regarding prevention of intentional and accidental releases.	Medium	Medium
Vehicle Traffic		
Provide a voluntary vehicle wash station and signage along Mauna Kea Access Road, at the southern border of Hale Pōhaku. Wash station could be a simple grated area where cars and trucks could be parked and hosed down. Signage would request vehicle drivers with muddy or dirty vehicles (primarily those who go off road frequently) to hose down tires, bumpers, and the undercarriage of their vehicle, as well as any mud.	Evaluate[35]	Medium
Require all vehicles that regularly access the summit (including tour vans) to power wash the undercarriages of their vehicles weekly, at minimum, if they do not already do so. Any vehicles that are used for tours with destinations other than the summit should be washed prior to use at Hale Pōhaku and Mauna Kea.	High	None
Discontinue vehicle traffic to summit and replace with shuttle system, as described in 2000 Master Plan (University of Hawaii 2000).	Evaluate	High
Tourists, hikers, hunters and cultural practitioners		
Provide signage and educational material regarding spread of invasive species on equipment and clothing. Provide easily accessible information at the 'Imiloa Astronomy Center of Hawai'i in Hilo and on OMKM website regarding invasive species and requesting that visitors clean their clothes and shoes prior to arriving at the mountain.	High	Low
Install boot-brush area at the Visitors Information Station.	High	Low
Provide a 'weed seed removal area' where visitors can brush down their clothing and inspect their equipment for unwanted hitchhikers. Preferably this should be an enclosed area with a hard floor.	Medium	Low
Request tour companies to ask their clients to brush down or inspect their clothing, equipment and shoes prior to boarding the tour vehicle.	Medium	None

[33] The cost of fencing may be reduced if DLNR is willing to build the fences necessary to protect endangered species on UH Management Areas.

[34] Cost of using locally grown, weed free, native plant species will likely be somewhat higher than using materials from off island or that are not considered weed free.

[35] The term "Evaluate" indicates that an in-depth cost-benefit evaluation of this option is needed

Management Action	Priority	Cost
Require tour companies to routinely clean the clothing (e.g., jackets, hats) that they have on hand for visitors who do not bring their own, if these items are used in other locations than the UH Management Areas.	Medium	None
Support state and nation-wide effort to educate tourists about invasive species and preventative activities (e.g., the onboard movie during Hawai'i bound flights).	High	None
OMKM staff and visiting scientists		
Require natural resources staff, VIS staff, rangers, scientists and observatory staff to maintain a separate set of clothes and shoes for use only at the UH Management Areas. Provide lockers to allow these items to be stored on site to discourage wearing or using these clothes in other locations.	Low	Low
Require visiting scientists to carefully inspect and clean equipment, luggage, and personal belongings prior to arriving at the UH Management Areas.	High	None
Scientific equipment and supplies		
Require detailed inspection of all shipments of goods from high-elevation locations worldwide, prior to arrival on mountain. Preferably this should be conducted at the port of entry by qualified biologists.	High	Low[36]
Require that shipments of food and material goods are inspected and invasive species are removed prior to delivery to Hale Pōhaku (preferably prior to entering Hawai'i).	High	Low
Any items that are found to be contaminated with invasive species (such as ants found in food containers) must be wrapped in plastic, placed in the freezer, and subsequently removed from the area. Pest control measures should be taken to ensure there were no escapees. It is important not to simply throw the contaminated item in the trash. Sample specimens should be kept to aid identification of the species, if needed.	High	Medium
Maintain pest traps around storage areas for food and material goods.	High	Low
Construction equipment, road grading equipment, and supplies		
Require that all construction and road grading tools and equipment be washed down prior to arrival at the mountain, preferably using a pressure washer.	High	Low
Develop a memorandum of understanding with Pōhakuloa Training Area to allow construction vehicles to use PTA's vehicle wash rack prior to proceeding up the mountain.	High	Low?
Require that all fill and construction materials brought from offsite be inspected for invasive species by a qualified biologist.	High	Low[37]
Whenever possible, use fill from onsite sources and minimize use of off-site materials.	High	Medium
Require construction workers to clean their boots, tools, and clothing prior to arrival at the work site.	High	Low
Require contractors to eradicate ants and other pests at the equipment storage facilities and base yards to avoid transporting these species to UH Management Areas (Pacific Analytics 2000).	High	Low
Require that all proposed projects, in the planning stage (e.g., in Environmental Impact Statements), consider the potential for introduction of invasive species, and prevention measures to be taken.	High	Low[38]

Objective 2: Develop an invasive species monitoring program

Detection of invasive species will occur in part through the monitoring program described in Section 4.1, Inventory, Monitoring and Research. However, additional effort will be needed to ensure the early detection of new invasive species needed for a rapid response, before the populations become established

[36] Prices for goods may increase somewhat if detailed inspections are required prior to delivery.

[37] Cost to be borne by construction project.

[38] Cost will be low to OMKM (mainly in time for review of EIS and planning documents).

and spread. This section describes the Invasive Species Monitoring Program. Rapid response activities are discussed under Objective 3, below.

A stand-alone monitoring program for invasive species is desirable, as the schedules for invasive species monitoring activities will differ from the standard monitoring plans for abiotic conditions and plant and animal communities. Unlike the plant and animal community monitoring plots, which cover a variety of habitat types and locations, invasive species monitoring should be done predominantly in high traffic areas and other high risk locations where new invasive species are likely to appear, and in certain ecologically important areas such as habitat for rare species such as Mauna Kea silverswords or wēkiu bugs.

Actions

1. Conduct baseline inventory (as described in Section 4.1) to create a list of invasive species present on UH Management Areas.
2. Develop a list of incipient invasive species.
    a. Work with other agencies and experts to determine locations of populations of incipient invasive species. Focus on species that have the potential to invade subalpine and alpine environments.
    b. Use the list of incipient invasive species to identify special monitoring efforts or needs for UH Management Areas. Species found on nearby properties that have not yet invaded UH Management Areas should be given top priority for monitoring and rapid response efforts.
    c. Develop a set of photo cards (or drawings where photos are not available) to help in identification of high priority incipient invasive species in the field. Distribute to all personnel who regularly work outdoors including the NRC, field biologists, VIS staff, and OMKM Rangers.
        i. Produce an "Invader of the Month" memo for field personnel, to familiarize them with the appearance and natural history of incipient invasive species.
    d. The NRC should stay current with invasive species literature, attend presentations, conferences and meetings to learn about current work by researchers and land managers in Hawai'i, attend Big Island Invasive Species Committee (BIISC) meetings and read their newsletters.
    e. Update the UH Management Areas invasive species list semi-annually and when new incipient invasive species are identified.
3. Consult with the National Park Service (NPS), U.S. Geological Survey (USGS), USDA Forest Service, DLNR and other agencies in Hawai'i regarding established monitoring protocols for invasive species. Adapt these protocols, if available, to fit conditions on Mauna Kea. Otherwise, working with experts, design protocols as needed. Invasive species monitoring protocols may be the same as those used for standard monitoring activities as described in Section 4.1, Inventory, Monitoring and Research.
4. Develop the Invasive Species Monitoring Plan. At a minimum the plan should call for:
    a. Semi-annual surveys for incipient invasive plant species in high traffic areas at Hale Pōhaku, Summit Access Road, and the developed areas of MKSR. Field personnel should be trained to recognize invasive species, including those species, such as fountain grass, that are not yet on the properties but that are likely to appear.

b. Annual aerial monitoring of MKSR for new populations of invasive plant species. If budget allows, conduct semi-annual aerial photo monitoring.

   i. Investigate use of aerial photography, Light Detection and Ranging (LIDAR), or satellite imagery to detect plants in remote areas.

c. Continual monitoring for invasive hymenoptera (wasps and ants) at Hale Pōhaku using bait stations maintained by VIS staff. For ants, monitoring will entail putting out ant bait traps in areas where people are likely to eat food or dispose of waste. Two types of bait should be used for ants: meat (canned cat food or Spam) for protein-loving ants, and honey or sugar solution for sugar-loving ants (Hawaii Ant Group 2007). The ant baits should be collected and replaced after 24 hours.

   For yellowjacket (wasp) monitoring, follow the protocol described in *Management Strategies for Western Yellowjackets in Hawaii* (Gruner and Foote 2000). Monitoring consists of hanging Sea Bright Yellow Jacket Inn traps baited with heptyl butyrate (Montgomery 2008). Traps should be changed as necessary to ensure integrity and freshness of bait. Bait stations should be clearly labeled and placed out of the way in high traffic areas such as the picnic area at the VIS.

d. Annual monitoring for invasive invertebrates (arthropods) at Hale Pōhaku, Summit Access Road, and observatories, using baits, pitfall traps, and sticky traps, as appropriate. The Bishop Museum began an invasive arthropod monitoring program along the Summit Access Road in 2007. Their protocol may be followed, or adapted as needed, to continue this effort.

e. Annual monitoring for new invasive birds, mammals, reptiles and amphibians at Hale Pōhaku and MKSR (as part of the normal community monitoring protocols described in Section 4.1).

f. Monthly visits to Hale Pōhaku, Summit Access Road, and developed areas of MKSR by the NRC and field staff, to observe general conditions and look for unusual species.

g. Speedy recording of opportunistic observations of new species (or the spread of established invasive species into new locations). If an incipient invasive species is spotted, do not wait for scheduled monitoring events to record its presence and begin rapid response protocols (see Objective 3). Locations of individuals and populations should be carefully documented with GPS before removal efforts are undertaken.

Objective 3: Develop rapid response program to eradicate incipient invasive species

Once a new invasive species is detected on UH Management Areas, rapid assessment of the threat and rapid response to the detection are essential in order to maximize chance of eradicating the species, preventing a population explosion and accompanying ecosystem damage. Rapid response will minimize long-term management costs (National Invasive Species Council 2008). Early detection and eradication of a newly established invasive species is often the most neglected phase of the invasion process (Holt 1996), yet it could be considered the phase of invasive species control where probability of success is highest if regular and thorough efforts are put forth (National Invasive Species Council 2008).

Actions

1. Develop relationships with local, state, and federal authorities and experts in the field of invasive species control. They may be able to provide assistance or useful information to aid in rapid-response activities.

2. Develop an Invasive Species Rapid Response Plan. This should be done in conjunction with development of the Invasive Species Monitoring Plan, or immediately following it.

    a. Ideally, the rapid response plan should be developed prior to discovering new invasive species, because waiting to develop it until after the discovery of a new species will unnecessarily delay the response. However, it may be prudent to begin monitoring for certain high risk invasive species (such as fountain grass, ants and yellowjackets) before completing the rapid response plan. If new species are observed before the plan is complete, contact local experts to determine the best course of action and control methods.

    b. If time and budget allows, it would be beneficial to develop specific rapid response plans for the following groups of invasive species. These plans would then be on hand for use if any of the species are discovered on UH Management Areas. Rapid response plans specific to a species or a group of species are often referred to as Contingency Plans.[39]

        i. Hymenoptera (wasps and ants)[40]

        ii. Grasses (e.g., fountain grass) and other weedy non-native high-elevation plants.

    c. Plan Contents: The rapid response plan should contain information needed to respond quickly with general (non-species specific) actions to the discovery of any new species, and with specific control methods for selected species (or groups of species such as ants) deemed likely to invade in the near future.

        i. The plan should contain decision-making tools to determine if rapid response control efforts are warranted for the newly detected potentially invasive species. This is discussed further under No. 3, below.

        ii. Useful information to include in the plan:

            1. List of contacts in state and federal agencies who may be able to aid in eradication efforts.

            2. Contact information for managers or owners of neighboring properties, in case their cooperation is needed.

            3. List of invasive species control experts on island, including members of BIISC.

        iii. General response activities to include:

            1. Mapping the extent of the invasion using GPS and detailed field surveys.

            2. Notification of neighboring land managers, BIISC, DLNR, and other appropriate state and federal authorities.

            3. List of equipment/supplies needed to conduct the response activities.

        iv. Data management requirements. It is recommended that the GPS location data be uploaded to the GIS database directly after collection (see Section 4.5). Population boundaries should include metadata such as date of collection, names of field personnel who collected the data, and locations surveyed.

[39] Many contingency plans also contain preventative measures. These may be included in the rapid response plan if desired.

[40] A contingency plan for prevention of establishment of new ant species has been developed by the Hawaiian Ant Group (2007).

v. Reporting needs. It is recommended that rapid response efforts be documented in an annual report.

d. Development of specific response activities: Consult with NPS, USGS, DLNR, USDA, BIISC, other land management agencies, and local experts to determine the most effective rapid response procedures for invasive species (or groups of species) identified as being potentially invasive in the subalpine and alpine zones of Mauna Kea (See Objective 2, above). This will ensure that plans are in place for response to presence of these species prior to detection.

i. Control methodology already tested and proven successful in Hawai'i is preferable to those not yet tested. However, in some cases there will be no established control methods. In these cases, control methods for similar or related species may be appropriate.

e. Updates: Annually update rapid response control methodologies for high-risk invasive species by consulting BIISC, local experts, and the scientific literature.

3. Determine if the newly detected incipient invasive species is a potential threat to high-elevation ecosystems.

a. Ensure proper identity of species. May require consultation with an expert.

b. Consult with local experts, literature, or the websites listed below in No. 7. In many cases, information will exist on whether the species is considered a threat in the Hawaiian Islands.

c. Use the process of risk assessment to determine if the species is high priority for control. Risk assessments have been conducted for many invasive or potentially invasive plant species in Hawai'i (US Forest Service Institute of Pacific Islands Forestry 2005; Daehler and Denslow 2008).

d. Immediate control efforts (without further analysis of threat) are recommended when:

i. The number of individuals observed is small, or the population is limited to a small area, making it easy to eradicate.

ii. The species is known to be invasive elsewhere or if it is known to occur in a similar climate or habitat. These are the best predictors of invasiveness (Wittenberg and Cock 2001).

iii. Little is known about invasiveness of the species in Hawai'i.

iv. There is not sufficient time to conduct detailed research (e.g., the species has a fast reproductive rate or is very mobile).

4. Conduct rapid response control efforts upon detection of a new, potentially invasive, species.

a. Obtain funding. The OMKM natural resources management program should set aside some funding for each fiscal year for rapid response activities. However, additional funds may be needed for larger or more expensive control projects.

i. Check with state and federal agencies to determine if funding is available.[41]

[41] For example, the USDA has the authority to use any available funds for emergency control or eradication. If the species is new to the islands, this may be a way to obtain additional funds or field assistance in rapid response.

  ii. One of the objectives of the National Invasive Species Council is to develop mechanisms for cooperating and funding rapid response efforts, such as matching grants to states (National Invasive Species Council 2008). Check with the council to determine if matching funds are available.

b. If needed, seek additional information on the species and help with response efforts from local federal and state entities that deal with invasive species.

c. Conduct control efforts if deemed appropriate.

d. Keep careful records of rapid response control methodology, dates, personnel involved, and agencies notified. This information should be included in a rapid response report (see No. 6 below).

e. It would be beneficial to create an invasive species "emergency response" kit that contains equipment and supplies needed to respond to invasive species on the OMKM high priority list. This may include sample-collection jars or bags, flagging, GPS unit, and perhaps non-species specific insecticides and herbicides. All equipment must be maintained in working order and stored in a readily accessible place identified in the rapid response plan (Wittenberg and Cock 2001).

5. Begin post-control monitoring program for the area where control efforts were conducted to ensure eradication was achieved.

   a. Conduct monthly inspections of the general vicinity of the site of the discovery and the eradication efforts, to determine if species has spread. Continue inspections for a minimum of six months to one year, depending on the number of individuals detected, how contained the original invasion was, and reproductive rate of the species.

   b. Check nearby areas for the species during future regular monitoring events.

6. Produce a yearly report on rapid response activities, detailing discoveries, successes, and failures of eradication efforts. Share reports, or discuss control successes (and failures), with others in the invasive species control community (e.g., BIISC, neighboring land owners, and at conferences).

7. Useful websites for determining whether a species may be a threat in high-elevation ecosystems, control methods, and general information include

   a. Hawaii Ecosystems at Risk: http://www.hear.org/

   b. Pacific Islands Ecosystems at Risk: http://www.hear.org/pier/

   c. Hawaii-Pacific Weed Risk Assessment: http://www.botany.hawaii.edu/faculty/daehler/wra/full_table.asp

   d. Big Island Invasive Species Committee: http://www.hawaiiinvasivespecies.org/iscs/biisc/

   e. College of Tropical Agriculture and Human Resources

      i. Weeds of Hawai'i's Pastures and Natural Areas: http://www.ctahr.hawaii.edu/forestry/Data/Weeds_Hawaii.asp

      ii. Free publications on various pest species: http://www.ctahr.hawaii.edu/ctahr2001/PIO/FreePubs.asp

   f. Invasive Species Council: http://www.invasivespecies.gov

   g. Global Invasive Species Database: http://www.issg.org/database/welcome/

h. US INVADERS database system (early detection, alert & tracking of invasive plants): http://invader.dbs.umt.edu/

i. The Nature Conservancy weed database: http://tncweeds.ucdavis.edu

j. Weeds Gone Wild: Alien Plant Invaders of Natural Areas: http://www.nps.gov/plants/alien/

Objective 4: Control established invasive species in sensitive areas

The aim of any control program is to reduce the abundance or density of an invasive species to keep ecosystem damage to an acceptable level, and to reduce the rate of range-expansion (Wittenberg and Cock 2001; National Invasive Species Council 2008). The main methods of control are mechanical (e.g., pulling weeds); chemical (herbicides, pesticides, baits); habitat management (prescribed burns, fencing); and hunting (Wittenberg and Cock 2001). Usually more than one method is used at a time, to improve chances of successful control. Control efforts that cover a large area should be conducted in conjunction with restoration of native species, to help reduce the chance of reinvasion (Wittenberg and Cock 2001). Control efforts should be conducted primarily in sensitive areas with high ecological value, or in high-traffic areas that may act as gateways for new invasions.

Actions

1. Prioritize invasive species control activities.
    a. Box 4.2-1 provides a stepwise approach for prioritizing species and specific infested areas for control that was developed by the Global Invasive Species Programme (Wittenberg and Cock 2001).
2. Prioritize locations in need of invasive species control activities. Priority of areas can be generalized as follows, with the top priority areas listed first and lower priority areas listed last:
    a. Areas with rare or endangered native plant or animal populations.
    b. Restoration areas.
    c. High traffic areas such as roadsides and trails (pathways for movement of invasive species).
    d. Isolated areas with smaller invasive species populations (isolated well defined populations of invasive species may act as a source point for invasion into less disturbed areas but may also be effectively treated or even eradicated).
    e. Highly invaded areas (these areas are least likely to contain native species, and least likely to achieve successful control given the extent of invasion).
3. Research successful invasive species control techniques.
    a. Consult with local experts to learn about methods tested in the Hawaiian Islands. Experts to consult include BIISC, federal and state land managers and biologists, researchers, and invasive species web sites (see list of websites under Objective 3, above).
    b. Techniques for invasive species control vary depending on the species. Standard techniques for the various groups of invasive species (plants, invertebrates, mammals, birds) are listed below. Combining one or more of these techniques may be necessary to control a particular species.
        i. Plants

1. Herbicide application
2. Hand removal (e.g., weeding)[42]
3. Mechanical control (e.g., mowing)
4. Controlled burns (not recommended for subalpine and alpine ecosystems in Hawai'i, because native plants are not fire-adapted).
5. Biological control (to be conducted by USDA).

ii. Invertebrates

1. Pesticides
2. Bait stations/traps
3. Handpicking (snails and other larger, sedentary species)
4. Removal of host species (e.g., infested plants)
5. Biological control (by USDA)

iii. Birds and Mammals

1. Trapping
2. Hunting
3. Bait (bait stations or widespread dispersal of toxicants)
4. Fencing/netting (with removal of animals within fenced area)[43]

c. Conduct cost-benefit analysis to help determine which control method(s) to use. Control methods vary greatly in ease of application, cost per unit area (or individual animal), success, undesirable side-effects, and duration of effect. These factors must be taken into consideration when choosing methodologies to employ.

4. Develop invasive species control plan(s).

a. An invasive species control plan may be species specific, such as a fountain grass control plan, or address a group of species, such as a plan that covers all grasses or a plan that covers all established high priority invasive plants.

b. Control activities that have not been previously tested or used on Mauna Kea high-elevation ecosystems should first be conducted as research projects in limited areas to test their effectiveness and to detect unintended negative impacts on native flora and fauna. Plans should reflect the need for testing and monitoring.

c. Planning for management of invasive species should involve various stakeholders from the beginning, to avoid unnecessary interruption of the program once it begins. This is especially true for controversial control programs such as feral cat control.

d. Control plans should include the following elements

i. Introduction

[42] Some basic tools for invasive plant control and removal are presented at http://tncweeds.ucdavis.edu/tools.html.

[43] Fencing is used to exclude non-native mammals from an area, and has been used extensively in New Zealand to great effect. The species to be excluded will determine the size of the link used in the fence. It is possible to fence an area to exclude animals as small as baby mice (e.g., see www.xcluder.com). Once the fence is in place, all the mammals within the fenced areas must be removed through trapping, bait, or hunting.

1. Review of impacts of the species on ecosystem functioning
2. Description of basic life history of the invasive species to be controlled
3. Review of known control methodologies used for this species and effectiveness (from scientific literature, invasive species information web pages, and local experts)

ii. Goals of the control program

1. Type of control desired (eradication, control, containment, or mitigation)[44]
2. Total area of desired control
3. Desired reduction of abundance/density
4. Desired outcomes (e.g., native plant regeneration, use by native birds, reduction of spread into un-invaded areas, reduced erosion, and improvement of viewshed)
5. Timeline

iii. Funding needs and sources

iv. Education and outreach activities needed to increase public support of the program and to increase likelihood of a successful outcome

v. Methodology

1. Description of control methodology to be used on UH Management Areas, including detailed step-by-step instructions of protocols to follow
2. Location of control activities, including map
3. Total area to be treated

vi. Monitoring methodology, including descriptions of

1. Methods for testing effectiveness of control activities
2. Detection and measurement of unintended side effects/impacts to native ecosystems
    a. This may be accomplished in part through monitoring of selected native species abundances before, during, and after control

vii. Evaluation of further control needs

1. Flow chart or decision matrix describing how monitoring results should be used to determine if further control efforts are needed

viii. Reporting needs

[44] Wittenberg and Cock (2001) define eradication, control, containment, and mitigation as follows: *Eradication* is the removal of the entire population of an invasive species, including any resting stages, in the management area. Eradication is generally successful only for small or geographically isolated populations. *Control* is the long-term reduction of invasive species density and abundance to an acceptable threshold. *Containment*, a subset of control, is the goal of restricting the spread of an invasive species, with the goal of containing it to a defined geographical area. *Mitigation* occurs when it is not possible to control an invasive species. Mitigation activities are generally directed towards native species impacted by the uncontrollable invasive, and may include such actions as translocation, outplanting programs, provision of predator proof nesting boxes, or feeding or provisioning of the native species.

1. This section of the control plan should briefly describe what elements should be included in invasive species control project reports, and frequency of reporting.

5. Conduct control activities.
    a. Whenever possible, conduct control activities on UH Management Areas in conjunction with control activities on neighboring properties.
    b. Participate in any state- or island-wide (or Mauna Kea-wide) multi-agency control efforts.
    c. Begin invasive plant control efforts prior to fencing an area to exclude ungulates. This will reduce the need to spray herbicides in the fenced exclosures, reducing impact on native species that begin regenerating once the ungulates are gone (Evans 2008). Follow fencing activities with weed control maintenance activities as needed.
    d. Develop weed control buffers around important areas such as populations of native plants. Successful weed control buffers used at Pōhakuloa Training Area range from 80 to 165 ft (25 to 50 m) in width (Evans 2008).
    e. Whenever possible, invasive species control activities should be coupled with restoration efforts, particularly in the case of invasive plant control. See Section 4.3 for more information on restoration activities.
6. Monitor success.
    a. Monitoring should focus on the numbers of individual pests that remain, rather than the number removed, as the former is the best indication of success of control methods (Wittenberg and Cock 2001).
    b. Monitoring the response of native species in the area will provide information on the benefits/value of the control efforts.
    c. Monitor response by other non-native species, to determine if control of additional species is needed. This may occur if control of one invasive species leads to the increase of another.
    d. For invasive plant removal projects, monitoring may have to continue for several years, depending on the longevity of seeds in the seedbank.
7. Produce annual report.
8. Evaluate program and adapt as necessary.

Table 4.2-9. High Priority Invasive Species for Control Activities on UH Management Areas

Type	Common Name (Scientific name)[45]	Control Locations
Plant: Grasses	- Needlegrass (*Nassella cernua*) - Ripgut brome (*Bromus diandrus*) - Orchardgrass (*Dactylis glomerata)* - Velvet grass (*Holcus lanatus*) - Kentucky bluegrass (*Poa pratensis*) - Sweet vernal grass (*Anthoxanthum odoratum*) - Fountain grass (*Pennisetum setaceum*) *	- Silversword exclosures - Restoration areas at Hale Pōhaku - VIS & Dorm landscaping - Summit Access Road banks
Plant: Herbs	- Common mullein (*Verbascum thapsus*) - Telegraph weed (*Heterotheca grandiflora*) - Fireweed (*Senecio madagascariensis*)	- Silversword exclosures - Restoration areas at Hale Pōhaku - VIS & Dorm landscaping - Summit Access Road banks - Hiking trails & dirt roads
Plants: Shrubs	- Gorse *(Ulex europaeus)**	- Lower elevation property boundaries, if found.
Invertebrates[46]: Hymenoptera	- Yellowjackets (*Vespula pensylvanica*) - European Paper Wasp (*Polistes dominula*)* - Argentine ant (*Linepithema humile*)* - Cardiocondyla ant (*Cardiocondyla venustula*)* - Big headed ant (*Pheidol megacephala*)* - Guinea ant (*Tetramorium bicarinatum*)* - Pharaoh ant (*Monomorium pharaonis*)*	- Control if found at any location
Mammals: Ungulates	- Feral Sheep (*Ovis ovis*) - Feral Mouflon (*Ovis musimon*) - Feral Goats (*Capra hircus*)	- Throughout properties
Mammals: Predators	- Cats (*Felis catus*) - Mongoose (*Herpestes auropunctatus*) - Rats (*Rattus rattus, R. exulans, R. norvegicus*) - Mice (*Mus musculus*)	- Any areas found to be used by native bird species - Control rats and mice at summit if present (to protect summit arthropods)
Mammals: Seed eaters	- Rats (*Rattus rattus, R. exulans, R. norvegicus*) - Mice (*Mus musculus*)	- Silversword exclosures - Restoration areas - Areas with rare or protected native species or high native plant density

[45] Species followed by an asterisk (*) are not yet established but should be controlled if found.

[46] Invasive invertebrates currently established at the summit, such as the ground hunting spider (*Meriola arcifera*), are not targeted for control because of the difficulty of controlling these species without harming native invertebrates.

Box 4.2-1: Ranking of invasive species for priority setting

Excerpted from Invasive Alien Species: A Toolkit of Best Prevention and Management Practices (Wittenberg and Cock 2001)

The priority-setting process can be difficult, partly because you need to consider so many factors. It has been found that it helps to group these factors into four categories, which you can think of as filters designed to screen out the worst pests:

1. Current and potential extent of the species on or near the site;
2. Current and potential impacts of the species;
3. Value of the habitats/areas that the species infests or may infest; and
4. Difficulty of control.

Ignore categories that are unimportant to your site. Below we suggest how species should be ranked within the four categories. If a species is described by more than one of the criteria in a given category, assign it the highest priority it qualifies for. You may assign priority in a ranking system (e.g. 1, 2, 3) or by class (e.g. A = worst pests, B = moderate pests, C = minor pests).

I. Current and potential extent of the species: Under this category, priorities are assigned to species in order to first, prevent the establishment of new pest species, second, eliminate small, rapidly-growing infestations, third, prevent large infestations from expanding, and fourth, reduce or eliminate large infestations. To do this, assign priorities in the following sequence:
    a. Species not yet on the site but which are present nearby. Pay special attention to species known to be pests elsewhere in the region.
    b. Species present on the site as new populations or outliers of larger infestations, especially if they are expanding rapidly.
    c. Species present on the site in large infestations that continue to expand.
    d. Species present on the site in large infestations, which are not expanding. You may have to learn to "live with" certain species or infestations that you cannot control with available technology and resources. However, keep looking for innovations that might allow you to control them in the future.

II. Current and potential impact of the species: the order of priorities under this category is based on the management goals for your site. We suggest the following sequence:
    a. Species that alter ecosystem processes such as fire frequency, sedimentation, nutrient cycling, or other ecosystem processes. These are species that "change the rules of the game", often altering conditions so radically that few native plants and animals can persist.
    b. Species that kill, parasitize, hybridize or outcompete natives and dominate otherwise undisturbed native communities.
    c. Species that do not outcompete dominant natives but:
        i. Prevent or depress recruitment or regeneration of native species; or
        ii. Reduce or eliminate resources (e.g. food, cover, nesting sites) used by native animals; or
        iii. Promote populations of invasive non-native animals by providing them with resources otherwise unavailable in the area; or
        iv. Significantly increase seed distribution of non-native plants or enhance non-native plants some other way.
    d. Species that overtake and exclude natives following natural disturbances such as fires, floods, or hurricanes, thereby altering natural succession, or that hinder restoration of natural communities. Note that species of this type should be assigned higher priority in areas subject to repeated disturbances.

III. Value of the habitats/areas the species actually or potentially infests: Assign priorities in the following order:
    a. Infestations that occur in the most highly valued habitats or areas – especially areas that contain rare or highly valued species or communities and areas that provide vital resources.
    b. Infestations that occur in less highly valued areas. Areas already badly infested with other pests may be given low priority unless the species in question will make the situation significantly worse.

IV. Difficulty of control and establishing replacement species: Assign priority in the following order:
    a. Species likely to be controlled or eradicated with available technology and resources and which desirable native species will replace with little further input.
    b. Species likely to be controlled but will not be replaced by desirable natives without an active restoration program requiring substantial resources.
    c. Species difficult to control with available technology and resources and/or whose control will likely resulting in substantial damage to other, desirable species and/or enhance other non-indigenous species.
    d. Species unlikely to be controlled with available technology and resources. Finally, pest species whose populations are decreasing or those that colonize only disturbed areas and do not move into (relatively) undisturbed habitats or affect recovery from the disturbance can be assigned the lowest priorities.

4.2.3.8 Population Decline and Loss of Diversity

Threat Level: Hale Pōhaku: High; MKSR: Unknown (High)

Declines in populations of native plants and animals and loss of native biological diversity have been especially profound in the Hawaiian Islands. There are many known causes of population declines and loss of species in the high-elevation ecosystems of Mauna Kea, including habitat loss and disturbance (see Section 4.2.3.1); invasive species impacts (see Section 4.2.3.7); changes in weather patterns and fire regimes (see Sections 4.2.3.11 and 4.2.3.10); and (historically) hunting and collection of specimens (see Section 4.2.3.9 for information on current day collecting). Often it is the cumulative impacts of more than one of these threats, acting together, that causes the decline or extinction of a species. The reduction of māmane forest cover and its associated native community in the subalpine regions of Mauna Kea and the loss of the Mauna Kea silversword and other native plant species in the alpine regions of Mauna Kea have been well documented, and their causes are fairly well understood. Population changes in the summit invertebrate community are less well understood, although current research suggests that declines have not been as drastic as once thought (see Section 2.2.2.2 for information on summit invertebrates). The health of the subalpine and alpine ecosystems on Mauna Kea will likely change as the impacts of global climate change increase.

The sources and impacts of population decline and loss of biodiversity are discussed further in the following sections of the NRMP:

- Plants: 2.2.1.3
- Invertebrates: 2.2.2.3
- Birds: 2.2.3.3
- Mammals (native bat): 2.2.4.3
- Impacts to native plant and animal communities through human uses and activities: 3.2

Goal TPC-9: Maintain native plant and animal populations and biological diversity

The goal of maintaining native plant and animal populations and biological diversity on UH Management Areas can be accomplished through the following objectives: 1) minimizing human-induced population declines and loss of biodiversity; 2) detecting changes in population size of rare or protected native species; 3) determining causes of population declines; and 4) restoring declining populations through adaptive management.

Many of the known causes of declines in native plant and animal population are addressed elsewhere in this Threat Prevention and Control Component Plan. This subsection provides general management actions that can aid in prevention, detection, understanding, and response to declining populations of native plants and animals. Once the major causes of population losses are determined, the management actions in other sections can be used to help address the problem.

Objective 1: Minimize human-induced population declines and loss of biodiversity

Preventing losses of individuals and populations is the preferred management option, because restoring a degraded natural community is not always possible. Once a species becomes extinct, there is no hope of restoring it, and often the loss of one species will cause a cascade of losses of other species. For example, the loss of māmane trees in the subalpine zone would immediately cause the loss of (at minimum) the Palila and several endemic moth species. However, preventing population declines is not simple. Even if all people stopped using the subalpine and alpine regions on Mauna Kea, and it was set aside as a nature preserve, there would still be other impacts to the native populations from causes such as invasive species, disease, wildfires, and climate change.

Table 4.2-10 lists the known sources of impacts to native plant and animal populations, management activities that can help reduce these impacts, the priority of the management action, and its relative cost. In some cases the activity section refers the reader to another section of this component plan, because the actions are addressed more specifically there. Other sources have not been specifically addressed elsewhere, and are addressed here in detail.

Table 4.2-10. Management Actions to Minimize Population Decline and Loss of Biodiversity

Management Action	Priority	Cost
Invasive species		
Establish invasive species prevention and control program. See Section 4.2.3.7. Actions to be taken include predator/herbivore removal, fencing, and invasive weed control.	High	Medium to High
Habitat alteration		
Conduct habitat restoration projects, and minimize additional habitat loss. See Sections 4.3 and 4.2.3.1.	High	Variable
Hunting and Sample collection[47]		
Prohibit[48] the collection or hunting of all rare, sensitive, or protected (Threatened and Endangered) native species. Collections for scientific research are excluded from this prohibition, but reducing the impact of scientific research is addressed in Section 4.2.3.9.	Medium	Low[49]
Wildfires		
Reduce frequency and extent of wildfires through habitat modification. See Section 4.2.3.10.	Low[50]	High
Pollution		
Use best management practices to minimize the release of contaminants into the environment. See Sections 4.2.3.2, 4.2.3.3, and 4.2.3.5.	Low[51]	Low
Loss of pollinators and seed dispersers[52]		
Collaborate with DLNR, USGS, USFWS, and other local experts on restoration and planting projects.	High	Variable[53]

[47] Historically, hunting and sample collection has reduced populations of native animals and plants in the islands. Although native species are rarely hunted or collected now, in some cases these populations have never recovered.

[48] The restriction on hunting or collection does not apply to non-native species.

[49] Costs associated with this action are primarily due to the need for ranger patrols.

[50] There are no available records of wildfire in the vicinity of Hale Pōhaku, and, the true threat of wildfires at Hale Pōhaku is unknown and deserves further study. The threat of fire in MKSR is minimal, because of the sparseness of vegetation in the alpine ecosystem. If wildfires become a problem in the future, the priority would become High, because native plant communities in the subalpine region are not fire-adapted.

[51] Priority is low because currently pollution is not considered to be a major factor in population decline on Mauna Kea.

[52] The loss of pollinators can block reproduction in many of the subalpine and alpine species, because several of them are self-incompatible. It will also cause genetic bottlenecks. The loss of seed dispersers can slow or even halt the spread and establishment of many species. For example, germination rate of pūkiawe (*Leptecophylla tameiameiae*) seed is very low if the seed does not first pass through the gut of a bird.

[53] Costs will depend on the amount contributed by OMKM to these projects. Costs can range from low (contributing employee time and restoration sites) to high (if entire project is funded by OMKM).

Management Action	Priority	Cost
Restore plant and pollinator populations using - Hand pollination (work with experts to develop protocols or collaborate in existing programs). - Outplanting of greenhouse-grown plants in fenced areas to increase plant density.[54] - Rearing and introduction of native pollinators (collaborate with experts).	Depends on need[55]	Variable
For missing seed dispersers consider: - Hand spreading of seed (pre-treat seed if necessary for germination) - Re-introducing seed dispersers - Studying effectiveness of other species as seed dispersers.	Depends on need	Variable
Genetic bottlenecks (Inbreeding depression)		
Collaborate with DLNR, USGS, USFWS, and other local experts on restoration and breeding projects.	Depends on need	Variable
Small population size[56]		
Collaborate with DLNR, USGS, USFWS, and other local experts on restoration and breeding projects.	Depends on need	Variable
Climate change		
See Section 4.2.3.11. Activities could include control of invasive plants to allow for migration of native plants, watering (in restoration areas) in response to drought, and monitoring of natural communities.	High	Variable

Objective 2: Detect changes in population sizes of rare or protected native species

Detecting changes in population sizes of native plant and animal species on UH Management Areas should be accomplished through the Inventory, Monitoring, and Research Program (Section 4.1). Changes in population locations and sizes can be visualized through spatial analysis using the GIS natural resources database (see Section 4.5). Collaboration with other state and federal agencies monitoring rare and protected native species is highly recommended.

Objective 3: Determine the causes of population declines

To effectively counter population declines, natural resource personnel must first understand what factors are contributing to the decline. In some cases the causes will be obvious, such as smothering of native plants by invasive grasses or browsing by herbivores. In other cases, determining the cause will require additional effort. The NRC following actions can be used to determine causes for population declines:

1. Conduct literature review to determine if causes for declines in this species have been studied elsewhere in Hawai'i.
2. Consult with local experts and state and federal agencies regarding causes for declines in this species. There is often considerable unpublished information available.

[54] Increasing plant density will most likely be necessary to allow for establishment of self-sustaining populations of native pollinators.

[55] "Depends on need" indicates that the priority of conducting these activities will depend on the status and trends of the species (such as changes in population size) on Mauna Kea, chances of extinction, and other factors which may come into play (such as compliance with the Endangered Species Act).

[56] Small and isolated populations are often susceptible to extirpation by random events.

3. Look for correlations between population changes (magnitude and direction) and environmental conditions (such as rainfall, or density of invasive species) at sites on UH Management Areas (or elsewhere in similar ecosystem types), to look for potential causes of population declines.
4. Conduct field studies to observe impacts to the species (e.g., predation by non-native mammals, absence of pollinators).
5. Conduct research to test the response of species to the removal of a threat factor (e.g., weeding invasive plants, watering to alleviate drought conditions, fencing to keep out herbivores).
6. Encourage research on UH Management Areas by UH faculty, scientists, and federal and state agencies that addresses cause of population declines.

For more information, refer to Section 4.1.2.3, which describes how to establish a Research Program.

Objective 4: Restore declining populations through adaptive management

Management activities needed to help restore declining populations depend upon the causes of decline. As often as not, there are several forces that cumulatively contribute to population decline. Ideally, these should be responded to at the same time, to avoid undesirable or unpredictable responses to management efforts. For example, restoration of native plant communities would require exclusion (or removal) of invasive herbivores, as well as control of invasive weed species, and may also require out-planting of greenhouse-grown seedlings or saplings. Once the causes of population decline are identified, refer to the appropriate threat section in this NRMP for potential management responses, and to Section 4.3 for more information on conducting restoration projects.

4.2.3.9 Sample Collection/Scientific Research

Threat Level: Hale Pōhaku: Low; MKSR: Medium

Scientific research can disturb or alter habitat and impact species with small populations or patchy, isolated distributions through sample collection and incidental take.[57] Ground disturbing activities can impact cultural sites and physical resources. Some research activities, such as trapping insects and collection of botanical samples may cause the death or removal of the organism being studied. Most researchers try to use sampling methodologies designed to minimize direct and incidental take, but some take does occur. Arthropod sampling, for example, often results in the death of the specimens, even when researchers use live trapping methods (Englund et al. 2002; Englund et al. 2007). Amateur collectors and tourists also occasionally collect plants and animals, or unintentionally harm them.

The impacts of scientific research are discussed further in the following sections of the NRMP:

- Impacts
  - Physical Resources: 2.1.1.6, 3.2.1
  - Invertebrates: 2.2.2.2.3
- Sources/pathways of disturbance: 3.2.9

[57] Incidental take is the unknowing or accidental killing or removing of an organism.

Goal TPC-10: Limit impacts to natural resources from scientific research and sample collection.

The goal of limiting impacts to natural resources from scientific research and sample collection can be accomplished through the following objectives: 1) preventing unnecessary losses; 2) monitoring research projects; and 3) mitigating losses caused by research activities.

Objective 1: Prevent unnecessary losses from scientific research

Careful planning and execution of research projects, combined with respect for the natural resources, can minimize, and in some cases, virtually eliminate loss of individuals through sample collection and incidental take. Table 4.2-11 lists the types of research activities on UH Management Areas, management activities that can help reduce impacts from these, the priority of the management action, and its relative cost.

Table 4.2-11. Management Actions to Minimize Impact of Research Projects

Management Action	Priority	Cost
All: General		
Require review and approval of all research protocols by NRC and MKMB Environmental Committee before projects begin.	High	Low
All: Site access through hiking		
See Section 4.2.3.1 for details.	Medium	None to Low
All: Site access through off-road vehicle use		
Restrict or prohibit off-road vehicle use in sensitive areas.	High	Low
All: Habitat alteration or disturbance		
See Section 4.2.3.1 for details.	High	Low
Astronomy		
Restrict or prohibit development in sensitive areas. See Section 4.2.3.1 for details.	High	Low
Reduce or eliminate release of contaminants into the environment through best management practices. See Sections 4.2.3.3, and 4.2.3.5.	High	Low
Meteorological: Placement of weather stations		
Minimize area disturbed; use established stations when possible.	Low	None
Geological: Soil boring		
Require research projects to return site to original (or improved) condition at end of project, if habitat is disturbed.	High	None
Limit number of soil borings.	High	None
Hydrological		
Limit number of wells.	High	None
Biology: Taxonomy and genetics studies		
Minimize number of samples collected for rare or patchily distributed species.	High	Low
Spread sampling effort over multiple areas to reduce impact to any one population.	Medium	Low
Biology: Inventory and Monitoring		
Work with local experts to establish low-impact sampling techniques.	High	Variable[58]
Use remote sensing whenever feasible. This will also help reduce habitat disturbance (Section 4.2.3.1) and spread of invasive species (Section 4.2.3.7).	Medium	Medium to High
Minimize number of samples collected or number of days when sampling occurs.	High	Low
For high mortality sampling, reduce sampling frequency and number of traps to minimum needed.	High	Low

[58] The cost of non-lethal sampling methodologies will vary depending on the organism.

Tourists & amateur collectors		
Prohibit the collection or hunting of all native species. Provide information regarding this at VIS, websites, text on maps, and handouts, and brochures.	High	Medium
Educate public about the uniqueness of the subalpine and alpine ecosystems on Mauna Kea. See Section 4.4.	High	Medium
Enforce collection prohibitions via ranger patrols.	High	Medium

Objective 2: Monitor research projects to assess impact

Careless project design can cause unnecessary environmental impacts. Requiring all research proposals to be reviewed and approved by the NRC and the MKMB Environmental Committee will help reduce these unnecessary impacts on Mauna Kea. However, some follow-up is required to ensure that the projects are being conducted according to the proposal and that inadvertent damage is not being caused. The following actions will help the NRC monitor the impacts of the various research projects being conducted on UH Management Areas.

1. For projects not run by OMKM, require
    a. Regular (semi-annual) presentations by project lead investigators for ongoing scientific projects that take place in the field (natural areas).
    b. Interim and final reports on the progress of projects, to be submitted to the NRC and MKMB Environmental Committee.
    c. Regular visits by natural resources staff to locations of research projects being conducted by non-OMKM staff.
    d. Final site inspection by NRC of all locations where research activities resulted in frequent site access or habitat disturbance. If damage is observed, require project to clean up or restore sites as needed and deemed appropriate by OMKM.
2. For OMKM projects, see Section 4.1 (Inventory, Monitoring, and Research) for reporting and monitoring needs.

Objective 3: Mitigate losses caused by scientific research

For projects that cause habitat loss or take of a large number of individuals (incidental or planned), conduct habitat restoration or population recovery activities as deemed appropriate. See Section 4.3, Natural Resources Preservation, Enhancement, and Restoration for a discussion of restoration activities following decommissioning of telescopes and for general habitat restoration, planning, and techniques. If the project results in the take of protected species (unlikely but possible), consult with USFWS and DOFAW regarding appropriate actions.

4.2.3.10 Fire

Threat Level: Hale Pōhaku: Unknown; MKSR: None

Many native Hawaiian plants such as pūkiawe (*Leptecophylla tameiameiae*) are not fire tolerant (Hughes et al. 1991; Smith and Tunison 1992). However, many invasive plant species (especially grasses) are fire-adapted and recover quickly from fires, either through regeneration or germination of new plants from seeds. The result of fire in a Hawaiian plant community that has been invaded by fire-adapted species is often the conversion of the community from a native-dominated community to an invasive-dominated one

(Hughes et al. 1991; Smith and Tunison 1992; D'antonio et al. 2000). Subalpine native plant communities are patchy by nature, providing naturally discontinuous fuel beds for fire. The presence of invasive grasses in these communities, however, provides a source of continuous fine fuels and increases the risk of fire (Smith and Tunison 1992; Hess et al. 1999). Prior to the introduction of invasive grass species, wildfires were most likely infrequent in the subalpine zone. Potential causes of wildfire include vehicle accidents, improperly disposed cigarettes and matches, sparks from automobile catalytic converters (especially on unpaved hunting roads), arson, military training activities at PTA, lightning strikes, and campfires. Currently, the threat of fire at Hale Pōhaku is unknown. However, specialists at PTA, Federal Highway Administration (FHWA), and DOFAW are working on fire models and prevention on Mauna Kea, and would be a valuable source of information on the risk of fire in the region.

The sources and impacts of fire are discussed further in the following sections of the NRMP:

- Impacts:
  - Plants: 2.2.1.3.2.
  - Birds: 2.2.3.1.1.
- Sources/pathways of disturbance: 3.2.10.

Goal TPC-11: Prevent fires

The goal of preventing fires on UH Management Areas can be accomplished through the following objectives: 1) reducing fire risk through habitat management and regulations; 2) detecting changes in fire frequency and locations; and 3) restoring fire-damaged areas.

Objective 1: Reduce fire risk through habitat management and regulations

The main methods of preventing the spread of fires in the subalpine zone should be 1) control of the invasive grasses and other weedy invasive species that grow in high densities, especially in areas frequented by people, and 2) reducing sources of ignition through regulations and education. Table 4.2-12 lists the sources of increased fire risk on UH Management Areas, management activities that can help reduce these impacts, the priority of the management action, and its relative cost.

Table 4.2-12. Management Actions to Minimize Risk of Fire

Management Action	Priority	Cost
Invasive grasses		
Weed control activities at Hale Pōhaku, with focus on: - Roadsides - Pullouts used by the tour companies - Unpaved parking lots - Unpaved 4WD roads	Unknown[59]	Medium
PTA (military activities)		
Create firebreaks along Hale Pōhaku boundaries (weed control buffers).	Unknown	Medium
Vehicles		

[59] The priority of these activities depends on whether fire is deemed to be a threat to Hale Pōhaku. If fire is determined to be a threat, then these would be high priority activities.

Management Action	Priority	Cost
Ask tour companies not to idle their vans in unpaved areas where sparks may ignite grasses.	Unknown	None
Rangers who notice idling vehicles in grassy areas should request that the driver turn off the vehicle or move on to an un-vegetated area.	Unknown	Low
Cigarettes		
Provide ashtrays in conspicuous areas around VIS.	High	Low
Provide educational signage requesting that visitors do not smoke on trails, in the DOFAW silversword exclosure, and in unpaved areas.	Unknown	Medium
Campfires		
Prohibit camping on UH Management Areas.	Medium	Low
Slow response time		
To minimize the impacts of a fire once it occurs, MKSS and OMKM staff should be trained to respond quickly to fires detected on or near UH Management Areas.	High	Medium
Lack of information		
Collaborate with fire experts at PTA, FHWA, and DOFAW on fire prevention efforts on Mauna Kea.	High	Low

Objective 2: Detect changes in fire frequency and locations

Determining whether the threat of fire in the subalpine zone on Mauna Kea is increasing, decreasing, or staying the same can be accomplished through tracking of the location, frequency and severity of fires utilizing the spatial analysis capabilities of the GIS system. Additionally, fuel loads on UH Management Areas can be determined by a local expert, and this information can be added to the GIS to allow for analysis of areas with high potential for fires. The most cost effective method of achieving this objective is for OMKM to work with fire experts at PTA, FHWM, and/or DOFAW to determine risks of fire and methods of prevention for Hale Pōhaku.

Objective 3: Restore fire-damaged areas

Areas damaged by wildfires in the subalpine zone will most likely become even more heavily invaded by non-native grasses than before, and native vegetation is unlikely to recover without management intervention. Restoration activities on fire-damaged lands should include control of invasive grasses followed by monitoring for native plant recovery. If native plant recovery does not appear to be occurring, then out-planting of native species such as māmane, pūkiawe, and native grasses is desirable. See Section 4.3, Natural Resources Preservation, Enhancement, and Restoration for more information on restoration projects and species lists.

4.2.3.11 Climate Change

Threat Level: Hale Pōhaku: Unknown (High); MKSR: Unknown (High)

Although there is general consensus in the scientific community that climate change is happening, there is currently a great deal of discussion about what effects climate change will have on the weather in the Hawaiian Islands, especially at high elevations (Giambelluca and Luke 2007; Hamilton 2007b). All climate change scenarios predict an overall warming in the Hawaiian Islands and that the higher-altitude areas on the islands will see greater gains in temperature than lower-altitude areas (Giambelluca and Luke 2007; Hamilton 2007a). Some climate change models predict an increase in rainfall and, possibly an increase in snowfall in the higher elevations. Other climatologists predict that conditions in high-elevation areas in the Hawaiian Islands will become much drier due to changes in the trade wind inversion such as have been observed in the last several decades (Giambelluca and Luke 2007). Increased temperatures in high elevations may move the tree line upslope, moving plant and animal communities along with it. However, the kind of impact that climate change may have on high-elevation ecosystems will depend greatly on whether up slope areas get drier or wetter. Increased drought may make germination and survival of plants, especially māmane trees, more difficult. Changes in snowfall or wind patterns at the summit could threaten the aeolian community. Invasive species compound the problem by competing with native species for habitat and resources. Invasive plants may block native species from moving up or down the mountain as they seek their preferred rainfall and temperature conditions.

The sources and impacts of climate change are discussed further in the following sections of the NRMP:

- Impacts
  - Physical resources: 2.1.4.5, 2.2.1.3.6
  - Plants: 2.2.1.3.6
  - Invertebrates: 2.2.2.3.4
  - Birds: 2.2.3.3.4
- Sources/pathways of disturbance: 3.2.11

Goal TPC-12: Manage ecosystems to allow for response to climate change

The goal of managing ecosystems to allow for response to climate change can be accomplished through the following objectives: 1) detecting the impacts of climate change; 2) understanding the impacts of climate change on natural resources; 3) aiding or supplementing natural migration of communities using adaptive management; and 4) collaborating with other landowners and managers on Mauna Kea.

Objective 1: Detect impacts of climate change

Plants and animals often respond to unfavorable changes in environmental conditions by moving to habitats with more favorable conditions. This movement, also called climate tracking (Mace and Purvis 2007), can occur very gradually over an extended period of time, and so, without careful records of community composition and boundaries, it may not at first be apparent that anything is happening. Long-term monitoring of the elevational extent and composition of the native plant and animal communities on Mauna Kea will help determine whether the communities are responding to changes in climate. Long-term monitoring of plant and animal communities is discussed in Section 4.1 (Inventory, Monitoring and Research Component Plan), and is touched on above, in Section 4.2.2.

Objective 2: Understand the impacts of climate change on natural resources

In order to be able to achieve the goal of managing the natural resources to allow for adaptation to climate change, natural resource managers must understand the impact that climate change is having on the resources. Monitoring the response of physical resources and native plant and animal populations to climate change is one way to achieve this (see Objective 1 above). However, monitoring alone will not provide all the information needed to make informed management decisions. Natural resource managers must also determine why climate change is impacting the resources that they want to protect. The following items are research questions that may aid in determining the best response to a negative response by native plants and animals to climate change on Mauna Kea. Many of these can be answered by looking at the historical ranges of the species and the climate in which it lived prior to increased global warming. Other questions may have to be answered through research. See Section 4.1.2.3 for more information on developing a research program. Once these questions are answered, the NRC will be able to design a program to help improve the chances of the natural populations surviving climate change.

1. What is the preferred climate and habitat of the species?
    a. How much rainfall (or snowfall) does it require to survive and reproduce?
    b. Is it frost tolerant? Does it depend on a freeze-thaw cycle to reproduce?
    c. What is the historical temperature range that it occurred in?
    d. What soil types can it occur on?
    e. What sort of plant community did it occur in?
    f. Where on the mountain did the species occur (old habitat), and where are these desirable climatic conditions now found?
2. What other species does the species of interest rely on?
    a. For plants, do they need pollinators or seed dispersers, and if so, where are these species found? Are these species found in the new habitat the plant must move to in order to survive?
    b. For animals, what do they eat, and where is their food found? Are their food items found in the new habitat?
3. What factors are blocking the natural migration of the species?
    a. Is the species impacted by the presence of invasive species?
        i. Is their movement prevented by presence of invasive predators in the new habitat?
        ii. Are invasive plants preventing the movement of the species by occupying habitats with the species' preferred environmental conditions?
        iii. Have invasive species replaced the native species that the plant or animal depends on?
    b. Are there man-made factors blocking the migration (such as roads, buildings, agriculture or ranches)?
    c. Are the natural dispersal rates of the species too slow or does the species lack the ability to disperse? Many species in the Hawaiian Islands have evolved mechanisms to reduce dispersal distances, to avoid dispersing too far and ending up in the ocean or too far from their ideal conditions, which can change rapidly with steep terrain.
    d. Are their reproductive rates too slow? If individuals are killed by unfavorable climatic conditions such as a drought, before they are able to reproduce, the species may be lost before it is able to migrate to more appropriate environmental conditions. This is a real threat in species like the Mauna Kea silversword, which takes many years to reach reproductive maturity.
4. Are there genetic bottlenecks or other problems with the species (due to its rare or endangered status) that may cause difficulties in adapting to new environmental conditions?

Objective 3: Aid or supplement natural migration of communities using adaptive management

As discussed in Objective 2, invasive species and impassable barriers can prevent natural communities from migrating to more favorable conditions in response to climate change. Table 4.2-13 lists potential barriers to plant and animal migration on UH Management Areas, management activities that can help overcome these barriers, the priority of the management action, and its relative cost. Priorities are based on the assumption that climatic conditions are negatively impacting native species. If no negative impacts of climate change are detected, then the priority is Low for all of the activities until they are detected. The one exception to this is the control of invasive plants in nearby downslope habitats, because this will also help prevent movement of invasive species up slope in response to warming. This is presently considered a high priority activity. All management activities should be evaluated for effectiveness and modified if not achieving the desired effect (adaptive management).

Table 4.2-13. Management Actions to Minimize Barriers to Species Migration

Management Action[60]	Priority	Cost
Development (roads, buildings)		
Plants: Conduct outplanting and restoration projects on the other side of the development (down slope if species are moving to lower elevations, or up slope if species are moving to higher elevations).*	Depends[61]	Variable[62]
Animals: Translocate into new habitats.*	Depends	Variable
All: Plan future development to allow for corridors of natural habitat across elevational gradients.	High	Low
Invasive plants		
Control invasive plant species in lower-elevation habitats near and on UH Management Areas[63]	High	High
Conduct invasive species control projects in the new habitats, in conjunction with habitat restoration and/or outplanting projects[64]	High	High
Invasive animals (herbivores & predators)		
Remove (through trapping or hunting) or exclude (through fencing) invasive animals from the desirable habitat. This may have to be done in conjunction with control activities in the old habitat to allow for reproduction and migration.	High	High
Missing species[65]		
Conduct outplanting or translocation projects to provide missing species in the new habitat.*	Depends	Variable

[60] An asterisk (*) indicates that these actions should either be conducted by the appropriate authority (USFWS, DOFAW), or in close collaboration with them.

[61] "Depends" in the priority column indicates that this priority will depend on the status of the species of interest. The priority would be high for species that are likely to become extinct due to climate change impacts and low for those that appear to be adapting on their own to climate change.

[62] "Variable" in the costs column indicates that the cost will depend on the level of involvement in the project by OMKM.

[63] Control of invasive species in lower elevation habitats near (but not on) UH Management Areas would need to be conducted by the landowner or manager of the property on which they occur. OMKM should attempt to work with adjacent landowners to the extent possible, to aid with control projects.

[64] The invasive species control projects would be conducted in the area where the species of interest are likely to find the environmental conditions suitable to them ("new habitat").

[65] Missing species refers to the lack of a plant or animal species that the species of management interest relies on. For example, there may be a lack of pollinators or seed dispersers in either the old habitat (preventing movement out of it), or in the new habitat (reducing the species' ability to become established in the new habitat).

Management Action[60]	Priority	Cost
Low dispersal rates & distances		
Aid dispersal through seed collection and distribution to new habitat, or germinate seeds in a greenhouse and outplant seedlings to new habitat.*	Depends	Variable
Small population of native species		
Breeding programs and reintroduction projects.*	Depends	Variable

Objective 4: Collaborate with other landowners and land managers on Mauna Kea

Like invasive species, the climate does not recognize political affiliations or property boundaries. The impacts of changing weather patterns will be felt throughout Mauna Kea, the Hawaiian Islands, and the world. Because of the scale of the problem, it is imperative that OMKM work with other landowners and managers on the mountain to protect native plant and animal communities. A great deal of cooperation, collaboration, and planning will be required to respond to this problem. Depending on the magnitude and direction of the change, entire ecosystems may shift up or down the mountain. Community composition and the abundance of non-native species will also change (Mace and Purvis 2007). Some species will thrive as a result of the new environmental conditions, and others will perish. Landowners and natural resource managers will have to work together to detect changes in abiotic conditions and in plant and animal communities, understand the impacts these changes are having on native species, and plan conservation and restoration projects.

To make informed decisions, managers will need a landscape-level view of the impacts and outcome of climate change. In order to promote the level of collaboration needed to accomplish this, it is recommended that all stakeholders on the mountain form a committee to deal with landscape-level issues such as climate change, invasive species, and conservation of native biodiversity. At minimum, the committee should consist of members from OMKM, PTA, DLNR DOFAW and NARS, USDA Forest Service, Institute of Pacific Islands Forestry (IPIF), USGS, private landowners, Hawai'i Conservation Alliance, The Nature Conservancy, climate change experts and biologists from the University of Hawai'i, BIISC, Hawaiian Watershed Alliance, and Native Hawaiian groups. Ideally the committee would meet annually to discuss the current conditions on the mountain, and as needed to plan and carry out inter-agency management activities. The formation of an interagency work group is discussed in more detail in Section 5 (Implementation and Evaluation Plan).

4.3 Natural Resources Preservation, Enhancement and Restoration Component Plan

4.3.1 Introduction

The actions of preserving, enhancing, and restoring natural resources are part of a continuum of management activities intended to protect the sustainability of native plant and animal communities and their habitats. The level of intervention and kinds of management activities necessary to protect the natural resources determine whether preservation, enhancement, or restoration actions are needed. Preservation activities rely on monitoring and prevention as their foundation, while enhancement and restoration depend on active intervention, such as removing a source of disturbance or "enhancing" populations of native species. Management activities referred to as "enhancement" are similar to restoration activities, although they do not go to the extremes that restoration projects would go in order to restore the native communities. For example, native plant community enhancement activities could include planting of native vegetation around developed areas and in educational gardens, while restoration would include larger-scale planting of several native species, combined with fencing and control of invasive species within the fenced enclosure. In areas that are relatively intact, preservation is the main management goal. Areas that are disturbed or degraded will require enhancement or restoration.

In addition to preservation, enhancement, and restoration, there are several related management tools that can be used to repair or enhance habitat that has been disturbed or degraded by human activities. These include rehabilitation projects, which are conducted to repair basic functions of damaged ecosystems, and mitigation projects, which are generally done to compensate for environmental damage or habitat loss due to development. Although mitigation and rehabilitation are similar to ecological restoration, they are discussed separately in this plan because the complexity of mitigation and rehabilitation projects is often less than restoration projects, and the actions resulting in the need for the projects (and their legal ramifications) are often different.

Ecosystem[1] restoration is defined by the Society for Ecological Restoration as "the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed" (Society for Ecological Restoration International Science & Policy Working Group 2004). The goal of ecosystem restoration is to return an ecosystem to its historic condition, including species composition and diversity. The methods employed depend on the specific needs of the system to be restored and can range from removing or modifying a specific disturbance and allowing natural recovery, to deliberate reintroduction of native species that have been lost and the elimination of harmful invasive species (Society for Ecological Restoration International Science & Policy Working Group 2004). Complete recovery of an ecosystem to its historical state may not be possible, due to contemporary pressures or constraints, or lack of information regarding the historic condition of the site. Ecosystem restoration differs from ecosystem management in that restoration aims at assisting or initiating recovery, while management is intended to guarantee the continued well-being of the ecosystem (Society for Ecological Restoration International Science & Policy Working Group 2004).

Ecosystem restoration is conducted when a site has become so disturbed that it can no longer return to its historical condition on its own. A site can reach this state due to fire, physical disturbances such as excavation or construction, over-use, or the introduction of invasive species. Often it is a combination of several types of disturbances or the frequent re-occurrence of disturbances that prevent an ecosystem from recovering. The main goal of restoration should be to restore ecosystem integrity and health. Ecosystem

[1] An ecosystem consists of the plants, animals, and microorganisms within an area, the environment that sustains them, and their interactions. An ecosystem can range in size from a tiny site containing only a few species, such as an isolated wetland, to a huge area containing thousands of species, such as a tropical rainforest.

integrity is achieved when an ecosystem has the biodiversity characteristics of a reference ecosystem[2] such as species composition and community structure, and is fully capable of sustaining normal ecosystem functioning. Ecosystem health is the condition of an ecosystem in which its dynamic attributes are expressed within the range of activity normal for its stage of development (Society for Ecological Restoration International Science & Policy Working Group 2004).

In order to effectively preserve, enhance, or restore any native ecosystem, the land manager must first be aware of the historical conditions of the site. Knowledge of the historical ecosystem conditions, often referred to as the reference ecosystem, will enable the manager to measure the effectiveness of preservation, enhancement and restoration activities. A reference ecosystem is a model for planning a restoration project and allows for evaluation of success of the project when it is done (Society for Ecological Restoration International Science & Policy Working Group 2004). The reference ecosystem could be a nearby existing site or it could be derived from historical accounts and oral histories; there is a range of possibilities. Because the subalpine and alpine shrubland and grassland ecosystems below the summit area have been severely disturbed by feral ungulates and invasive plants, there are few existing sites that can serve as ideal reference ecosystems on Mauna Kea. There are also few detailed descriptions of native plant communities as they existed before the introduction of feral ungulates. The undeveloped areas of the summit (Mauna Kea alpine stone desert) have not faced the same level of disturbance as the lower alpine and subalpine regions and can serve as reference ecosystems for planning restoration projects in the developed areas of the summit. The reference ecosystems described below are simple summaries of the species recorded in the ecosystem, historically and recently, without reference to species densities or distributions within the ecosystem. Before conducting any enhancement or restoration projects, the Natural Resources Coordinator (NRC) should clarify project goals, if possible, by working with local experts to determine the plant densities and species composition that would best suit the purpose of the project. The reference ecosystem model developed will depend in part on the goal of the project. For example, restoration of Palila habitat will require a different reference ecosystem model than restoration of silversword habitat, even if both projects take place in the same location in the subalpine zone. It is beyond the scope of this plan to determine these details, in part because the nature and goals of the restoration projects to be undertaken are unknown at this time.

4.3.2 Reference Ecosystems

The following reference ecosystems can provide general guidance concerning species composition in the UH Management Areas. Detailed information on the abiotic conditions and physical resources found in these ecosystems is presented in Section 2.1. Section 2.2 contains detailed information on the plants and animals currently and historically found there.

4.3.2.1 Subalpine Māmane Woodlands

The subalpine ecosystem extends from approximately 5,600 ft to 9,800 ft (1,700 m to 3,000 m) elevation on Mauna Kea. Hale Pōhaku is located at the upper limit of the subalpine ecosystem, from approximately 9,100 ft to 9,800 ft (2,770 m to 3,000 m). The existing vegetation community at Hale Pōhaku is described in Section 2.2.1.1, but before any habitat restoration activities begin, it is recommended that the species list be updated through a baseline inventory of the plant and animal communities (see Section 4.1.4).

There are no detailed historical quantitative descriptions of the vegetation community at Hale Pōhaku, but a reference ecosystem can be inferred from the extant native species present in the woodlands at Hale

[2] See Section 4.3.2 for information on reference ecosystems.

Pōhaku and other high elevation māmane woodlands on Mauna Kea. A list of native plant species that commonly occur in māmane woodlands is presented in Table 4.3-1. This list should be used as a guide when choosing species for habitat mitigation, enhancement, rehabilitation, or restoration projects. The list should be updated to include new native species found during baseline inventory and monitoring activities.

Table 4.3-1 Vascular Plant Species Found in the Subalpine Māmane Woodlands

Scientific Name[3]	Common Name	Legal Status[4]
Ferns		
Asplenium adiantum-nigrum	**'Iwa 'iwa, Bird's nest fern**	**--**
Asplenium fragile var. *insulare*	Diamond spleenwort	FE, SE
Asplenium trichomanes	**'Olali'i, 'owali'i**	**--**
Cystopteris douglasii	Douglas' bladderfern	SSOC
Dryopteris wallichiana	Alpine woodfern	--
Pellaea ternifolia	**Kalamoho, lau-kahi**	**--**
Microlepia strigosa	Palai, palapalai	--
Grasses		
Agrostis avenacea	He'upueo, Pacific bentgrass	--
Agrostis sandwicensis	**Hawai'i bentgrass**	**--**
Deschampsia nubigena	**Alpine hairgrass**	**--**
Eragrostis sp.	Lovegrass	--
Sisyrinchium acre	Mau'u lā'ili, Hawai'i blue-eyed grass	--
Trisetum glomeratum	**Pili uka, he'upueo, mountain pili**	**--**
Herbs		
Fragraria chiloensis	'Ōhelo papa, Hawaiian strawberry	--
Hesperocnide sandwicensis	Hawai'i stinging nettle	--
Pseudognaphalium sandwicensium	**'Ena 'ena**	**--**
Ranunculus hawaiensis	Makou	FC, SC
Sanicula sandwicensis	Hawai'i black snakeroot	SSOC
Vicia menziesii	Hawaiian vetch	FE, SE
Vines		
Phyllostegia racemosa racemosa	Kiponapona	FE, SE
Stenogyne microphylla	**Littleleaf stenogyne**	**--**
Stenogyne rugosa	**Mā'ohi'ohi**	**--**
Shrubs		
Argyroxiphium sandwicense sandwicense	**'Āhinahina, Mauna Kea silversword**	**FE, SE**
Chenopodium oahuense	**'Āheahea, 'āweoweo,**	**--**
Coprosma ernodeoides	'Aiakanēnē, kūkaenēnē	--
Coprosma montana	**Alpine mirror plant**	**--**
Dodonaea viscosa	'A'ali'i	--
Dubautia arborea	**Mauna kea dubautia, na'ena'e**	**SSOC**
Dubautia ciliolata glutinosa	**Lava dubautia, na'ena'e**	**--**
Geranium cuneatum hololeucum	**Nohoanu, hinahina**	**--**
Leptechophylla tameiameiae	**Pūkiawe**	**--**
Osteomeles anthyllidifolia	'Ūlei	--
Rubus hawaiensis	'Ākala	--
Rumex giganteus	Pāwale	--
Silene hawaiiensis	Hawai'i catchfly	FT, ST

[3] Species in bold are either known to occur at Hale Pōhaku, or are important species for the community that may be a good choices for outplanting projects.

[4] Legal Status: FC = Federal Candidate for listing, FE = Federally Endangered, FT= Federally Threatened, SC = State Candidate for Listing, SE = State Endangered, SSOC = State Species of Concern, ST = State Threatened.

Scientific Name[3]	Common Name	Legal Status[4]
Silene struthioloides	**Alpine catchfly**	--
Tetramolopium humile humile	Alpine tetramolopium	--
Vaccinium reticulatum	**'Ōhelo, 'ōhelo 'ai**	--
Trees		
Chamaesyce olowaluana	'Akoko	SSOC
Metrosideros polymorpha	'Ōhi'a, 'ōhi'a lehua	--
Myoporum sandwicense	Naio	--
Santalum ellipticum	'Iliahialo'e, coast sandalwood	--
Santalum paniculatum	'Iliahi	--
Sophora chrysophylla	**Māmane**	--

The substrate on which the māmane woodland occurs on Mauna Kea is deep, light brown, dusty ash with occasional lava outcrops (Mueller-Dombois and Fosberg 1998). Māmane forests are thought to have always been fairly open. The understory community consists of drought-adapted herbaceous species and shrubs, most of which are concentrated beneath māmane trees, where they receive fog drip (Mueller-Dombois and Fosberg 1998). The densities of māmane trees, and other plants, were likely much higher prior to the introduction feral sheep and goats (Cuddihy and Stone 1990).

Important native invertebrates found in māmane woodlands include pollinators such as native bees (*Hylaeus* sp.) and a variety of native moths in the genera *Cydia*, *Peridroma*, and *Scotorythra* that feed upon the māmane seeds, and in turn are eaten by the Palila. Invertebrate communities are further discussed in Section 2.2.2.1. Native birds that utilize māmane woodlands include Palila (*Loxioides bailleui*), 'Amakihi (*Hemignathus virens*), 'Apapane (*Himatione sanguinea*), 'Elepaio (*Chasiempis sandwichensis sandwichensis*), 'Akiapola'au (*Hemignathus munroi*), 'I'iwi (*Vestiaria coccinea*), and occasionally 'Io (*Buteo solitarius*), Kolea (*Pluvialis fulva*) and Pueo (*Asio flammeus sandwichensis*) (Scott *et al.* 1986). The only native mammal that utilizes māmane woodlands is the 'Ope'ape'a, or Hawaiian hoary bat (*Lasiurus cinereus semotus*).

Large-scale restoration projects conducted in the subalpine zone on Mauna Kea should focus on creating viable habitat for the Palila, which is an Endangered species, and for native pollinators such as the *Hylaeus* bees, without which many plant species will not be able to reproduce.[5] Critical habitat for the Palila exists at Hale Pōhaku and throughout the māmane woodlands on Mauna Kea. Palila are most abundant in areas containing many large, mature māmane trees, with lots of seedpods (van Riper et al. 1978; Hess et al. 2001). Banko et al. (2005) found that sites with Palila reproduction had mature māmane trees (> 2 m tall and wide) in densities ranging from 29 to 47 trees per acre (71 to 116 trees per hectare). Because Palila prefer māmane woodland over mixed māmane-naio woodland (Banko et al. 2005), the planting of naio trees at Hale Pōhaku is not recommended.

4.3.2.2 Alpine Shrublands and Grasslands

Alpine shrublands are found from approximately 9,800 ft to 11,150 ft (3,000 m to 3,400 m), and are gradually replaced by alpine grasslands, from approximately 11,150 to 12,800 ft (3,400 to 3,900 m) (Mueller-Dombois and Fosberg 1998). Many of the species found in the alpine shrublands and alpine grasslands are also found in the subalpine plant communities. On UH Management Areas, alpine shrublands are found primarily along the Summit Access Road between Hale Pōhaku and the Mauna Kea

[5] Since the UH Management Area at Hale Pōhaku is only 19 acres, it is likely that any large-scale restoration project would be conducted in cooperation with DLNR DOFAW, USGS, USDA Forest Service, or USFWS (see Section 4.3.3.4).

Science Reserve (MKSR), whose lower border is at approximately 11,500 ft (3,505 m). Most of the MKSR is made up of alpine grasslands and alpine stone desert (see Section 4.3.2.3).

The alpine shrublands on Mauna Kea are dominated by pūkiawe (*Leptecophylla tameiameiae*), with scattered herbs, shrubs, and grasses. A list of native plant species that commonly occur in alpine shrublands and grasslands is presented in Table 4.3-2. The density and diversity of plant species found in the alpine shrublands decreases with altitude. At the upper elevations of its range, the alpine shrublands consist mainly of scattered pūkiawe shrubs and tufts of native grasses (Mueller-Dombois and Fosberg 1998).

Table 4.3-2. Vascular Plant Species Found in the Alpine Shrublands and Grasslands

Scientific Name	Common Name	Legal Status[6]
Ferns		
Asplenium adiantum-nigrum	'Iwa 'iwa, Bird's nest fern	--
Asplenium trichomanes	'Olali'i, 'owali'i	--
Cystopteris douglasii	Douglas' bladderfern	SSOC
Pellaea ternifolia	Kalamoho, lau-kahi	--
Grasses		
Agrostis sandwicensis	Hawai'i bentgrass	--
Trisetum glomeratum	Pili uka, he'upueo, mountain pili	--
Herbs		
Fragraria chiloensis	'Ōhelo papa, Hawaiian strawberry	--
Pseudognaphalium sandwicensium	'Ena 'ena	--
Shrubs		
Argyroxiphium sandwicense sandwicense	'Āhinahina, Mauna Kea silversword	FE, SE
Dubautia arborea	Mauna kea dubautia, na'ena'e	SSOC
Dubautia ciliolata glutinosa	Lava dubautia, na'ena'e	--
Geranium cuneatum hololeucum	Nohoanu, hinahina	--
Leptechophylla tameiameiae	Pūkiawe	--
Silene struthioloides	Alpine catchfly	--
Tetramolopium humile humile	Alpine tetramolopium	--
Vaccinium reticulatum	'Ōhelo, 'ōhelo 'ai	--

Above 11,150 ft (3,400 m), the alpine shrublands are replaced by alpine grasslands, which are predominantly made up of two native grasses, Hawaiian bentgrass (*Agrostis sandwicensis*) and pili uka (*Trisetum glomeratum*), although scattered ferns, pūkiawe, and other shrubs can occasionally be found (Mueller-Dombois and Fosberg 1998).

The endangered Mauna Kea silversword, or 'āhinahina (*Argyroxiphium sandwicense sandwicense*) historically occurred from 8,500 ft to 12,300 ft (2,700 m to 3,750 m) (Wagner *et al.* 1990; Robichaux *et al.* 2000). Small populations of this plant are still found on Mauna Kea. Restoration efforts conducted in the alpine region should focus on increasing the density and abundance of silversword on the mountain.[7] Other genera that should be included in restoration projects include native shrubs such as *Dubautia, Vaccinium, Geranium,* and *Leptechophylla.*

[6] Legal Status: FC = Federal Candidate for listing, FE = Federally Endangered, FT= Federally Threatened, SC = State Candidate for Listing, SE = State Endangered, SSOC = State Species of Concern, ST = State Threatened.

[7] Because it is an endangered species, any restoration work involving the Mauna Kea silversword should be conducted in coordination with DLNR and USFWS.

Very little is known about the invertebrate community in the alpine region below the summit (i.e., alpine shrublands and grasslands), and before any effort to restore native invertebrate communities can begin, more information is needed. At a minimum, the presence of native pollinators must be determined, because the reproduction of self-incompatible plants such as the Mauna Kea silversword depends on them. There are no known native vertebrates that regularly utilize the alpine shrublands and grasslands along the Summit Access Road and in the MKSR. More information is needed regarding whether the ʻUaʻu (Hawaiian Petrel, *Pterodroma sandwichensis*)[8] nests in the lower alpine region of Mauna Kea. Because the petrel nests in the upper elevation areas but does not feed there, restoration of vegetation there will have little effect on their presence or absence. The only exception would be if vegetation were established in burrow areas, as this may block access to the burrows.

4.3.2.3 Alpine Stone Desert

The alpine stone desert is found from approximately 12,800 ft to 13,796 ft (3,900 m to 4,205 m), the region referred to as the "summit." The vegetation community in the alpine stone desert consists of several species of mosses and lichens, an unknown number of species of algae, and a small number of vascular plants, predominantly the same species found in the alpine shrublands and grasslands (Hartt and Neal 1940; Char 1999). The most abundant native vascular plant species found in these elevations are two grass species, Hawaiian bentgrass (*Agrostis sandwicensis*) and pili uka (*Trisetum glomeratum*), and two fern species, ʻiwaʻiwa (*Asplenium adiantum-nigrum*) and Douglas' bladderfern (*Cystopteris douglasii*). Of these four species, Hawaiian bentgrass is the most common.

Over 21 species of lichen and approximately 12 species of moss have been identified in the alpine stone desert (Smith et al. 1982). Around half of the lichen species and most of the moss species found on Mauna Kea are endemic. One species of lichen, *Umbilicaria pacifica,* is found only on Mauna Kea (Smith et al. 1982; Char 1999). Another lichen species, *Pseudephebe pubescens,* is primarily found in high altitude and alpine regions of the world, and within the Hawaiian Islands is found only on Mauna Kea (Smith *et al.* 1982). *Lecanora muralis* is the most abundant lichen on Mauna Kea, and is found throughout the summit, on all substrate types, including cinders and colluvial material on the cinder cones up to the summit of Puʻu Wēkiu (Smith *et al.* 1982). Other common lichen species on the summit are *Lecidea skottsbergii* and *Candelariella vitellina.* The most common species of moss in the alpine stone desert are *Pohlia cruda* and an undescribed species of *Grimmia* (Smith *et al.* 1982). Two moss species, *Bryum hawaiicum* and *Pohlia mauiensis* are endemic to Hawaiʻi (Smith *et al.* 1982). A more detailed description of the plant community in the alpine stone desert can be found in Section 2.2.1.2.3, and lists of lichen and moss species found there are presented in Tables 2.2-4 and 2.2-5.

The arthropod community at the summit of Mauna Kea is unusual in that most of the resident species feed on insects and other materials blown up from lower elevations on the mountain. Native resident species include the wēkiu bug (*Nysius wekiuicola*), a noctuid moth (*Agrotis* sp.), a hide beetle (*Dermestes maculatus*), a large wolf spider (*Lycosa* sp.), two sheet-web spiders (*Erigone* spp.), an unidentified linyphiid sheet-web spider (Family Linyphiidae), two unknown entomobryid springtails (Family Entomobryidae), a Collembola springtail (Class Collembola, family and species unknown), two species of mites (Families Anystidae and Eupodidae), a bark louse (*Palistreptus inconstans*) and a centipede (*Lithobius* sp.) (Howarth and Stone 1982).

[8] Although it is listed as the Dark-rumped Petrel (*Pterodroma phaeopygia sandwichensis*) under the Endangered Species Act, this species has recently undergone a name change and is referred to as the Hawaiian Petrel (*Pterodroma sandwichensis*) in recent literature.

There is little information regarding the habits of most of the summit species, but the wēkiu bug (*Nysius wekiuicola*) is the best-studied invertebrate at the summit. Wēkiu bugs live mainly on or near the crater rims of cinder cones that formed nunataks[9] or that lay at the glacier limit during the last glaciation. The bug is most abundant on the north-facing and east-facing slopes (and on slopes shaded by local topography), where seasonal snow remains the longest (Porter and Englund 2006). Crests of glacially overridden cones and inter-cone expanses of glacial till appear to lack suitable wēkiu bug habitat (Porter and Englund 2006). The bugs utilize stable accumulations of loose cinders and tephra rocks, where the interstitial spaces are large enough to allow them to migrate downward, to moisture and shelter (Howarth and Stone 1982). See Section 2.2.2.2.1 for more information on the wēkiu bug.

The focus of most restoration projects on the summit will be to restore wēkiu bug habitat disturbed through various human activities, including construction and decommissioning of astronomy facilities. In 2000, Pacific Analytics created a wēkiu bug mitigation plan for the Keck Outrigger Telescope Project (Pacific Analytics 2000). This plan provides information on protection and restoration of wēkiu bug habitat that could be used for other projects at the summit. Management recommendations from this plan are incorporated into Section 4.3.3.4.1.

4.3.3 OMKM Natural Resources Preservation, Enhancement, and Restoration Program

The purpose of this component plan is to provide information and suggest management actions that will enable OMKM to meet the goals of preserving, enhancing, and restoring native plant and animal communities on the UH Management Areas. The OMKM Natural Resources Preservation, Enhancement, and Restoration Program will be the organizing force behind these goals. It is recommended that this program be developed after the baseline inventory has been conducted and monitoring efforts have begun, as described in Section 4.1. The baseline inventory and follow up monitoring will provide a better understanding of the condition of native plant and animal communities of the high elevation areas of Mauna Kea. It is likely that the importance of some of the management actions and goals presented in this section will change in light of the new data from inventory and monitoring. The inventory and monitoring activities may also identify new management needs and actions, which should be integrated into this plan during regular updates (see Section 5).

The specific goals addressed by this preservation, enhancement and restoration component plan are summarized below. Management objectives and actions for reaching these goals are discussed under the subsection for each goal. Where a variety of potential actions is identified, the actions are included in table format, indicating the action, priority, and an estimated relative cost. Priorities are ranked as high, medium, or low, and are based on current understanding of the state of the natural resources on Mauna Kea. A high rank indicates that this action would afford the highest level of resource protection, and/or is perceived as being an important management action given the current understanding of natural resources on UH Management Areas. Ranks are intended to aid in prioritizing management actions, as it is recognized that time and budget constraints will most likely not allow all actions to be completed. These management actions are intended to be recommendations only. If a recommendation is implemented and it results in an action that would require ground disturbance or alteration of the existing environment, a separate environmental analysis will be conducted in compliance with existing State law.

[9] Nunataks are areas that remained ice-free by being above the surrounding glacier during the previous glaciation period.

Program Goals		Section
Goal PER-1	Preserve sensitive habitats and unique high-elevation ecosystems	4.3.3.1
Goal PER-2	Enhance existing native communities and unique habitats	4.3.3.2
Goal PER-3	Mitigate or repair damage to sensitive ecosystems	4.3.3.3
Goal PER-4	Restore damaged ecosystems	4.3.3.4

It should be noted that any project that involves or may impact a Federal or State listed Threatened or Endangered species should be done with the approval of, and preferably with assistance from, the appropriate authority, such as the U.S. Fish and Wildlife Service (USFWS), or Hawai'i Department of Land and Natural Resources (DLNR). Additionally, a provision in the University of Hawai'i's lease requires that any project that involves the planting of vegetation get approval from the Board of Land and Natural Resources (BLNR) prior to implementation.

4.3.3.1 Preservation

Preservation of the unique high-elevation ecosystems on Mauna Kea requires minimizing threats and monitoring the natural resources to ensure that ecosystem health and integrity are maintained. Preservation activities range from non-intensive management actions, such as setting aside sensitive areas to protect them from future development, to actively managing ecosystems to prevent and control threats.

Goal PER-1: Preserve sensitive habitats and unique high-elevation ecosystems

The goal of preserving sensitive habitats and unique high elevation ecosystems on UH Management Areas can be met through the following objectives: 1) minimizing threats to sensitive ecosystems, 2) protecting sensitive ecosystems from further development, and 3) actively monitoring natural communities and ecosystems for changes.

Objective 1: Minimize threats to sensitive ecosystems

Minimizing the impacts of threats to sensitive ecosystems on Mauna Kea requires both preventative measures and rapid responses to detected threats. Management actions to aid in the prevention and control of damage to natural resources from specific threats are presented in detail in Section 4.2. Table 4.3-3 presents some general or property-wide management actions that can help minimize the impacts of threats to Mauna Kea high-elevation natural resources.

Table 4.3-3. Management Actions to Preserve Sensitive Habitats

Action	Location	Priority	Cost
Fence areas of high native biodiversity or populations of endangered plant species.	Hale Pōhaku, lower MKSR	High	Variable[10]
Control threats (see Section 4.2).	All	High	Variable
Limit access by hikers and vehicles to sensitive habitats.[11]	All	High	Low to Medium
Educate stakeholders and the public about Mauna Kea's unique natural resources (see Section 4.4).	All	High	Medium

Objective 2: Protect sensitive ecosystems from further development

One of the most efficient ways of preserving a sensitive ecosystem is to limit future development in the area. This objective has been met, to a large extent, by the establishment of the 525-acre Astronomy Precinct at the summit (Group 70 International 2000). Development is allowed only within the Astronomy Precinct and at Hale Pōhaku (19 acres). The remaining 10,763 acres of the MKSR is set aside for the preservation of natural and cultural resources.

An additional measure of protection of sensitive habitats within the Astronomy Precinct can be achieved by prohibiting development of any currently undeveloped pu'u at the summit (see Section 4.2.3.1, Habitat Alteration). However, there may be additional unique biological communities and physical resources within the Astronomy Precinct that are not protected from development by this prohibition. Efforts should be made to delineate and protect areas of high native diversity or unique communities.[12] This can only be accomplished once the baseline inventory is completed.[13] Following the baseline inventory, spatial analysis of distributions of rare and unique communities or physical resources in the Astronomy Precinct and Hale Pōhaku will allow a determination of areas that may deserve protection from development.

[10] The cost for fences depends on the size of the area fenced. The cost to OMKM for fencing large areas will be high unless another entity, such as DLNR, does the fencing. Fencing projects can range in size from small enclosures to protect individual silversword plants, to large enclosures that protect representative ecosystems. The purpose of fencing is not to limit access by people, but rather, to keep out invasive feral ungulates. For more information on feral ungulates, see Section 2.2. Ideally, DLNR DOFAW will obtain funds to complete and maintain the fence around base of the Mauna Kea Forest Reserve. Once the fence is completed, and feral ungulates are removed from the mountain, there will be no need for individual fencing projects. Although the removal of ungulates from Mauna Kea was ordered by the Federal District Court in 1979 (Mull 1979), DLNR has not yet obtained sufficient funds to complete the fence, and it is likely it will not receive these funds in the near future. DLNR does conduct annual ungulate control efforts on the mountain, but these are not enough to protect the native plant communities, because a small number of animals can cause a great deal of damage. Fencing should be placed wherever unprotected populations of Mauna Kea silversword are detected. In addition, fencing should be considered for areas of high diversity of native species that are identified during baseline inventory and monitoring (see Section 4.1). Fences must be inspected regularly and any damage repaired in a timely manner.

[11] Limiting access to sensitive habitats is an effective means of reducing impacts to these habitats. However, it is recommended that the baseline inventory be completed before determining which areas to limit access to. Limiting access can be achieved through removal or relocation of existing trails, educational information and signage, and ranger patrols.

[12] An effort to do this was conducted as part of the Mauna Kea Science Reserve Master Plan in 2000 (see Section 4.5.1.2), but sufficient detail is lacking on community composition and species abundances to enable decision making on the fine scale.

[13] See Section 4.1 for information on developing the baseline inventory.

Objective 3: Monitor natural communities and ecosystems for undesirable changes

Monitoring to detect changes in natural communities and ecosystem functioning is an important component of any conservation or preservation program. This objective is described in detail in Sections 4.1, 4.2.2 and 4.2.3.7.

4.3.3.2 Enhancement

For the purposes of this component plan, enhancement refers to projects, programs, or management activities that contribute to the conservation of natural resources through such means as landscaping, establishing native gardens, and outplanting native species in sensitive habitats or in unique natural areas, to increase plant density and species diversity. In a broad sense, enhancement is a form of restoration; however, the two are distinguished because restoration generally takes the process to greater lengths, is more costly, and involves a greater degree of management intervention.

Goal PER-2: Enhance existing native communities and unique habitats

The goal of enhancing existing native communities and unique habitats on UH Management Areas can be reached through the objective of increasing native plant density and diversity in sensitive or unique habitats.

All native planting projects should use plants that have been propagated from local seed stock or cuttings. Plants may be grown either on site or at a nursery willing to ensure that the stock is not contaminated with weedy species. Plants grown in the local environment to which they will be outplanted are more likely to survive than those that are grown under different conditions. Per UH's lease terms, all species to be used in planting projects must first be approved by the Board of Land and Natural Resources.

Objective 1: Increase native plant density and diversity in sensitive or unique habitats

Management activities to increase native plant density and diversity are presented in Table 4.3-4.

Table 4.3-4. Management Actions to Enhance Native Communities

Action	Location	Priority	Cost
Create educational native gardens	Hale Pōhaku, lower MKSR	High	Low to Medium
Use native plants in landscaping	Hale Pōhaku, Access Road	Medium	Low to Medium
Outplant native species as part of habitat restoration and rehabilitation efforts	All	Medium	Low to Medium

Educational native gardens serve the dual purpose of 1) educating the public through living examples of the unique and rare plant species found in high-elevation areas on Mauna Kea and 2) bolstering native plant populations in the area. By necessity, a native garden must be fenced, to keep out feral ungulates and other pests that may harm the plants. Creating a new fenced garden area at Hale Pōhaku would be somewhat costly, mainly due to the cost of fencing materials and installation; however, an excellent opportunity for a native garden already exists in the DLNR silversword exclosure found near the Visitor Information Station (VIS). This area already contains native species of interest, such as the Mauna Kea silversword, but it also contains weedy non-native species. An agreement could be made with DLNR to improve the exclosure through a volunteer-based weeding and watering program. Volunteers could be OMKM employees, VIS staff and volunteers, or even school groups and university students. The native plant community found within the exclosure could be enhanced by planting species not yet present and by planting more silverswords, to increase their density. DLNR Division of Forestry and Wildlife (DOFAW) resource managers have expressed an interest in seeing improvements to the DLNR exclosure, providing that OMKM coordinate watering and monitoring of the site (Bergfeld 2008).

Another method of increasing native plant diversity and density on UH Management Areas is through the use of native plant species in landscaping projects. Currently, the VIS and dormitories at Hale Pōhaku are surrounded by weedy invasive plant species. Removal of these invasive species, followed by planting of selected native species, would greatly enhance the plant communities as well as the aesthetics of the developed areas. This could be done by volunteer groups, led by the NRC, or by MKSS. Although these plantings would not be fenced, the proximity of the plants to buildings may discourage feral sheep from feeding on them.[14]

In addition to using native plants in landscaping around buildings at Hale Pōhaku, native plants could be planted along the Summit Access Road. There are already native species found along the road, mixed in with invasive weedy species. Plantings can occur in areas of interest, such as near pullouts; sites where invasives species control has occurred; or in areas where rehabilitation activities occur, such as where roadsides are repaired following accidents or at the sites of erosion control efforts.

Outplanting native species can greatly enhance plant densities and species diversity. This can be done as part of a full-scale habitat restoration effort (see Section 4.3.3.4) or alone, as an effort to enhance the existing plant communities. Outplanting native species without further restoration efforts will be most beneficial in areas that are not heavily invaded by non-native species. Planting native species is also recommended in areas where habitat rehabilitation occurs (see Section 4.3.3.3). Native species that can be used in outplanting projects are discussed in Section 4.3.2.

4.3.3.3 Mitigation and Rehabilitation

Mitigation is the planned creation of new habitat, or the restoration of existing habitat, to replace habitat that is destined to be destroyed or disturbed by development. Rehabilitation, for the purposes of this plan, is the repair of habitat following an unplanned disturbance, such as a vehicle accident, hazardous materials spill, or erosion event. Rehabilitation emphasizes the repair of ecosystem processes, productivity, and services.[15] Rehabilitation differs from restoration in that restoration also includes the goals of re-establishing the pre-existing structure of the biotic community and species composition. Mitigation differs from rehabilitation in that it is a planned effort that is incorporated into the design of a particular project.

[14] Survival of plants, and signs of herbivory, should be carefully monitored in small test plots prior to larger-scale landscaping to determine if feral ungulates will damage plants.

[15] Ecosystem services are the processes by which the environment produces resources that we rely on as clean water, timber, habitat for fisheries, and pollination of native and agricultural plants. For more information, see the Ecological Society of America website, http://www.esa.org/ecoservices/comm/body.comm.fact.ecos.html.

Goal PER-3: Mitigate or repair damage to sensitive ecosystems

The goal of mitigating and repairing damage to sensitive ecosystems can be met through the following objectives: 1) incorporating mitigation plans into project planning, 2) conducting mitigation projects before, during, or after completion of a new development project (as appropriate), and 3) conducting habitat rehabilitation projects following unplanned disturbances.

Objective 1: Incorporate mitigation plans into the project planning process

All future developments in the Astronomy Precinct and at Hale Pōhaku should include mitigation plans to prevent or repair damage to sensitive habitats caused by construction and development activities. It is recommended that any habitat that will be permanently removed be replaced on at least a one-to-one basis, through either creation of new habitat, restoration of degraded existing habitat, or by permanent protection of similar unique habitats.[16] It is further recommended that mitigation plans be paid for and prepared by the project proposer, but should be reviewed and approved by OMKM.[17] If the disturbed habitat contains protected species or other critical habitats, mitigation plans may also need approval from state and federal agencies.

Objective 2: Conduct mitigation projects

Mitigation projects should be completed if habitat will be disturbed, damaged or destroyed during construction activities. Table 4.3-5 provides examples of mitigation projects that may occur on UH Management Areas. An example of habitat mitigation for disturbance of wēkiu bug habitat at the summit is provided in the Environmental Assessment for the Outrigger Telescopes Project (Pacific Analytics 2001a). Although the project was cancelled, the mitigation program included as part of project planning may prove to be useful for other projects.

Mitigation activities can be carried out prior to beginning a project (to prevent damage), during the project, or when site-altering activities stop, depending on the nature of the mitigation activity. A contractor approved by OMKM and paid for by the developer should carry out mitigation projects. The approved contractor must have a biologist on staff (or could provide funds for OMKM to hire one) to ensure that mitigation projects for biological and physical resources are completed correctly. Mitigation projects must follow their plans as approved by OMKM. Any changes to plans must be approved by OMKM. The NRC should inspect all mitigation projects, to ensure that they have met the project goals.

Not all types of habitat disturbance or habitat loss are easy to mitigate. In certain cases, funds designated for mitigation projects may be better applied to habitat management or restoration projects on other portions of the UH Management Areas, particularly if the mitigation project will be difficult to conduct without increasing habitat disturbance or if it is likely to have little positive effect on the disturbed ecosystem. In these cases, OMKM and the developer should come to an agreement on how the mitigation funds will be used. The developer would then provide OMKM with the funds to conduct the mitigation or

[16] Mitigation projects that result from a planned impact to critical habitat or threatened or endangered species will have different requirements, which will be determined by the USFWS. The ratio of disturbed to restored land in mitigation projects required by the USFWS depends on a number of factors, including the quality of the habitat destroyed, the type of habitat destroyed, and the quality of the restored habitat.

[17] Review and approval to be conducted by the NRC, the Mauna Kea Management Board (MKMB), the MKMB Environmental Committee, and Kahu Kū Mauna.

restoration project and would no longer be responsible for mitigating habitat damage or loss at the site of the disturbance.[18]

Mitigation projects should include a minimum of two to five years follow-up monitoring to assess the results. The length of time that monitoring must occur will depend on the scale of the project and the organisms for whom the habitat is being mitigated. For example, two years may be sufficient to determine if native plants are surviving in the mitigation area, while organisms that can only be monitored during certain times of year, or that recover slowly from disturbance, such as the wēkiu bug, will require longer monitoring periods. Monitoring efforts can be conducted by a qualified biologist hired by the developer and approved by OMKM, or by the NRC and field staff, with funds provided by the developer.

Table 4.3-5. Management Actions to Mitigate Habitat Loss

Action	Location	Priority	Cost[19]
Wēkiu bug mitigation: create new habitat.	Summit	High	Low
Māmane woodland mitigation: restore or enhance existing māmane woodlands.	Hale Pōhaku	High	Low

Objective 3: Conduct rehabilitation projects following unplanned habitat disturbance

Rehabilitation activities should be conducted when unintentional damage occurs. The purpose of a rehabilitation project is to minimize the damage and return the area to a minimum functioning state. If desired, habitat can be restored rather than rehabilitated (see Section 4.3.3.4). Table 4.3-6 provides examples of rehabilitation projects that may occur on UH Management Areas.

Unintentional damage often occurs from on-going activities. For example, cinder compaction and soil erosion can result from over use of existing dirt roads and trails, from the creation of shortcuts associated with existing roads and trails, and from the creation of new trails. Stormwater runoff from impervious ground surfaces and infrastructure such as buildings and roads can also cause erosion, particularly at Hale Pōhaku. Besides detracting from the scenic viewshed, erosion and cinder compaction can adversely impact natural resources through dust depostition, soil loss, and habitat alteration. Activities to help prevent or reduce soil erosion and cinder compaction are discussed in Section 4.2.3.

Because of the local climate and sparsity of vegetation, erosion repair options are limited and will require mechanical solutions and time. Rehabilitation activities for eroded or compacted areas include reducing access, reducing visual indications of impact, controlling stormwater runoff when necessary, and protecting the ground surface from the effects of wind, water and traffic (foot, animal, vehicular). Stabilization methods include outplanting (in the subalpine ecosystem) and applying erosion control blanketing. These methods will reduce soil detachment and movement and provide a somewhat natural look to the area.

Rehabilitation activities for compacted cinder include placement of additional cinder on top of impacted area, or removal, sifting, and replacement of compacted cinder. For light cinder compaction associated with newly established trails, compaction is reduced by raking cinder to "erase" the trail. More severely

[18] Developer would still be responsible for mitigating for any additional, unplanned, habitat disturbance that occurs during development activities.

[19] The cost to OMKM of conducting these projects will be low because most of the cost will be borne by the entity or project that is causing the habitat loss. The total cost for the projects will depend largely on the scale of the project.

etched trails may require physical barriers and signage to inform visitors of a restoration site while initiating raking, cinder replacement, or erosion control measures (as needed).

Table 4.3-6. Management Actions to Rehabilitate Damaged Habitats

Action	Location	Priority	Cost
Conduct cleanup of contaminant spills.[20]	All	High	Variable[21]
Conduct roadside repair projects (following vehicle accident).	Access Road	Medium	Variable
Conduct erosion control projects.	All	Medium	Medium to High

4.3.3.4 Restoration[22]

Restoration is a more comprehensive action than rehabilitation (see Section 4.3.3.3), because it seeks to restore the site to a historical condition, including physical habitat attributes as well as community composition and native species abundance. Restoration can occur on a variety of scales, from a small, localized effort, to a project encompassing the entire mountaintop. In most cases, funding and time are the limiting factors preventing large-scale restoration. This section focuses on smaller-scale restoration projects, and on restoration following decommissioning and removal of telescopes and provides general information and recommendations for restoring ecosystems on UH Management Areas.

It is a requirement in all subleases that cinder habitat on summit puʻu be restored following the removal of telescopes and that this will be funded by the entity that controls the telescope. Section 4.3.3.4.1 presents more detailed recommendations and information regarding restoration of cinder habitat on summit puʻu following telescope removal.

One restoration activity that would benefit all of Mauna Kea is the removal of all feral ungulates from the mountain from the Mauna Kea Forest Reserve to the summit. Restoration of damaged native ecosystems will be easier following this achievement, as it will eliminate a major source of disturbance. However, this goal depends entirely on the State providing DLNR with sufficient funds to complete the forest reserve fence and follow-up aerial hunting. Until then, all restoration projects on Mauna Kea must include feral ungulate exclusion, through fencing.

Goal PER-4: Restore damaged ecosystems

The goal of restoring damaged ecosystems can be achieved through the following objectives: 1) creating restoration plans, 2) conducting restoration activities, and 3) monitoring and maintaining restoration projects.

[20] Contaminant-spill clean-up activities often require removal of substrate materials. Habitat rehabilitation activities following clean-up of a spill at the summit would include replacement of the removed substrate with screened cinder materials larger than ½ inch (1.3 cm) in diameter (Pacific Analytics 2001a). Spill clean-up activities at Hale Pōhaku should include replacement with suitable soil material or fill (if the spill occurred in a parking area). Spill areas should be planted with approved native vegetation following soil replacement, if appropriate

[21] Cost to OMKM will be low if the spill was caused by an observatory. Cost of clean-up may be high if the spill was caused by MKSS or OMKM personnel.

[22] An introduction to the concepts behind and purposes of conducting ecological restoration is presented in Section 4.3.1.

Objective 1: Create restoration plan

Restoration takes time, money, and above all, careful planning. Prior to conducting restoration on any scale, the NRC must first complete a restoration project plan and, if necessary, obtain funding to implement the plan.[23] It is often the case that resource managers must make decisions about restoration projects with insufficient information. Generally they must make do with a combination of the best available scientific information, common sense, and past experience. Sometimes the decisions made will be correct, and at other times they will not (White and Hashisaki 1996). Because of this, it is important for all restoration projects to contain an element of adaptive management that will allow for "course corrections" if the restoration process does not proceed as planned.

Important things to be considered when determining if a restoration project should be conducted include:[24]

1. Is the area restorable? Will native plants and/or animals return to and survive in the restored area?
2. Will the restoration project cause additional site disturbance or increase the area of habitat impacted?
    a. Some restoration projects will require replacement of cinder or other disturbed substrates. Where will these cinder materials come from? Will obtaining and moving the cinder damage more habitat than it repairs?
3. Will the site recover on its own, given time? In some cases, removal of the source of disturbance is the only management action needed to allow ecosystem recovery.
4. Will the restored ecosystem need continuous maintenance to function? For example, a restoration project adjacent to a large patch of invasive plants will most likely require continual weeding to prevent invasion by the invasive species. Weed control buffers or other preventative maintenance activities may be needed in perpetuity.
5. Would the money needed for the restoration project be better spent elsewhere (e.g., on protecting an area of high diversity)?

Important ecological information needed when planning a restoration project include:

1. What are the keystone species in the ecosystem? (See Sections 2.2 and 4.3.2 for discussion of native species found in the subalpine and alpine regions on Mauna Kea).
    a. Are they currently present?
    b. Are they abundant enough to fill their functional role in the ecosystem?
    c. What is blocking their recovery (e.g., invasive species, herbivory, disease, soil disturbance, drought, lack of propagules)?
2. What are the relationships between key species found in the ecosystem?
    a. Are there species that rely on each other's presence for survival or reproduction? If one or more of these species is missing, plans must be made to either reintroduce the species or replace the service provided by the missing species.

[23] Baseline inventories must be completed prior to any restoration planning activities (see Section 4.1).

[24] In addition, cultural sensitivities should be considered with input from Kahu Kū Mauna.

i. Mycorrhizal fungi: if soil has been barren or disturbed for a long time, soil fungal species that form symbiotic associations with the roots of plants may be absent (Habte 2000; Smith et al. 2008). Inoculation of greenhouse-grown plants with mycorrhizal fungi may be necessary to support growth in the restoration site.

ii. Food or prey items: is the food base sufficient to support viable populations of the key species?

iii. Seed dispersers: seeds of some plants such as pūkiawe will not germinate without first passing through the gut of a bird. Other seeds will not germinate beneath their parent plant, and must be dispersed away from the plant.

iv. Pollinators: many of the subalpine and lower alpine plant species, such as the Mauna Kea silversword, are self-incompatible and must be cross-pollinated with other individuals to produce viable seeds. If pollinators are missing from the system, hand-pollination by the biologist will be necessary.

3. What are the spacing needs of individuals (or territory size for animals)?
4. What are the habitat requirements of, and environmental conditions (rainfall, soil type, temperature ranges) favored by the key species?
5. What stressors are normally present in the ecosystem? Stressors are disturbances or perturbations that naturally occur in the ecosystem and serve to maintain ecosystem integrity by preventing the establishment of other species not adapted to those stress conditions (Society for Ecological Restoration International Science & Policy Working Group 2004). If the stressors needed to maintain the ecosystem are no longer present, or recur at different frequencies than normal, the ecosystem may shift to one supported by the current stressors, and it may be difficult to restore the site to the reference ecosystem.
6. Are there sources of major disturbance (beyond the normal range or frequency of stressors that help maintain the ecosystem) that are degrading the ecosystem? If so, what can be done to reduce the frequency or severity of these disturbances?
   a. Invasive species: Fencing and weed control will most likely be necessary for subalpine and lower alpine restoration projects.
   b. Frequent fires: If fire frequency increases on the mountain, fire control efforts may prove necessary, as the subalpine ecosystem is not fire adapted.
   c. Repeated disturbance by human activities: Do off-road vehicles or other impacts repeatedly disturb habitats and/or substrates?

Once these questions have been addressed, the NRC will be ready to create the restoration plan. The Society for Ecological Restoration recommends that restoration plans include the following (Society for Ecological Restoration International Science & Policy Working Group 2004):

1. A clear rationale for the restoration
2. A description of the current ecological condition of the site designated for restoration
3. A statement of the goals and objectives of the restoration project
4. A designation and description of the reference ecosystem (see Section 4.3.2)
5. An explanation of how the proposed restoration will integrate with the landscape

6. Explicit plans, schedules, and budgets for site preparation, installation, and post-installation activities, including a strategy for making prompt mid-course corrections
7. Well-developed and explicitly stated performance standards, with monitoring protocols by which the project can be evaluated
8. Strategies for long-term protection and maintenance of the restored ecosystem
9. Designation, when feasible, of at least one untreated control plot for the project, for purposes of comparison with the restored ecosystem

Scheduling is an especially important part of restoration planning. Adequate lead time must be given before the project can be implemented, as some processes take a long time and others can be implemented only during narrow windows of opportunity (Newton and Claassen 2003). For example, timing of planting may be a consideration in projects that involve propagating and planting native species. Unless watering will be part of the restoration methods, planting should be done immediately prior to or during the peak rainfall season in dry areas such as the subalpine zone. Plants must be of sufficient size to survive, and lead-time is needed to collect seeds or cuttings and to grow the seedlings or root the cuttings. Permitting is a process that also takes time, and any project that requires permits, such as projects that involve earthmoving, must take this into account. The best advice is to contact the appropriate county, state, and federal agencies early in the planning process, to allow them sufficient time to respond to permit applications (Newton and Claassen 2003).

Because restoration projects can be expensive and time consuming, and require a lot of field work, it is recommended that any large-scale projects be coordinated with state and federal agencies such as DLNR DOFAW, USGS, USDA Forest Service, Institute of Pacific Islands Forestry, and USFWS. Many of these agencies have existing restoration programs or projects that might be expanded to include UH Management Areas, provide assistance or funding, or provide guidance and techniques for restoration planning. Any restoration projects involving protected species or critical habitat should involve the appropriate state and federal agencies. Additionally, OMKM may wish to collaborate with university researchers, local experts and concerned citizens (e.g., Silversword Alliance, Big Island Invasive Species Committee (BIISC), Nature Conservancy, or the Sierra Club), as sources of expertise, funding, or volunteers. Restoration projects, whenever possible, should involve the public and schools, through volunteer opportunities and organized field trips.

Objective 2: Conduct habitat restoration

Once the restoration project plan has been written, approved by OMKM and appropriate state and federal agencies, and funded, then restoration can begin. Table 4.3-7 provides a list of potential restoration projects for sensitive habitats on OMKM, as well as priorities and relative costs. Whenever possible, restoration should be conducted as part of a scientific research project, with treatment and control plots to enable assessment of success.

Table 4.3-7. Management Actions to Restore Sensitive Habitats

Action	Location	Priority	Cost
Restore wēkiu bug habitat in disturbed areas (e.g., trails, near existing observatory facilities).	Summit	Medium	Variable[25]
Restore habitat following observatory decommissioning.	Summit	High	Low[26]
Conduct roadside restoration projects.	Access Road	Medium	Variable
Conduct silversword restoration projects.	Hale Pōhaku and lower MKSR	High	Medium[27]
Conduct māmane woodland restoration through fencing, invasive species control, and out-planting.[28]	Hale Pōhaku	High	High

Objective 3: Monitor and maintain habitat restoration projects

Too often, restoration projects are conducted without real follow-up monitoring or maintenance. When this occurs, unless the sources of disturbance were effectively removed during restoration, restored areas often return to the degraded condition that existed before restoration. Monitoring of the results of the restoration project and adaptive management of the project is necessary to justify the effort of ecosystem restoration. Monitoring should continue for several years following the restoration project. For large restoration efforts, the restoration site should be included in long-term annual monitoring efforts for a minimum of five years, and preferably for as long as funding allows (see Section 4.1). For smaller sites, annual monitoring of the restoration project should continue for a minimum of two years.

One of the main purposes of monitoring the restoration project is to determine whether it was successful in meeting its goals. An ecosystem restoration project has been successful when the ecosystem "contains sufficient biotic and abiotic resources to continue its development without further assistance or subsidy" (Society for Ecological Restoration International Science & Policy Working Group 2004). In their *Primer on Ecological Restoration*, The Society for Ecological Restoration lists nine attributes of restored ecosystems that can be used to determine whether a restoration project has been successful. These attributes need not be achieved in full – it is necessary only for the ecosystem to demonstrate development towards the intended goal or reference ecosystem (Society for Ecological Restoration International Science & Policy Working Group 2004). The nine attributes are:

1. "The restored ecosystem contains a characteristic assemblage of the species that occur in the reference ecosystem and that provide appropriate community structure.
2. The restored ecosystem consists of indigenous species to the greatest practicable extent. In restored cultural ecosystems, allowances can be made for exotic domesticated species and for non-invasive ruderal and segetal species that presumably co-evolved with them. Ruderals are plants that colonize disturbed sites, whereas segetals typically grow inter-mixed with crop species.

[25] Variable indicates that the cost will depend on the size of the area restored and whether volunteers are used.

[26] Actual cost is high, but will be borne by the observatory.

[27] Conduct in conjunction with DLNR DOFAW, USFWS, and university experts. Costs may be shared with these entities.

[28] Goals of habitat restoration in māmane woodland would be to enhance habitat for the endangered Palila and native bees, and to enhance native plant diversity.

3. All functional groups necessary for the continued development and/or stability of the restored ecosystem are represented or, if they are not, the missing groups have the potential to colonize by natural means.
4. The physical environment of the restored ecosystem is capable of sustaining reproducing populations of the species necessary for its continued stability or development along the desired trajectory.
5. The restored ecosystem apparently functions normally for its ecological stage of development, and signs of dysfunction are absent.
6. The restored ecosystem is suitably integrated into a larger ecological matrix or landscape, with which it interacts through abiotic and biotic flows and exchanges.
7. Potential threats to the health and integrity of the restored ecosystem from the surrounding landscape have been eliminated or reduced as much as possible.
8. The restored ecosystem is sufficiently resilient to endure the normal periodic stress events in the local environment that serve to maintain the integrity of the ecosystem.
9. The restored ecosystem is self-sustaining to the same degree as its reference ecosystem, and has the potential to persist indefinitely under existing environmental conditions. Nevertheless, aspects of its biodiversity, structure and functioning may change as part of normal ecosystem development, and may fluctuate in response to normal periodic stress and occasional disturbance events of greater consequence. As in any intact ecosystem, the species composition and other attributes of a restored ecosystem may evolve as environmental conditions change."

4.3.3.4.1 Habitat restoration following telescope decommissioning and removal

The lease between the State of Hawai'i and the University of Hawai'i allows for the construction of buildings, with the approval of the Board of Land and Natural Resources. The conditions in the lease are included in the subleases between the University of Hawai'i and the entities that own or operate the telescopes at the summit. There are two options for the disposition of telescope facilities following termination or expiration of the subleases: 1) surrender of the telescope facilities to the University of Hawai'i upon approval of the University and the chairman of the Board of Land and Natural Resources or 2) remove the facilities and restore the property at the expense of the owner of the telescope. This essentially means that 1) the telescope facilities will either continue to be used for research, 2) the telescope facility will be removed and replaced with a new facility, or 3) the telescope facility will be removed and the site restored to its historical condition prior to construction of the facility. Table 4.3-8 presents management actions relating to planning and implementation of habitat restoration projects following telescope decommissioning and removal.

Restoration of the cinder habitats and pu'u that were disturbed during the construction of the scopes will be challenging and expensive. The level of restoration attempted and the impact of the restoration activities on the surrounding habitat must be carefully considered before conducting any restoration projects on this scale. Factors that need to be considered include:

1. What is the purpose of the site restoration? Is it mainly to provide habitat for the aeolian arthropod fauna, such as the wēkiu bug, or is it to restore the look and feel of the summit prior to construction of the facilities?

2. What are the cultural considerations that must be made? How do the local community and cultural practitioners feel about the various options for restoration? All restoration planning must explore these issues through community consultation.

3. What are the costs associated with site restoration?

4. To what depth will the building be removed? Many of the telescope facilities have one or more stories underground, which would require considerable excavation efforts to remove. The following options exist with regards to removal of the facility:

    a. The entire facility can be removed, including the belowground levels. This will leave a very large hole in the substrate that will have to be filled with some sort of material. Questions to consider include:
        i. What material will be used? If cinder, where will the cinder be collected?
        ii. How will digging out and hauling so much cinder impact the collection area?
        iii. What are the cultural considerations of bringing cinder from a different place to the summit of Mauna Kea?
    b. The underground portion of the facility can be left in place, and only the above ground levels be removed. In this case, the structure would probably be capped with an impermeable material such as concrete, following which, it would be topped with cinder materials. Questions to consider include:
        i. Where will the cinder fill material come from?
        ii. What would be the impacts to the site, if any, of leaving the remaining structure underground?

5. To what level will the pu'u be restored? Would the restoration effort attempt to mimic the original shape of the cone? More closely restoring the pu'u to its original shape would require more cinder material to be collected, hauled, and placed on the restoration site. Moving cinder has implications for 1) the area it is collected from, 2) the pathway taken by the construction equipment, and 3) the habitat surrounding the restoration area. Best management practices such as ensuring that cinder is free of invasive species and contaminants and limiting dust released into the environment when cinder is moved can reduce the impact to the environment, but the impact will never be zero.

Because the summit pu'u provide habitat for a rare arthropod community, including the wēkiu bug, a Federal Candidate species, any restoration projects at the summit should focus on creating habitat that can be used by the native arthropods. Although habitat requirements of the wēkiu bug are fairly well understood, no restoration projects have been attempted to date. An untested set of guidelines was developed for wēkiu bug habitat restoration projects and associated monitoring protocols by Pacific Analytics (Pacific Analytics 2000, 2001b, a; Brenner and Lockwood 2005). General recommendations for restoration made include:

1. Cinder should be a minimum of 12 to 18 inches deep, and in some cases, deeper.

2. Cinder should be level with adjacent habitat.

3. Cinder placed in the restoration area should be ½ inch (1.3 cm) in diameter or larger.

4. Cinder should be screened and washed to remove small particles and dust before it is placed in the restoration site.

5. Uneven surface layers of cinder are preferred over leveled layers, as this will create additional microhabitat.

6. To reduce dust generation, water should be applied to the cinder excavation area and to stockpiles during earthmoving events.
7. Soil-binders must not be used in wēkiu bug habitat.
8. Care should be taken not to compact or crush the cinder in the restored area by driving on it.
9. To prevent transporting invasive species, all earthmoving equipment must be washed clean and be inspected for invertebrates and seeds prior to arriving at the summit for work.
10. A baseline inventory of wēkiu bug populations in the area should be conducted prior to beginning the restoration project. The restoration area should be monitored for a minimum of five years after the work is complete.

The above guildelines should be evaluated against best current knowledge of the wēkiu bug habitat needs at the time of any attempted restoration project, and can be altered as appropriate. As habitat restoration for the wēkiu bug has never been attempted before, it is recommended that any restoration attempts be conducted as a research project, with statistical analysis of differences between wēkiu bug abundances before, and after, the project, and comparison of wēkiu bug abundances between the restored area and nearby undisturbed habitats. Some adjustments may have to be made to the methodologies employed in wēkiu bug habitat restoration attempts, once experience has been gained from previous projects. It may be desirable to conduct small-scale trial restoration projects to determine their efficacy, before investing in large scale projects.

Table 4.3-8. Management Actions for Site Restoration Following Telescope Decommissioning

Action	Location	Priority	Cost
Require observatories to develop plans to recycle or demolish facilities once their useful life has ended, in accordance with their sublease requirements, identifying all proposed actions. Plans will require OMKM approval and compliance with the Comprehensive Management Plan (CMP), including all maintenance and construction management actions.[29]	Summit	High	Low[30]
Require observatories to develop a restoration plan in association with decommissioning, to include an environmental risk-benefit analysis and a cultural assessment. Plans will require OMKM approval and compliance with the CMP, including all maintenance and construction management actions.[31]	Summit	High	Low
Require any future observatories to consider site restoration during project planning and include provisions in subleases for funding of full restoration.[32]	Summit	High	Low

[29] All observatories to provide written confirmation that they understand and will comply with the conditions of their sublease related to site recycling or demolition.

[30] Cost for the action will be low for OMKM but may be high for the telescope facility.

[31] In some cases, it may be beneficial to negotiate termination arrangements different from those specified in the sublease. For example, resources that would have been used for certain required aspects of removal and restoration could be applied instead to other things that are considered more beneficial. Such modifications in termination requirements would need the approval of OMKM, lessor (DLNR), lessee/sublessor (UH), and sublessee (observatory).

[32] Three levels of restoration have been identified for future projects: minimal, moderate, and full. All three require all infrastructure materials to be removed, including buried utilities and underground structures, unless it is determined that removal would cause irreversible damage to resources. *Minimal* restoration will require that the footprint of the constructed area be leveled and left in safe condition. *Moderate* will require use of materials (e.g., cinders) along with topographic manipulation to achieve a morphologic condition that will enhance physical habitat for wēkiu bugs and other native arthropods. *Full* restoration will require returning the topography of the site to its condition prior to grading and site manipulation. The decision as to which level is executed will be determined after careful analysis of the impacts of each level and shall be approved by OMKM, DLNR,

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UH and the observatory. It is recommended that observatories expend monies equal to the estimated cost for full restoration regardless of the level that is implemented, with differential savings placed into a revolving fund to be used by OMKM.

4.4 Education and Outreach

Many are drawn to Mauna Kea to star-gaze and explore the universe; for others, it is the natural resources of the mountain, itself. For yet others, the mountain is a source of profound cultural and spiritual connection. It is therefore important for managers to emphasize the existence and importance of the cultural and natural resources on Mauna Kea, to protect them from damage and disrespect. Lack of education has been identified as a source of unintentional human impact to Mauna Kea's unique resources. Education should be aimed at raising awareness and appreciation of the area being experienced, for both those who visit and for those who work at Mauna Kea (Hughes and Morrison-Saunders 2002). The idea of education as an important component of the experience for all who visit and work at Mauna Kea is part of a broader ethic that aims to foster a mutually beneficial relationship between those who use the mountain and the mountain itself (Hughes and Morrison-Saunders 2002). Efforts at public outreach and education that address community concerns and needs, while highlighting measures developed to protect Mauna Kea's resources, will increase support for management activities. Visitors to, and users of, Mauna Kea who understand the significance of the resources on the mountain will contribute to more effective protection of them.

4.4.1 Current Efforts

Expanded visitor facilities and improved access have led to increasing tourism and recreational use of Mauna Kea. These bring with them the potential for increased negative impacts on the fragile subalpine and alpine (summit) ecosystems and cultural resources. It is easy for visitors to overlook many of these elements in the UH Management Areas because, to the uneducated, the barren landscape of the Mauna Kea Science Reserve (MKSR) appears lifeless. Ranger observations indicate that impacts may be unintentional, with visitors uneducated about Mauna Kea's natural and cultural resources and the potential impacts of human use.

> These guests, like most visitors, are unaware of the cultural history of Mauna Kea, its unique natural resources, and the state-of-the-art astronomical observatories situated on its summit. They greatly appreciate the information and acknowledge the preciousness of the mountain (McLoud 2003).

Education regarding personal safety and the potential hazards of visiting the mountain is also essential. In addition to protecting the well-being of the visitors, education helps conserve management time and resources by reducing the number of instances requiring a response by the support staff such as search parties and medical assistance.

Visitors to Mauna Kea have access to a range of educational opportunities, but currently none is required of those visiting the mountain. Other users of the mountain, such as astronomers and other scientists, construction workers, and maintenance staff, also may or may not be educated about resources not directly related to their reason for being on the mountain. Some of the astronomy facilities have conducted education and awareness training for their staff, focusing primarily on cultural resources. Office of Mauna Kea Management (OMKM) Rangers and staff and volunteers at the Visitor Information Station (VIS) are familiar with the mountain's history, natural and cultural resources, and uses. They provide an essential repository of information.

Visitor Information Station (VIS) Facilities. The VIS provides some static and some interactive educational resources, most of which focus on the observatories. One of the most up-to-date and informative sources of information is the set of videos on safety, natural resources, cultural resources, and astronomy, some of which are available in Japanese. The static information on natural resources is limited to a decades-old wall-diorama on geology, a small poster on the wēkiu bug, and a laminated booklet describing some of the native and invasive vegetation found on Mauna Kea.

Brochures. Informational brochures include "Mauna Kea Hazards" (discussing exposure to altitude, snow recreation, falling ice, weather, driving and remote location); "Visiting Mauna Kea Safely and Responsibly" (which discusses high-altitude, road conditions, weather and atmospheric conditions, winter conditions, important telephone numbers, and summit map); "Mauna Kea, Ka Piko Kaulana O Ka 'Āina' (a description of the cultural landscape including place names and descriptions); and one on the 'Imiloa Astronomy Center. There is also a two-page, black and white photocopied handout containing information on the Palila, the wēkiu bug, and a list of Hawaiian and modern names for astronomical and geological features. Most of these have been developed over the past few years by OMKM.

Signage. Health and safety signage is prominently featured on the approach to Hale Pōhaku, along the Summit Access Road, and on the outside of the VIS. Posted on the outside of the VIS is information about winter hazards; general hazards related to altitude when traveling above Hale Pōhaku; a map, and information about littering and not disturbing the landscape. However, there is an identified need for more signage in the UH Management Areas, noted particularly by the rangers who have the most interaction with visitors. Past efforts have been helpful. For example, putting a sign at the visitor's station junction regarding hazardous conditions has increased the number of people stopping for information. There is no 'interpretive' signage other than that at the VIS. Signage identifying the boundary of the Mauna Kea Ice Age Natural Area Reserve is visible from the roadway.

Botanical exclosure. An excellent opportunity for increased visitor education on the natural resources of the subalpine ecosystem exists at the Department of Land and Natural Resources (DLNR) botanical exclosure, next to the VIS picnic tables. This area contains native vegetation not found in the unfenced areas of Hale Pōhaku, including several Mauna Kea silverswords. This area could be an excellent source of information and education for visitors, but is currently not managed in a way to accomplish this. For example, it lacks signage explaining what the area is.

Website. OMKM's website (http://www.malamamaunakea.org) serves as a resource for information on Mauna Kea. In addition to providing information about OMKM's management and committees and their operations, the website contains copies of current and past newsletters, meeting minutes, information on public safety, stories of interest, and astronomy education links. The VIS website (http://www.ifa.hawaii.edu/info/vis/) has additional resources for visitors, including directions to points of interest, facilities, health and safety, VIS programs, volunteer programs, hiking, tours, astronomy, and the natural and cultural resources of Mauna Kea.

Newsletter. Non-astronomy off-site educational opportunities are provided mainly through the distribution of informational material by OMKM. OMKM produces a newsletter with a hardcopy circulation of about 1,500 that provides regular updates of board members and activity, on-going research, planning efforts and Mauna Kea-related happenings. In 2006, the frequency of the hardcopy version was reduced from quarterly to semi-annually, coinciding with the launch of an electronic newsletter.

Educational Programs. The 'Imiloa Astronomy Center of Hawai'i, located in Hilo, is targeted at educating people about the connections between Hawaiian culture and astronomy. There is little information about the terrestrial natural resources in the exhibits. Educational outreach to schools is conducted mainly by the Institute for Astronomy (IfA) and the observatories. OMKM does not conduct an outreach and educational program for schools targeted at the natural and cultural resources of Mauna Kea.

Surveys. OMKM has used surveys to learn the general public's view concerning how to preserve and protect Mauna Kea, with a particular focus on managing access. The first survey, conducted in Fall 2002, used a mailed brochure and response card to gather community input on three primary questions: the need to protect Mauna Kea, vehicular access, and recreation. Of the approximately 2,050 surveys sent out, 557 responses were received, along with an additional 230 written or faxed submittals that were transmitted in response to an email broadcast by KAHEA, a non-profit environmental organization. The second survey, conducted by a social science class at the University of Hawai'i (UH) Hilo, focused on Big Island residents, and queried 626 interviewees by phone about how much they knew about various topics (cultural activities, scientific activities, unique species and key geological features) and the relative importance of management issues for the MKSR (Okinaka 2004). The results of the surveys are used by OMKM to inform management and decision-making.

4.4.2 OMKM Education and Outreach Program

Goal EO-1: Educate and involve the public to support and enhance conservation of the Mauna Kea's natural resources

The goal of educating and involving the public to support and enhance conservation of Mauna Kea's natural resources can be achieved through the following objectives: 1) improving educational materials and outreach efforts regarding the natural resources on Mauna Kea and 2) involving the public in protection and conservation of Mauna Kea.

Objective 1: Improve education materials and outreach efforts

Lack of educational and interpretive resources is often cited as a primary reason for human-induced impacts on Mauna Kea's resources. It is difficult to expect people to protect and value something if they are unaware of its existence and significance. Natural and cultural resource-related educational outreach at Mauna Kea can be expanded to better inform all of those who use the mountain of the potential negative consequences of their activities. Groups that should be targeted include tourists, local residents visiting the summit for hiking and snow play, cultural practitioners, researchers, observatory staff, and maintenance workers. By including natural resources in addition to those related to astronomy in the overall educational experience, users will understand the mountain better and, it is hoped, actively protect the resources.

Some examples of potential areas for improvement include interpretive signage, trail markers, VIS natural resources exhibits, interpretive materials and guided tours, and VIS natural resources handouts. Many of these options have been discussed before, and solutions have been proposed (Group 70 International 2000). Short-term solutions, such as providing a handout on the area's natural resources and having tour operators provide similar information, may fill the gap until an educational plan can be developed. Each of the areas of improvement is discussed below. Additionally, management actions to improve education and outreach are summarized and prioritized in Table 4.4-1. These management actions are intended to be recommendations only. Implementation will depend on available funding and resources. If a recommendation is implemented and it results in an action that would require ground disturbance or alteration of the existing environment, a separate environmental analysis will be conducted in compliance with existing State law.

Visitor Information Station Facilities. The main improvements that are recommended for the VIS Facilities are increasing its size, to accommodate more people; improving educational materials; and updating and improving upon the displays to incorporate more information about Mauna Kea's natural resources (Group 70 International 2000). See Section 4.4.3 for information on potential themes for display materials.

Brochures. There are several recommendations for improving the informational brochures on Mauna Kea's natural resources. First, a brochure detailing the physical resources should be produced; it should describe the geological history of Mauna Kea. Second, the existing brochure covering the biology of Mauna Kea can be improved. The brochure should describe the subalpine and alpine ecosystems, their key species, and current threats to conservation, rather than focusing solely on the wēkiu bug and Palila. In addition, the three-ring binder containing information on "Plants of Mauna Kea," located at the VIS should be updated to include more photos of native and invasive plant species. Another brochure that should be produced is a map of hiking trails, showing the locations of all accessible trails and containing information on trails that are no longer open. The map could also warn visitors not to go off trail and explain why, and could reiterate the need for behavior that is culturally sensitive and protective of natural resources. All brochures should be available as hard-copies at the VIS and ʻImiloa Astronomy Center of Hawaiʻi and electronically (as .pdf files) on the VIS and OMKM websites.

Educational signage: The use of signs as educational and interpretive tools has been explored, but conclusions differ as to the appropriate number of signs, the amount of information they should contain, where to put them (at trail sides or in central locations), and the type of signage (e.g., visitor's center display, kiosk, interpretive panel, trail markers, trail-side interpretation). Although signs are an economical and effective means of education, a balance must be struck between the quantity of signs provided and the minimization of distractions and visual pollution (Hughes and Morrison-Saunders 2002). Mauna Kea is a unique environment, with considerations that make the installation of signage challenging. There are cultural considerations related to the physical characteristics of structures (visual distraction, ground disturbance). There is the issue of contributing to increased travel to certain areas by making the public aware of their presence. Sign maintenance and removal or vandalism are also concerns. The extreme weather conditions at the summit also require planning for what type of sign might withstand the cold weather, bright sunlight, and high winds.

Desirable signage at Mauna Kea falls primarily into three main categories: educational and interpretive, directional, and health and safety. Signage alerting people to areas of sensitive habitat and requesting them to stay on trails would be valuable. Studies indicate that most visitors read signs at a centrally located area and that there is little difference, in terms of increasing visitor knowledge about the site, between signs placed in a central area (such as the VIS) or along trails (Hughes and Morrison-Saunders 2002). This suggests that improving the interpretive signage at the VIS, with the focus on important cultural and natural resources, will provide the information needed to educate visitors who intend to visit other parts of Mauna Kea. From a management perspective, centrally located signs are less likely to be vandalized, easier to maintain, and will not result in visual pollution or distract from scenic vistas. When combined with a detailed map, trail signage (both directional and safety) is more useful on-site, delineating access points for users. Trail signs must be designed to be easily seen by users but so they do not detract from the surroundings.

Botanical exclosure. The DLNR botanical exclosure can be greatly improved. Currently, there are no educational signs explaining what the exclosure is. An explanatory sign at the entrance, with a brief description of the subalpine vegetation community that is preserved within it would be useful. One option would be to create a brochure with a map of the exclosure, showing the locations of interesting native species, with brief explanations of their significance. Increasing the density of native plants and weeding out invasive species would also improve the area. If desired, a small area with invasive weeds with signage to inform the public that they are non-native and are competing with native plants could also be maintained. Any changes to the exclosure require the cooperation of DLNR, but this is not expected to be a problem. DLNR personnel have indicated that they would be grateful for support in maintaining the exclosure, such as volunteer efforts to water the plants within (Bergfeld 2008). The botanical exclosure also presents an opportunity to increase public involvement in conservation efforts to preserve Mauna Kea's natural resources (see Objective 2, below).

Newsletter: A column on Mauna Kea's high-elevation natural resources, perhaps detailing OMKM projects to protect these resources, could be presented in the semi-annual newsletter.

Website. OMKM's website is quite informative. There is room, however, to add pages on the subalpine and alpine ecosystems, with more detailed information on the flora, fauna, and geology of the region. The information on the VIS website concerning the "Plants of Mauna Kea" could be reorganized and expanded to point out the impacts of invasive species and to make it easier for visitors to distinguish between native and invasive species.

Educational outreach. If there is available space, it would be beneficial to provide information on Mauna Kea's natural resources at the 'Imiloa Astronomy Center of Hawai'i. If space is limited there, at minimum, providing some of the brochures available at the VIS would be useful. Currently IfA supports the Science Education and Public Outreach (SEPO) program, which is an active advocate of astronomy in general and specifically targets connections between Hawai'i and astronomy research at Mauna Kea. This program participates in external programs such as the Pacific Island Center for Educational Development. It also provides a free AstroTalk public lecture series at the University of Hawai'i at Hilo (http://astroday.net/news.html), as well as other presentations and educational tours. SEPO could be expanded upon or used as a template to develop additional outreach programs aimed at furthering education on natural resources at Mauna Kea. Nighttime lectures at the VIS could also be expanded to include lectures on natural resources and natural resource research projects occurring on the mountain.

Table 4.4-1. Management Actions to Improve Education and Outreach

Activity	Priority	Cost
Orientation		
Mandatory orientation video for anyone who accesses the UH Management Areas.[1] - Contents of the video should, at minimum, include o Health and safety orientation o Overview of rules and regulations (when implemented) o Introduction to the cultural and natural resources o Explanation of cultural resource sensitivity and general rules of conduct in culturally significant areas o Overview of causes of damage to cultural and natural resources o Introduction to the rangers as a resource o English and Japanese language versions - Require all visitors to watch orientation video annually. - Require observatory personnel, VIS staff, and volunteers to watch orientation video annually. - Maintain a database of registered users. - Visitors who attend will get a rear-view mirror tag, good for summit access for one year. - Orientation video could also be available online (on VIS website).[2]	High	Medium
Provide training to the commercial tour drivers, who can incorporate important natural resource issues in their narrative during trips.	Medium	Low
VIS Facilities		
Overhaul exhibits at the VIS to include more information about cultural and natural resources of Mauna Kea (see Section 4.4.3).[3]	High	High
Evaluate space needs for interpretive information displays and orientation at current VIS. Consider hosting some activities at a larger site.	High	Low
Consider expanding VIS facilities to include indoor telescope for use by volunteer-run star-gazing program.	Low	High
Brochures		
Continue to develop and update printed material explaining important aspects of Mauna Kea.	High	Medium
Develop a brochure on the natural resources of subalpine and alpine environments. The unique flora and fauna found on Mauna Kea, especially at the summit, may not be apparent to the uneducated or untrained eye.	High	Low
Develop a recreational trail map showing - General Mauna Kea features: VIS and Hale Pōhaku, Summit Access Road, astronomy facilities, pu'u, and trails - Trail system (length, change in elevation, history or legends, specific sights) - Information on safety hazards, emergency phone numbers, suggested equipment, and food/water to bring	High	Low
Maintain adequate copies of and distribute brochures at the following locations[4] - VIS - Hale Pōhaku (visiting astronomers) - IfA/OMKM office in Hilo - 'Imiloa - Provide brochures to commercial tour operators to share with their customers	High	Medium
Post all brochures on VIS and OMKM websites for online viewing and download.	High	Low

[1] Similar to what is required for entry to Hanauma Bay on O'ahu. It may be prudent to contact managers at Hanauma Bay for advice on implementation, community outreach, and problem solving. Implementation of a mandatory orientation video may require using a space other than the VIS. Possible alternative locations for orientation include 'Imiloa, commercial operator's vans, or lower Hale Pōhaku construction housing.

[2] Video watchers would register prior to watching the video. Upon completion of the video, the website would generate a downloadable and printable version of the rear view mirror tag, or a coupon for the tag that they could receive at the VIS.

[3] Coordinate overhaul with Mauna Kea Observatories Support Services (MKSS) and any planned renovation of the VIS facility.

[4] General brochure on Mauna Kea (Visiting MK Safely) should have the broadest distribution. Other brochures should be made available at the VIS and in pdf versions available on-line. To minimize cost of production tour operators could receive laminated versions of the brochures to share with their passengers on the bus. Interested visitors could obtain their own copy at the VIS.

Activity	Priority	Cost
Multimedia Presentations and Interpretive Materials		
Create webcasts and podcasts[5] with information on Mauna Kea's natural resources. Topics covered could include: - Self-guided tour of the DLNR Botanical Exclosure - Self-guided tour of the summit (showing telescope facilities and discussing the unique ecosystem at the summit) - Self-guided tour of the trail system (including information on native plant and animal species and physical resources) - Video or print versions of brochures available at VIS	High	Low
Create a high quality video on the unique natural and cultural resources of Mauna Kea. The DVD can be sold in the VIS and 'Imiloa gift shops for a nominal fee (to cover manufacturing expenses) and provided to tourists by tour guide operators as part of the tour package. Copies should also be donated to local schools and libraries, and made freely available on the internet.	Medium	Medium to High
Conduct guided tours with information on Mauna Kea's natural resources.	Medium	Medium
Interpretive Signage[6]		
Develop and install interpretive signage at HP and summit locations	High	Medium
Develop and install trail markers for primary trails.	High	Medium
Develop and install signage alerting people to areas of sensitive habitat and requesting them to stay on trails.	Medium	Medium
Label key native and invasive plant species near the VIS	Low	Low
Botanical Exclosure[7]		
Improve signage at the DLNR silversword exclosure - At the entrance to explain what the area is - Add explanatory signs and plant labels to educate visitors about the plants	Medium	Low
Conduct on-going restoration activities in the DLNR silversword exclosure	Medium	Low
Website / Email		
Update www.malamamaunakea.org regularly to include additional specific information on - unique natural and cultural resources found at Mauna Kea - visiting the mountain safely and responsibly - entrance requirements (if/when implemented) - rules and regulations (if/when implemented)	High	Low
Use website and email list-serve to distribute information pertinent to the community and keep the public informed - newsletters - e-newsletters - public meeting announcements - educational opportunities - Mauna Kea Management Board (MKMB) minutes	High	Low
Consider consolidating information from VIS website and OMKM website into a single, user-friendly website. This website would provide information on visiting Mauna Kea, natural and cultural resources, astronomy, and managing Mauna Kea.	Medium	Low
Newsletter		
Continue semi-annual publication of newsletter to inform and educate the public about activities taking place at Mauna Kea.	High	Low
Include column on natural resources and/or the OMKM natural resources management program (once established).	High	Low

[5] For download to MP-3 players, cell phones, and other electronic devices that can stream video.

[6] There are potential concerns related to establishing signage and trail markers in the MKSR because it may lead to an increase in visitor use both on and off trail. Consider the natural and cultural setting when locating signs. There are cultural sensitivity concerns relating to continued disturbance of the summit environment resulting from the installation of structures, including visual distractions and impacts on sacred land. Any signage installed in the summit region must be sensitive to cultural concerns and coordinated with Kahu Kū Mauna. Signage must be designed to withstand severe weather (wind, snow, sun). It is possible that improving interpretive information at the VIS will eliminate the need for interpretive signage in the summit region.

[7] These activities must be coordinated with DLNR Division of Fish and Wildlife (DOFAW). Cost-sharing with DLNR or use of volunteers will keep cost of these activities low.

Activity	Priority	Cost
Outreach		
Engage in outreach and partnerships to support development of public school curriculum exploring the cultural and ecological significance of Mauna Kea.	Medium	Medium
Conduct educational outreach to schools on cultural and natural resources of Mauna Kea.	Medium	Medium
Sponsor nighttime lectures on Mauna Kea's high-elevation natural resources.	Medium	Low
Support volunteer efforts to implement service projects that fulfill environmental enhancement objectives while also providing education and enjoyment to volunteers.[8]	Medium	Low
Sponsor a competition, internship or class project for students from media arts programs at local community colleges and the University of Hawai'i to develop new and innovative products for the VIS, including web and video productions.	Medium	Low to Medium[9]
Surveys		
Establish a comment box at the VIS for collecting visitor feedback.	Medium	Low
Maintain a web-based forum for suggestions and input for on-going public questions, input, and concerns.	High	Low

Objective 2: Involve the public in the protection and conservation of Mauna Kea's natural resources

There are many individuals and groups interested in the protection and restoration of Mauna Kea's natural resources. Involving the public in natural resources management activities on UH Management Areas will achieve three important things: 1) it will keep natural resource management costs down, allowing for a more complete natural resources management program, 2) it will make OMKM's efforts to manage the natural resources more visible and transparent, and 3) it will educate, inspire, and involve people who are concerned about human impacts on the mountain.

Volunteers can be used for many of the different aspects of natural resource management and protection on Mauna Kea. Volunteers could be individuals organized through an outreach effort by OMKM, various civic groups, or school groups. Volunteer opportunities include

1. Care of the botanical exclosure. This would entail weeding, watering, and inspecting the exclosure. Individuals or groups involved would require some training regarding the differences between the native species to be protected, and the invasive species to be removed. The three-ring binder located at the VIS containing photographs and descriptions of native and non-native plants could be used towards this end.
2. Enhancing native plant communities. Weeding, outplanting, and care of native species around VIS and dormitories could be conducted in a manner similar to that described above for the botanical exclosure.
3. Trail maintenance and development could be accomplished through local hiking clubs.
4. Restoration projects for native plant communities. These projects could be conducted on a larger scale than the DLNR exclosure if local school groups or university classes were involved in the process of growing the plants, planting them, and weeding and watering. Areas could be sponsored by different groups. A competition could be established, with awards to the group with the best success in their projects. Collaboration with local state or federal agencies on volunteer-based restoration projects would bring valuable expertise and resources to the projects, and would increase interactions between scientists, managers, and the general public.

[8] For example, encourage local hiking clubs to visit the mountain. Many in these groups know how to build and maintain trails; ask for their help in designing better trails and in maintaining them.

[9] Cost would depend on whether a prize was offered, and the amount of support provided to the media arts programs for development of the products.

4.4.3 Potential Themes for Natural Resources Education

Table 4.4-2 presents natural resources themes that could be developed in education and outreach efforts. These themes could be presented in a variety of ways including displays at the VIS, as brochures, as webcasts or podcast, and on the OMKM and VIS websites.

Table 4.4-2. Natural Resources Education and Outreach Themes

Natural Resources Education Themes
Geology and Mountain Building
Create large display map of the summit region, with an aerial image as the background, to include VIS and Hale Pōhaku, the Summit Access Road, the astronomy facilities, the trails, and all the pu'u, with names. The map could be displayed on a wall at the VIS, or it could be presented online as an interactive Geographic Information System (GIS) map.
Describe the geological context of Hawaiian volcanics such as: a map showing the Pacific Ocean and location of Hawai'i, locations of frequent earthquakes and associated Ring of Fire, hot spot data and graphics, information on why the islands have formed the way they have, and history of the entire island chain. Can be presented on a brochure or an interactive computer program, similar to what currently exists.
Update wall diorama to show pictoral backdrop of how Mauna Kea was formed.
Build a larger interactive display of rock samples and provide a brief explanation of how each were formed (e.g., a'a vs. pahoehoe; cinder vs. ash; Pele's hair vs. Pele's tears).
Provide information on volcanic hazards (lava flows, earth movement, noxious gases).
Glaciers and Glacial Features
Describe the three glacial periods at Mauna Kea; include approximate onset of ice sheets and approximate length of ice duration.
Display graphic showing what Mauna Kea looked like covered in ice. If this is done online, animate to show retreat of glaciers over time.
Explain material remains as evidence for the glacial periods (terminal moraines, till, erractics, hawaiite outcrops) and how each was formed.
Hydrology
Explain what is known of the mountain's hydrology including Lake Waiau, groundwater, and presence of springs and seeps.
Lake Waiau: - Historical documentation of the lake over time, using photos - Appearance with and without ice - Information on its size, shape, depth, watershed, and other attributes - Explanation of why the lake appears green
Climate, Weather, Air Quality, and Sonic Environment
Non-interactive monitor that displays real-time weather data by linking to existing weather and climate data stations at the summit.
Describe the importance of clear air, no-light, and minimal light-scattering properties within the air to astronomy facilities.
Visual
Photographs of Mauna Kea from all angles (e.g., from the ocean, from Hilo, from Kona, from other islands, from the summit, aerial view). Photos can demonstrate the grandeur of the mountain and its viewscape as a valued natural resource.
Threats and Impacts
Provide information on the impacts of hiking, going off-road/off-path, litter, hunting, and invasive plant and animal populations on the mountain.
Overview of Biology of Mauna Kea
Diagram of mountain, perhaps in cross section, showing vegetation communities and important animal species, from subalpine ecosystem to the summit. Could be expanded to include lower-elevation ecosystem types, to give a broader picture of the entire mountain, from sea level to summit.
Subalpine Ecosystem
Provide photos of key native and invasive plant species and text describing the roles (or threats) they play in the community. For example, māmane trees provide food for several species of native moth and the moth larvae and māmane seeds provide food for the Palila. Māmane flowers provide nectar for several species of native birds, including 'Amakihi, 'Apapane and 'I'iwi.

Natural Resources Education Themes
Provide photos or drawings of native bird species, with special emphasis on the federally endangered Palila, its nesting and foraging requirements, and why māmane woodlands must be protected.
Alpine Ecosystems
Provide photos and information on the native plants and animals that occur in the alpine ecosystem below the summit. Very little educational material is currently available regarding the area of Mauna Kea between Hale Pōhaku and the summit of the mountain.
Summit ecosystem: Photos and information on the unique aeolian ecosystem found at the summit, with an explanation of how the arthropods feed on insects and plants that blow up from lower elevations.
Silversword: Large photo and information on silversword natural history, endangered status, and conservation efforts to protect it. Consider possibility of small silversword garden outside entrance to VIS, like is found at Haleakalā.
Mauna Kea Natural Resources Management Program
Describe the OMKM Natural Resources Management Program (once established). Include information on current projects, priorities, and volunteer opportunities.

4.5 Information Management

Geographic and resource information is essential to support the planning, technical assistance, training, encroachment management, and community outreach services by the Office of Mauna Kea Management (OMKM). Accurate data must be readily available to engage in efficient and effective decision-making in support of adaptive management of resources. OMKM has collected a significant amount of information, but research and information compilation is a continual process. Long-term ecosystem based management requires standard protocols to ensure adequate collection and documentation of data. Structured organization makes this material accessible in a standardized format to managers, researchers, and the public. There are at least three complementary tools available to address OMKM's information management needs: 1) use, maintenance, and improvement of the OMKM library; 2) use of a geographic information system (GIS) as a data management and research tool; and 3) data management strategies for the collection, storage, and interpretation of field data. Section 4.5.1 provides information on these three information management tools and the current status of these tools at OMKM. Section 4.5.2 describes the formation of an OMKM Information Management Program, to enable efficient use of these information management tools.

4.5.1 Information Management Tools and Current Status at OMKM

4.5.1.1 Library

The OMKM library is a valuable resource that supports the on-going research and management of Mauna Kea. OMKM currently has three part-time staff to manage and update the growing library. A significant portion of the library contains information relevant to the cultural and natural resources of Mauna Kea. Documents are maintained in both hard-copy and electronic formats, and there is an on-going effort to acquire native electronic files and to convert hard-copy files into electronic files.

EndNote software is used to manage the library bibliography. In addition to making the references easily searchable and more easily used for document preparation,[1] a database of electronic files is linked to most references, facilitating ease of retrieval. Documents catalogued in EndNote include historical articles, journal articles, books, conference proceedings, government reports (grey literature), newspaper articles, theses and dissertations, environmental analyses, white papers, and websites. While some of this information has been generated specifically for OMKM, most of the library comprises information on Mauna Kea developed by various state, federal agencies, academic institutions, and private sector groups. Keywords have been used to provide a basic categorization of the library, making it searchable by topic. The library contains over 1,000 electronic references, and the library staff is continually inputting new information, including native electronic files where available and, alternatively, scanned documents.[2]

Hardcopy documents and their associated EndNote electronic files are housed in a library at OMKM's offices. The database is not available on line, and due in part to copyright concerns, access to the library database and associated document files is limited to those working for OMKM, including contractors. It is not available to the general public. Much of the information in the OMKM library could, in the future, be shared with the public; however concerns about access, sensitive information, and copyrights need to be addressed. In addition, there are concerns about overloading the OMKM librarians with requests for information and access from those outside the organization.

[1] When writing a document EndNote can be used in conjunction with word processing software to insert citations and instantly create a bibliography.

[2] Research for this Natural Resources Management Plan (NRMP) has used the resources already in the library and has added new files (new files are notated with "SRGII"). In addition, EndNote reference files have been edited, to facilitate their use in bibliographies.

4.5.1.2 Geographic Information System

A comprehensive resource management program should focus on available science to counter current and future ecosystem threats, using the most effective tools. Spatially based ecosystem management, using GIS linked to natural resource inventories and databases enables managers to address specific threats and identify areas of concern while incorporating real-time adaptive changes in management regimes. A GIS containing current regularly reviewed and updated data is an important component of adaptive management, and is particularly important for a successful monitoring program. The use of GIS allows managers to visualize distribution of natural resources and to analyze data for patterns of overlap or interactions among resources, human uses, and other abiotic or biotic factors that would otherwise not be obvious. An important feature of GIS is its ability to provide both spatial and temporal information, allowing for analysis of changes and trends through time and space.

Natural resources management programs can use a broad spectrum of data with the analytical tools of GIS to promote a better understanding of how the attributes of natural communities interact across a landscape. Incorporating other spatial data, including data on cultural resources, facilities, and surrounding land areas, creates a multi-dimensional platform to analyze natural resource components in support of comprehensive management planning. Accurate information about the local landscape is critical when making decisions about what to protect and how to protect it. Digital maps of sites can be linked to a relational database that stores topography, baseline data, site documentation, and aerial photography. GIS is ideal for mapping and inventorying geologic formations or vegetation across landscapes and to better understand inventories of threatened and endangered species for scientific and managerial applications. GIS is an important tool in the management and protection of habitat and species, enabling study at a variety of scales, and it provides analytical tools for investigating potential relationships with outside or indirect influences.

GIS is not currently used for management or decision-making for the UH Management Areas. Limited GIS was developed for use in creation of the 2000 Master Plan, to "provide a resource-based siting analysis of environmental conditions" (Group 70 International 2000). An overlay process was used to identify opportunities for both preservation and use. Data used included contours, roads, buildings, geology, archaeological sites, walking trails, habitat for flora and arthropods, ski areas, and the Mauna Kea Science Reserve (MKSR) boundary. OMKM has this data in GIS format. At a basic level, this is the recommended approach; however, analysis must consider the source and quality of the input data. Analysis of the Master Plan data as part of this assessment was challenging, because there was little documentation accompanying the data, and there were no metadata detailing specifics about the information contained in the data files.[3] Some of these data layers may be incorporated into the GIS being developed for OMKM, if they can be validated.[4]

The cultural resources consulting firm Pacific Consulting Services, Inc. (PCSI), has worked to develop a set of GIS base layers for use by OMKM in managing Mauna Kea's resources. This effort is being conducted concurrently with the effort to map cultural resources in the UH Management Areas, recording location and attribute information. Assembling the base layers (e.g., UH Management Area boundaries, roads, observatory locations, and elevations) has been challenging, due in part to inconsistencies, and "holes," in available data. Over the past few years, PCSI has developed a base map containing overlays that can be used to support a variety of uses by OMKM.

[3] Metadata provides content, quality, type, creation, and spatial information about a data set.

[4] The limited data provided as part of the 2000 Master Plan will need to be reviewed by experts for accuracy and brought up to current GIS standards before becoming part of the overall database.

4.5.1.3 Data Management

A range of data supports natural resources management activities at Mauna Kea, including completed stakeholder surveys, field data collected in support of scientific studies (e.g., wēkiu bug, meteorological analysis), and usage data collected by the rangers. The latter is entered into and maintained in a Microsoft Access® database that can be queried for either specific data or for trends over time (see Section 3.1.3.2). Rigorous management of field data must be factored into the management process, including financial and equipment resources for monitoring events and data collection in the field, analysis of monitoring data, potential long-term data storage, and the accessibility and retrieval of data for analysis. With the implementation of the Inventory, Monitoring, and Research Program (see Section 4.1), much data will be collected, and it will have to be stored in a format that is easily accessible for management, planning, and research needs. Research data will be delivered mainly in the form of studies and reports, although as OMKM develops its use of GIS to support decision-making processes (see Section 4.5.2), it will be important to collect and enter as much spatially based information as possible, such as the results of vegetation mapping, arthropod habitat, and recreational areas. The Inventory, Monitoring, and Research Program will likely be implemented by a combination of OMKM personnel, researchers, contractors, and volunteers. Natural resources management staff must be trained in global positioning system (GPS) data collection and the use of GIS for analysis of spatial data, to inform resource management.

Data are collected in many formats. Maintaining comprehensive records is important, and OMKM has begun the process of gathering data from a range of sources. Currently, the OMKM librarians provide assistance in cataloging scientific studies, survey results, and data analyses. While it is likely that researchers conducting studies on Mauna Kea will be familiar with existing data, it will be essential for any future researchers to have the benefit of reviewing existing studies for baseline data. Maintaining data compatibility is also an essential part of data management. Although data collection techniques may change over time, particularly in response to adaptive management strategies, it will be important to maintain continuity in certain parameters, so that the data can be analyzed for trends.

Another impediment to proper data management is the constant evolution of computer software and hardware that gradually renders certain data formats or storage media inaccessible. For example, very few computers now have floppy disk drives, and data stored on floppy disks may be unavailable to future users. This can easily occur with any storage media format (such as CDs or other currently accepted formats), and with old versions of software. Moving data into current, usable, formats, and storing it on current storage media, will be a constant task for OMKM data managers. Data can also be lost due to events such as electrical problems and computer failures. Paper copies of important data files may be necessary as a backup storage method.

4.5.2 OMKM Information Management Program

Goal IM-1: Maintain accessible, relevant information to meet management, educational, and research needs for Mauna Kea

The goal of maintaining accessible, relevant information to meet management, educational, and research needs can be achieved through the following objectives: 1) maintaining a comprehensive library of information related to Mauna Kea; 2) designing, building and maintaining a GIS to support decision-making; and 3) developing data management protocols. Each of these objectives is described in further detail below. Management actions recommended to aid in implementation of this Information Management Program are presented in Table 4.5-1. These management actions are intended to be recommendations only. Implementation will depend on available funding and resources. If a recommendation is implemented and it results in an action that would require ground disturbance or alteration of the existing environment, a separate environmental analysis will be conducted in compliance with existing State law.

Objective 1: Maintain a comprehensive library of information related to Mauna Kea

Information, in the form of reports, articles, studies, photographs, and other formats is an important component of resource management. In addition to providing a valuable database of historical and current information, a library is a dynamic tool that continues to gather relevant information and resources to support an increased knowledge base and to assist with management decision-making. Continuing the collection of information related to Mauna Kea should be a high priority. On-going efforts should be made to ensure that the OMKM library database is up to date, that all database entries have an electronic copy of the item available for viewing (if possible), and that formatting of database entries is consistent and correct.

Objective 2: Design, build, and maintain a GIS to support decision-making

The development of a geographic information system (GIS) is recommended as an essential support for integrated management by OMKM. This spatially-based tool will manage information for multiple purposes, including monitoring the condition of resources, management and evaluation, resource protection, research, and education and outreach. Without a GIS, OMKM has limited ability to analyze information about the distribution and condition of resources and associated impacts. Land managers have found such spatially oriented systems important to effective decision-making. In addition, the GIS could be used to support internal planning, public information, and educational needs. For example, it can be used to create displays for public meetings and maps of trail systems, sensitive sites, or restricted areas.

Since OMKM does not have in-house GIS capability, PCSI is currently under contract to provide maps to OMKM, on an as-needed basis. PCSI has presented various options to consider for future GIS support to OMKM, including on-site software (requiring at least one in-house user trained in the use of the software), contractor support, or a web-based GIS system that is hosted and maintained off site. In-house capability is recommended if GIS is to be used to its fullest capability to support resource management. This would require training of the Natural Resources Coordinator, Field Biologist(s), and Cultural Resources Coordinator in GIS software and data entry techniques.

Although many of the issues with the datasets used to develop a working base map have already been addressed by PCSI, some have not. Information incorporated from other sources (e.g., State of Hawaiʻi and U.S. Fish and Wildlife Service (USFWS)) will need to be regularly reviewed and updated to ensure that the most current data is being used for analysis. Additional information, such as vegetation surveys, can be added over time. OMKM should develop policies for internal and external data sharing, standards for data submission, and procedures for data review and update, to ensure that new data is compatible with their existing system.

Objective 3: Develop data management protocols

Information is essential for effective management, especially data collected over time that can be analyzed for trends. Ensuring that these data are accessible, searchable, and internally consistent is vital to a successful management program. Data management is challenging, and it will be important for OMKM to develop standard protocols for cataloguing, accessing, and sharing all data. File back-up should be a standard part of any data collection and storage protocol. Agreements with partner agencies that either share management responsibilities or collect data that could be used in the OMKM GIS will facilitate exchange of information.

Table 4.5-1. Management Actions to Improve Information Management

Management Action	Priority	Cost
Library		
Continue building library database by adding files from - Ongoing web search and literature review - Contractor and research work - Newspapers and websites - Project-specific documentation - Astronomical facilities	High	Low
Compile and catalogue photos of Mauna Kea over time, including historical photos.	Medium	Low
Maintain a single EndNote library with standardized protocols for updating.[5]	High	Low
GIS		
Develop a plan for building a GIS system to support resource management planning by OMKM.[6]	High	High
Develop protocols for provision of GIS information and incorporate them into any future contract and research requirements.[7]	High	Low
Use GIS and GPS for data collection and input.	High	Low to Medium
Continue building the GIS database by adding relevant natural resource data layers acquired from a range of sources.	High	Low
Conduct regular analysis of data layers as part of resource management strategy.	High	Low
Develop educational materials that interpret the data and make the information accessible to a wide audience.	Low	Medium
Data Management		
Develop and implement a strategy to regularly update and maintain OMKM databases.[8]	High	Medium
Develop protocols to ensure security of data (as needed) and to conduct regular back-up of database files.	High	Low
Develop protocols for access to the range of data managed by OMKM, both within OMKM or by others (e.g., researchers, contractors, public).[9]	Medium	Low
Stay current on technology.[10]	Medium	Medium

[5] OMKM's library comprises three separate EndNote libraries: journal article reprints, reports, and monographs. The separation of these files makes a comprehensive search for material cumbersome. Additionally, OMKM does not have standard protocols for updating or adding to the EndNote file, to ensure that the OMKM library is complete, formatted correctly, and not duplicative. As part of the process of developing this NRMP, the three libraries have been combined to improve database search capabilities and made recommendations to the librarians for improvements in data entry, to facilitate use in referencing (i.e., making them "citation ready").

[6] The plan should address equipment needs (e.g., hardware and software), types of data to include, training needs, metadata standards, and whether the system will be maintained in-house or by an outside contractor (see Section 5.1).

[7] If the project is not funded by OMKM, request data and a report as part of permit conditions.

[8] OMKM databases include the library bibliography (EndNote database and paper files), ranger reports (Access database), and GIS. Strategy would address integration and update of data sources developed and maintained by others (e.g., State of Hawai'i, Natural Resources Conservation Service (NRCS) [soils data]). Protocols for quality assurance and quality control of any data used by OMKM should be included.

[9] When sharing data, consideration should be given to issues including copyright and sensitivity of information. Regular data exchanges with regulatory agencies (e.g., State Historic Preservation Division (SHPD) and Department of Land and Natural Resources (DLNR)) and neighboring landowners (e.g., Natural Area Reserves (NAR), Division of Fish and Wildlife (DOFAW)) may provide opportunities for coordinated research and management.

[10] Technology includes the hardware and software being used to collect and store data, along with any training required to use the information effectively for resource management. Regular consultation with the University of Hawai'i's Information Technology (IT) department is recommended as a means to stay current with hardware and software packages available to aid in information and data management, and receive training. Occasionally, specialized training from outside sources may be required for certain software packages.

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5 Implementation and Evaluation Plan

Establishing and implementing a successful Natural Resources Management Program (NRM Program) requires careful planning, sufficient funding, adequate staffing, and ongoing review and evaluation of program successes and failures. This section outlines the nuts and bolts of developing the NRM Program for the UH Management Areas on Mauna Kea and for implementing the management actions developed in Section 4. It also provides a methodology for evaluating the success of the program and for determining any need for changes in management strategies.

5.1 Implementation Plan

5.1.1 Programmatic Management Actions

Most of the goals, objectives, and actions of the NRM Program are presented in the component plans in Section 4. However, there are several management actions at the programmatic level that apply to either the overall NRM Program or that should be completed prior to enacting the actions in the various component plans. These programmatic management actions include:

1. Complete formal adoption of the NRMP by the University of Hawai'i. Initial implementation of the plan components can be undertaken by existing OMKM staff while the funding and staffing activities are in progress.
2. Establish a Natural Resources Management Program within the Office of Mauna Kea Management (OMKM).
   a. Obtain sufficient funding to support the program (see Section 5.1.4).
   b. Hire staff members. Although many of the management activities can be conducted with the aid of volunteers or in collaboration with other land management agencies, the minimum staffing needs for this program are one full-time Natural Resources Coordinator (NRC) and one or two full time field biologists. Support and administrative staff, such as secretaries and librarians, are already available at OMKM (see Section 5.1.2.1).
   c. Contract out high-priority, field-intensive projects such as baseline inventory studies, to ensure they are conducted quickly (see Section 4.1).
3. Continue and increase the role of the Mauna Kea Management Board (MKMB) Environment Committee in the NRM Program.

   The establishment of the MKMB and its associated committees has enabled the broader community to become directly involved in advising on the management of Mauna Kea. The committees have been useful in involving a range of interests to ensure a collaborative and informed management planning process. Each of the committees has its own mission, but there are few guidelines for how decisions are made, especially if there is no consensus or if the requisite expertise is not present. For example, the MKMB Environment Committee might more efficiently make defensible decisions if they had a protocol for evaluating the potential environmental impacts of proposed activities. The following activities are recommended to increase the decision-making power and participation in the NRM Program by the MKMB Environment Committee.

   a. Review and approve (or request revisions to) management decisions, plans, and reports made by the NRC (via semi-annual meetings and as needed).

i. Participate in annual and five-year reviews and revisions of Natural Resources Management Plan (NRMP). See Section 5.2.

b. Review and approve or reject (with input from NRC and expert advice, as needed) research proposals from outside persons or agencies.

c. Interact with other boards and committees (with participation of the NRC) to achieve agreement on management goals, objectives, and activities.[1]

d. Incorporate decisions from cross-board meetings into the NRMP (during revisions), and into daily activities conducted by the NRC. The NRC should keep detailed notes of decisions made during these board meetings for use during revision process, as it may be a year or more until the next NRMP revision cycle begins.

4. Continue to include the other advisory committees as integral parts of the NRM Program. The following committees and councils should meet annually (and as needed) with the NRC and the MKMB Environment Committee, to discuss natural resource management issues and strategies, including potential compatibility and conflicts with cultural issues:

   a. Wēkiu Bug Committee

   b. Kahu Kū Mauna

5. Continue to develop working relationships with federal and state agencies.

   Currently there is no mechanism for integrated or coordinated management of Mauna Kea's natural resources (including lands outside of the UH Management Areas). No regular meetings are held between the governmental agencies with management responsibilities for Mauna Kea—in particular involving OMKM and the various divisions of DLNR. Significantly, because there is so little interaction between the various state and federal agencies responsible for the management of Mauna Kea, applicable rules and regulations in the UH Management Areas are little enforced. Development of coordinated management between state and federal agencies and OMKM is discussed in Section 5.1.3.

6. To increase community involvement in decision-making processes, conduct public outreach and education.

   Encourage and seek out community participation, including Native Hawaiians, in educational and outreach efforts. Education and outreach activities are discussed further in Section 4.4. Education and outreach relating to natural resources will be conducted or overseen by the NRC, with input from the OMKM director and MKMB Environment Committee.[2]

7. Establish legal authority for OMKM to promulgate rules and enforce regulations on Mauna Kea properties leased by the University of Hawai'i.[3]

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[1] As the advisory board for OMKM, the MKMB has responsibility for making final recommendations, based on input from committees including Kahu Kū Mauna and the MKMB Environment Committee. Potential conflicts between interests must be considered as this is done.

[2] The NRC will work closely with an education and outreach coordinator when this position is filled.

[3] Although it is desirable that this action be completed prior to establishing the NRM Program, it is not a requirement. There are many management activities and projects that do not require regulatory authority, including baseline inventory, monitoring, research, education, and information management. Aspects of natural resources management that require regulatory authority are managing access, providing rangers with the authority to enforce laws, and establishing fines for rule-breaking. It is recommended that obtaining rule-making authority be completed concurrently with the establishment of the NRM Program, and that the program operate regardless of OMKM's ability to enforce regulations (see Section 1.4.2.3).

8. Manage access to the summit to reduce impacts to natural resources. Unrestricted access to the summit region can negatively impact resources. See Sections 3 and 4.2 for more information on the potential impacts of human use. Strategies for access management are presented in Sections 4.2 and 4.4.

9. Provide that the MKMB Environment Committee will have an active role in advising MKMB and OMKM with regard to natural resources when considering proposed future land uses (see Section 3.1.1.4) and ensuring the compatibility with recommendations in approved management plans, with the goal of protecting natural resources.

   Although the UH Board of Regents and the President retain project approval and design review authority over all major developments within the UH Management Areas on Mauna Kea, OMKM, MKMB, and Kahu Kū Mauna are also charged with reviewing projects to ensure that they conform to the standards and guidelines set forth in the 2000 Master Plan. The 2000 Master Plan established a set of guidelines for project review and design, to ensure that proposed projects conform to and implement the concepts, themes, development standards and guidelines set forth in the plan (see Section XI, (Group 70 International 2000)). A Design Review Committee was established to interpret the guidelines and to ensure that proposed projects conform to the goals and objectives of the 2000 Master Plan and are consistent with the design guidelines.

   The review process requires OMKM to work with other entities, including IfA, the University system, and DLNR. In addition to complying with federal, state and county rules and regulations, project proposers must be informed of additional conditions that OMKM may require. There is also a need, during the project design review process, for OMKM to provide clear facility planning guidelines to project proposers that address siting and design considerations, and to enforce them, so that proposed facilities result in minimal impacts to cultural and natural resources and the astronomical qualities of the MKSR. Many of these considerations have been developed in the 2000 Master Plan, and the MKMB Environment Committee should provide feedback and guidance on issues related to natural resources.

   As specified in the 2000 Master Plan, each redevelopment or proposed new facility, including non-astronomy facilities, will undergo individual project reviews, that will include an environmental analysis pursuant to Chapter 343, Hawai'i Revised Statutes and a comprehensive analysis of the potential cultural impact. In general, the review process is applicable to any project involving any construction, installation or alteration upon any site, roadway, utility line, building, or other type of structure; any excavation, filling or change to surface topography; and any planting or removal of vegetation at a site that may be undertaken in association with these procedures (Group 70 International 2000). The 2000 Master Plan is somewhat vague on the definition of minor and major projects and leaves to the President of the University the final determination how the project would be classified. However, the operating definition considers construction activities – including excavation or the construction of new buildings – to be "major projects", while "minor projects" are those such as building small structures (e.g., weather tower) on a previously modified surface, or an emergency staircase. The 2000 Master Plan established separate review processes for minor and major projects. Minor project review ends with the UH President, while major projects require formal approval by the UH Board of Regents. OMKM functions as a liaison to ensure consistency in the project review process and that the required entities engage in the process. A schedule for processing proposals submitted to OMKM was approved in January 2008 (see Figure 5-1).

Figure 5-1. Schedule for Processing Proposals Submitted to OMKM

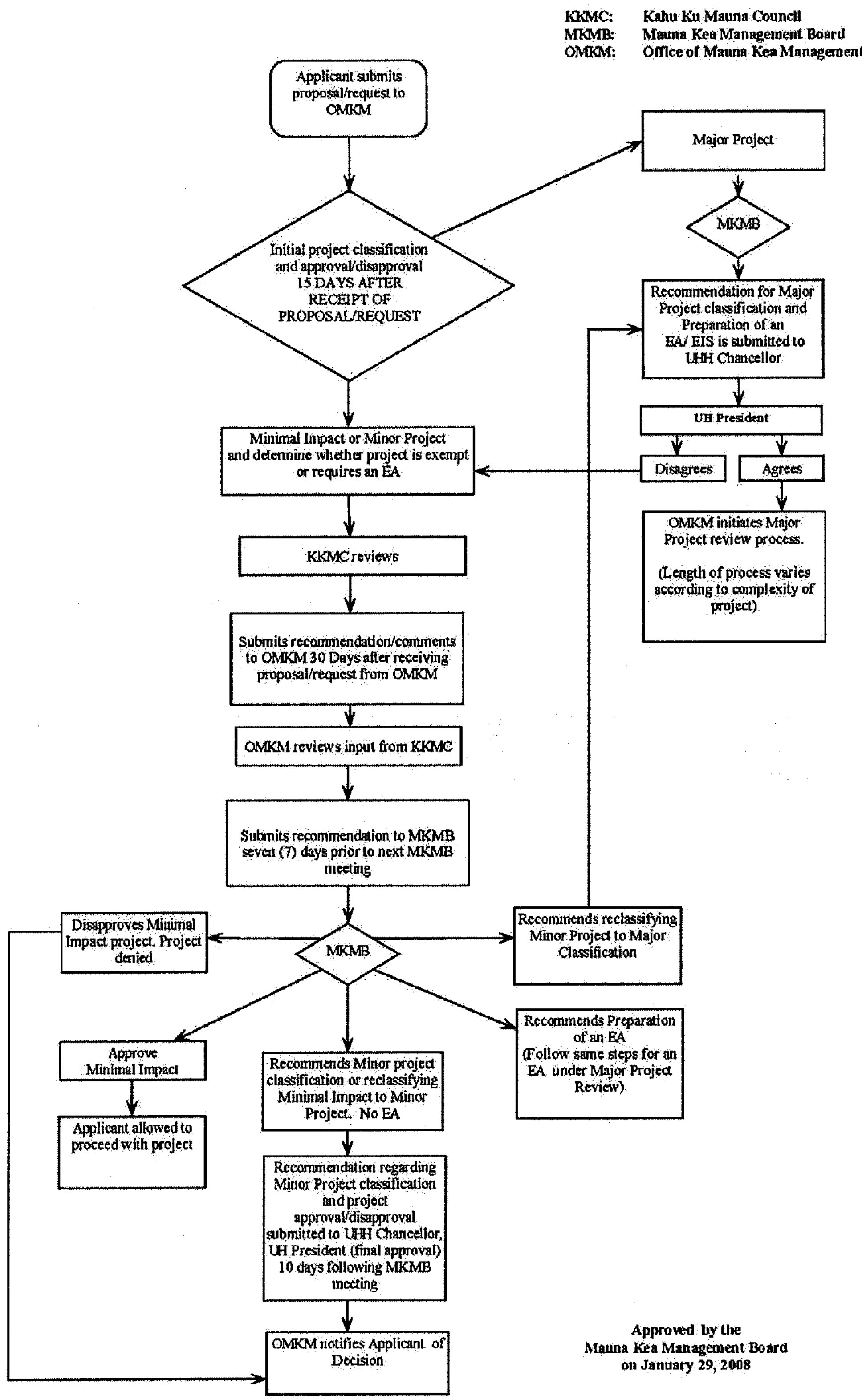
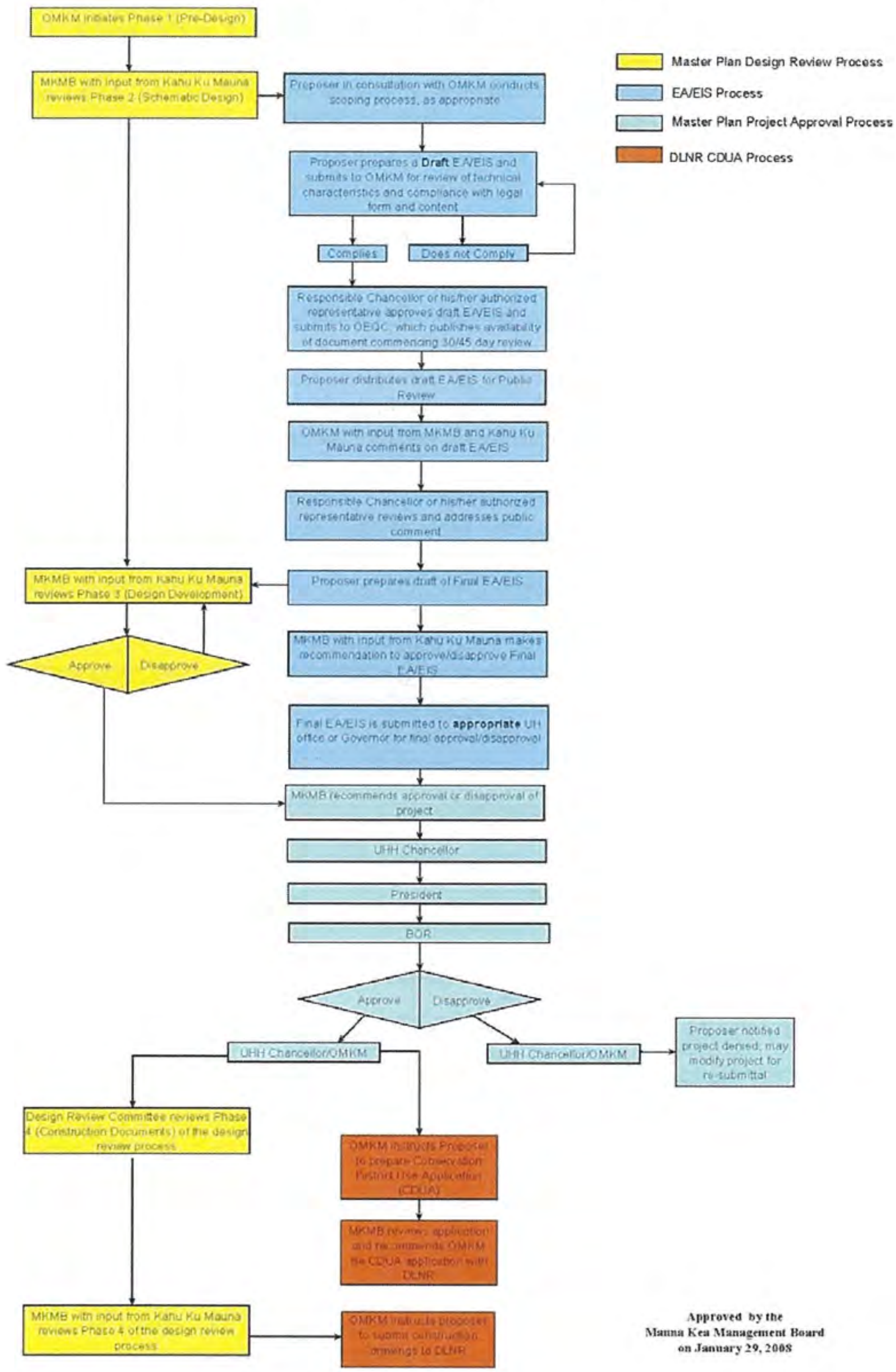


Figure 5-2. Major Project Review Steps



In January 2008, the MKMB approved "Major Project Design Review Steps" (see Figure 5-2). This flow chart details the Master Plan Design Review Process, EA/EIS Process, Master Plan Project Approval Process, and DLNR CDUA Process. Included in the overall design review process is the need to conduct required environmental analyses, such as an environmental assessment or environmental impact statement, for future proposed actions. As an advisory body to the MKMB, the Environment Committee plays a role in the project review process, especially with evaluating the potential impacts on natural resources.

5.1.2 Personnel, Training, Equipment, and Facilities

5.1.2.1 Staffing Requirements

Table 5-1 details the staffing requirements for oversight of the NRM Program and implementation of the NRMP. Most of the positions are existing, funded OMKM positions or volunteer boards or committees. A minimum of two new full-time OMKM positions are recommended for developing the NRM Program: a Natural Resources Coordinator and at least one field biologist.[4] The number of field biologists needed will depend in part on what proportion of the natural resources management actions is conducted in house by OMKM and what proportion is conducted by paid contractors (i.e., subject matter specialists, environmental consultants, Bishop Museum scientists, University of Hawai'i faculty, and graduate students) and volunteer groups. As of the first draft of this NRMP, there are no dedicated natural resources management personnel within OMKM—all natural resources management activities are currently conducted by contractors advised by the MKMB Environment Committee.

Table 5-1. Staff Requirements

Position	Role	Current Status	Location	Funding Status
OMKM Director	Oversight, guidance	Exists and filled (Interim director)	OMKM Hilo	Currently funded
OMKM Associate Director	Oversight, guidance	Exists and vacant	OMKM Hilo	Currently funded
Mauna Kea Management Board	Oversight, guidance	Exists and filled[5]	Various (meets at OMKM Hilo)	Unfunded volunteers
MKMB Environmental Committee	Oversight, guidance	Exists and filled[5]	Various (meets at OMKM Hilo)	Unfunded volunteers
Kahu Kū Mauna	Cultural guidance on NRMP issues	Exists and filled[5]	Various (meets at OMKM Hilo)	Unfunded volunteers
Natural Resources Coordinator	Implementation of NRMP	Position does not yet exist	OMKM Hilo/VIS	Requires funding
Natural resources field biologist(s)	Implementation of NRMP	Position does not yet exist	OMKM Hilo/VIS	Requires funding
Natural resources volunteers	Implementation of NRMP[6]	Needed	Various	Unfunded volunteers, but requires oversight by NRC, field biologist, or rangers.

[4] It is recommended that hydrological and geological studies be conducted by subject matter experts under contract.

[5] See Section 1.4.2.1 for more information on the MKMB and its associated committees, OMKM staff (director, administrators, librarian), rangers, Mauna Kea Support Services (MKSS), and Visitor Information Station (VIS) staff.

[6] Management actions conducted by volunteers could include invasive plant removal (weeding), establishing native gardens and maintaining them, education and outreach (on the mountain and at schools), plant and animal surveys (by qualified individuals), trail maintenance, and trash and debris removal. Activities that occur in the field would require a safety orientation and supervision by OMKM natural resources staff or rangers, to ensure safety of volunteers.

Position	Role	Current Status	Location	Funding Status
Contractors (scientists, environmental consultants, GIS database management)	Implementation of NRMP[7]	Needed[8]	Various	Requires funding (project specific)
Rangers	Visitor safety and outreach; natural resources protection	Exists and filled[5]	VIS	Currently funded
VIS Staff	Visitor outreach and education	Exists and is filled through MKSS[5]	VIS	Currently funded staff and unfunded volunteers
Education and outreach coordinator	Visitor outreach and education	Position does not yet exist[9]	OMKM Hilo, VIS	Requires funding
Administrative staff	Administrative duties	Exists and filled[5]	OMKM Hilo	Currently funded
Librarian	Document retrieval and organization	Exits and filled[5]	OMKM Hilo	Currently funded
MKSS	Facility support	Exists and filled[5]	Hale Pōhaku, VIS	Currently funded

5.1.2.2 Training Requirements

Training requirements for all OMKM personnel involved in field-based natural resource management activities includes general safety training, 4-wheel drive vehicle operation, orientation to working at high elevations, CPR and first aid, Global Positioning System (GPS) operation, rules and regulations, and recognition of culturally significant areas and items and protected flora and fauna. Additional training or educational needs for specific personnel are listed below.

Natural Resources Coordinator: Prior to hiring, the NRC should have extensive training in natural resources management issues, preferably in the form of a graduate degree and relevant work experience. On hiring, initial training would include training in project management, education and outreach methods appropriate to Hawai'i, and familiarization with the plant and animal species found on Mauna Kea, with emphasis on protected species. Other activities to maintain current working knowledge of natural resources management issues would include regular attendance of scientific meetings and conferences, participation in local working groups, and review of relevant scientific journals. Computer training for the NRC should include, if needed, use of statistical packages, Geographic Information System (GIS) software, word processing and database software. Optional training: GIS database management, spatial analysis, and advanced statistics.

Field biologists: Field biologists should have, at minimum, an undergraduate degree in biology or a related field. They should be familiar with field techniques to be used in day-to-day natural resources management activities and should be trained to recognize common Mauna Kea plant and animal species, as well as protected species. Optional training: GIS database management, relevant computer software.

[7] A range of management actions could be conducted by contractors, including GIS services, baseline inventory, hydrological studies, biological studies, various management actions, or research projects.

[8] There are currently several natural resource related contracts underway, including studies of the status of the wēkiu bug by Bishop Museum scientists, and a study of wēkiu bug population dynamics, genetics, and natural history by a University of Hawai'i professor and graduate student. See Section 2.2.2.2 for more information on these studies.

[9] New position recommended to coordinate non-astronomy related education and outreach activities.

Volunteers: Safety orientation; natural resources orientation (to be conducted by NRC or a field biologist).

VIS Staff and volunteers: Safety orientation; natural resources orientation (to be conducted by NRC or a field biologist).

5.1.2.3 Facilities and Equipment

Facilities and basic equipment needed to implement the NRMP include

Facilities	Equipment
• Office space for NRC and field biologist at OMKM, Hilo • Small office space and work area at Hale Pōhaku • Equipment storage area at Hale Pōhaku • Meeting room with audio-visual equipment at OMKM Hilo • Library space for NRMP-related books and documents at OMKM Hilo	• Computers for NRC and field biologist, with database software, word processing, and GIS software • Color printer • Digital cameras (2 for natural resources staff, 1 for ranger truck) • Walkie-talkies (minimum of 4 sets) • GPS Units (2 for natural resources staff, 1 for ranger truck) • 4-wheel-drive truck • Field equipment (backpacks, measuring tapes, metal stakes, flagging, compasses, field notebooks, binoculars, sample collection materials) • Identification guides (plants, birds, arthropods)

5.1.3 Ongoing Coordination with Other Agencies

Coordination between state and federal agencies regarding management of Mauna Kea's natural resources must be improved. This section describes two programs for coordinating multi-agency management activities on the mountain. The first (Section 5.1.3.1) is an interagency working group to streamline management activities on the mountain and to ensure that management occurs at an ecosystem level. The second (Section 5.1.3.2) is an annual interagency meeting to review and comment on the success of the OMKM NRM Program and the NRMP. Finally, Section 5.1.3.3 describes additional interagency coordination efforts that should be continued or undertaken to ensure the success of the NRM Program.

5.1.3.1 Mountain-wide Natural Resources Management Coordination

The principles of ecosystem management require that neighboring landowners and managers work together, guided by well-established management goals and visions. Overlapping and adjacent jurisdictions at the high elevations of Mauna Kea involve multiple agencies in management and decision-making (see Section 1.4.2). A good example of interagency coordination for land management on the Island of Hawai'i is the Three Mountain Alliance (TMA). It is recommended that the TMA management plan be reviewed and that prior to establishing the Mauna Kea working group, advice be sought from key personnel involved in the formation and operation of the TMA (Three Mountain Alliance 2007).

To increase participation and collaboration between OMKM and state and federal agencies on Mauna Kea, the following actions are recommended

1. Participate in the development of an interagency working group involving all entities that are responsible for or involved in natural resources management in high elevation areas (above 6,200 ft, or 1,900 m)[10] on Mauna Kea, including OMKM, state and federal agencies, non-governmental organizations (NGOs), private land owners, and other agencies and persons involved in the day-to-day management of Mauna Kea lands.

   Table 5-2 lists potential participants in the working group. If such a group already exists when the NRM Program is established, it is recommended that OMKM join it, and the NRC attend meetings.

2. Hold annual working group meetings.
   a. During the first annual meeting
      i. Develop an interagency set of mountain-wide management goals based on the principles of ecosystem management. Goals will need to take into account the participants' differing approaches to resource management, their policy foundations, and the decision criteria used by different institutions involved in multi-agency planning processes. Factors that will have to be taken into account include
         1. Department of Land and Natural Resources (DLNR) rules and regulations, including those specific to
            a. Natural Area Reserve (NAR)[11]
            b. Mauna Kea Forest Reserve
            c. Lands leased to UH[12]
            d. Conservation District lands
            e. Conservation District Use Permit regulations and stipulations
         2. Department of Hawaiian Home Lands rules and regulations
         3. Department of Defense, U.S. Army, Pōhakuloa Training Area (PTA) rules and regulations
         4. U.S. Fish and Wildlife Service regulations regarding protected species
      ii. Clarify management roles on the mountain: Who will carry out what activities and where the funding will come from. Managed activities could include
         1. Ecosystem restoration
         2. Protection and enhancement of protected species (e.g., silversword outplanting)
         3. Hunting
         4. Invasive species management

[10] For simplicity's sake, the working group, at least in the beginning, should focus on the high elevation areas. The cut-off (6,200 ft) was chosen because it is recognized as the boundary above which subalpine vegetation begins on Mauna Kea (Mueller-Dombois and Fosberg 1998). However, the working group may decide to change the area covered once it convenes.

[11] OMKM has developed a Cooperative Agreement to address cross-boundary management issues related to the Mauna Kea Ice Age NAR (see Section 1.3.3.1).

[12] As part of the lease agreement, DLNR and UH share responsibility for management in the Mauna Kea Science Reserve (MKSR) and at Hale Pōhaku. See Table VIII-1 in the 2000 Master Plan (Group 70 International 2000) for a detailed matrix showing responsibilities in the high elevation areas of Mauna Kea. These responsibilities may change if UH is able to obtain rule-making authority.

5. Access
6. Recreation
7. Trail and road maintenance
8. Commercial enterprises (e.g., sightseeing tours)

iii. Identify opportunities for collaboration, cooperation, and streamlining of natural resource management activities on the mountain.

iv. Identify gaps in management activities and funding, and collaborate in efforts to fill the gaps.

v. Identify time frames for various management projects and activities.

b. At subsequent annual meetings

i. Discuss progress towards identified goals.

ii. Determine causes of any delays in meeting goals and any problems with implementation.

iii. Revise goals, management roles, time frames, and methodology, as needed.

iv. Identify new sources of funding, funding gaps, and new potential partners.

Table 5-2. Potential Participants in Mauna Kea Natural Resources Management Working Group

Source	Agency
Federal: Landholders on Mauna Kea[13]	U.S. Army, Pōhakuloa Training Area (PTA)
Federal: Advisory or Regulatory Agencies	U.S. Fish and Wildlife Service (USFWS) U.S. Geological Survey (USGS) U.S.D.A. Forest Service, Institute of Pacific Islands Forestry (IPIF) U.S.D.A. Natural Resources Conservation Service (NRCS)
State: Landholders/leaseholders	University of Hawai'i (OMKM, IfA) DLNR: Division of Fish and Wildlife (DOFAW) and Natural Area Reserves System (NARS) Department of Hawaiian Home Lands (DHHL)
State: Advisory or Regulatory Agencies	Big Island Invasive Species Committee DLNR: DOFAW BLNR Office of Hawaiian Affairs
NGO	Silversword Alliance The Nature Conservancy Three Mountain Alliance Sierra Club Hawaii Watershed Alliance Hawaii Conservation Alliance
Individuals	Local natural resource experts Private landowners Community members Conservation advocates

[13] Landholders above 6,200 ft (1,900 m) elevation.

5.1.3.2 OMKM Natural Resources Management Program Interagency Review

OMKM personnel (including OMKM director, NRC, and members of the MKMB Environment Committee) should meet annually with relevant state and federal agencies to review the status of the OMKM NRM Program. Before the meeting, the NRC should prepare an annual progress report that describes the state of the resources, the status of the management program, progress towards meeting annual goals, and other pertinent information. The report will be reviewed and approved by the MKMB Environmental Committee and OMKM and will then be submitted to the stakeholders and agencies participating in the review process, allowing ample time before the meeting for the agencies to review it. The annual meeting will provide a mechanism for various agencies to review the OMKM NRM Program, provide feedback on management activities, and suggest additional activities or changes to the management program. Agencies to involve include USFWS, DLNR, and any other state or federal agencies participating in management activities or agreements with OMKM. The annual progress report is discussed further in Section 5.2.

5.1.3.3 Other Interagency Efforts

Other interagency efforts that will increase the success of the NRM Program include

1. Continue participation of the Big Island NARS manager on the MKMB Environment Committee.
2. Ensure diverse representation on the MKMB Environmental Committee, including local scientific experts, conservation advocates, and land managers and agencies.
3. Establish working relations with environmental staff at PTA, to cooperate and coordinate on natural resources management projects.

5.1.4 Budgets and Funding

Start-up costs for the NRM Program include furnishing office space and storage areas and for purchasing basic equipment (see Section 5.1.2.3). Annual operational expenses for the NRM Program will include salary and benefits for the NRC and field biologist(s), maintenance of equipment and vehicles, expenditures for various contracts[14] (initial baseline inventory, specialized annual monitoring[15], GIS database management). Annual operational expenses should also include a travel allowance for the NRC to attend public meetings on-island and interisland, the Hawai'i Conservation Conference, and one other relevant conference annually. Although many of the management actions can be implemented by operational funds to support staff, project-specific funds may be required for one-time projects or projects that require large amounts of funding, such as baseline inventories, mitigation or large-scale restoration projects, and multi-agency projects.

Potential sources of funds for start-up and annual operation costs include

- Increase in base funding provided to OMKM by the University of Hawai'i
- OMKM Revolving Fund, which is supported in part by fees collected from commercial tour operators

[14] If not done in-house.

[15] Specialized annual monitoring is monitoring that requires in-depth knowledge that the NRM may not possess, such as identification of certain organisms or plants.

- Funds provided by existing observatories as good-will efforts, to aid natural resources management of the summit and Hale Pōhaku
- Funds provided through lease agreements for potential new astronomy development to support natural resources management activities
- User fees and licenses: vehicle entry fees (if implemented); license fees from commercial tour operations; fees for rental or use of facilities at Hale Pōhaku for non-astronomy activities, events, and research
- Revenue collected from enforcement of rules (if implemented)

Potential sources of project-specific funding include

- OMKM base-funding requests
- Cost-sharing through agency partnering
- Using volunteer labor when possible
- Funds provided by new projects and existing observatories as part of environmental analysis or mitigation of environmental damage
- Research and management grants provided by federal and state agencies

5.1.5 Schedule

Implementation of the NRMP will begin with the acceptance of the NRMP by the MKMB and BLNR (as part of the Mauna Kea Comprehensive Management Plan [CMP]). The development of the NRM Program would begin once the NRMP is accepted and funding sources are identified.[16] The following schedule begins once funding is secured for the NRM Program, including funding for baseline inventories.

<u>**Year 1**</u>

1. Obtain office space and equipment needed for NRM Program (see Section 5.1.2.3).
2. Advertise and fill NRC and field biologist positions (see Sections 5.1.2.1 and 5.1.2.2).
3. Request proposals for baseline inventories (plants, invertebrates, birds and mammals, hydrological and geological resources) and hire contractors.
4. Begin development of NRM Program.
    a. Begin developing component programs as described in the Section 4 component plans
    b. Begin education and outreach activities
5. Draft RFPs and determine funding sources for projects that cannot be completed in house.

<u>**Year 2**</u>

1. Complete baseline inventories and associated data analysis.
    a. Using data obtained from baseline inventories, designate high-priority management areas (e.g., areas with high ecological value, sensitive areas, critical habitat or rare species habitat,

[16] OMKM may need to secure increases in base funding or obtain funds from other sources. If funding is limited, this NRMP may be implemented incrementally.

and areas with significant ecological damage or problems). These areas will be the main focus of management activities.

2. Determine high-priority management actions for each of the component plans, using information obtained from baseline inventories.
3. Continue developing in-house programs, such as education and outreach activities, invasive species prevention and control.
4. Establish volunteer groups and conduct volunteer-based resource management activities.

Year 3

1. Review, evaluate, and revise NRMP as needed, to reflect findings from baseline inventories.
2. Establish priorities for management actions and develop a long-term timeline for natural resources management projects.
3. Begin annual monitoring (see Section 4.1).
4. Continue and improve upon component programs.

Year 4

1. Review, evaluate, and revise NRM Program as needed, based on Year 3.
2. Continue and improve upon component programs.

Year 5

1. Continue and improve upon component programs.
2. Review and evaluate NRM Program, in-depth.
3. Prepare stakeholder report on the status of Mauna Kea's natural resources, and the progress of the NRM Program.

Year 6

1. Continue and improve upon component programs.
2. Hold NRMP review meetings (see Section 5.2.2.2).
3. Revise NRMP, reprioritize NRM Program actions for following five-year interval.

5.2 Evaluation Plan

To ensure the best possible protection for Mauna Kea's high-elevation resources, the success of management actions to protect and conserve those resources must be regularly evaluated. This section describes methods that can be used to ensure that management actions are achieving stated NRMP goals and objectives in UH Management Areas. Section 5.2.1 describes how the NRC and OMKM will monitor progress towards meeting natural resources management goals. Section 5.2.2 describes the NRMP review and revision process.

5.2.1 Monitoring NRMP Implementation

Regular monitoring of NRMP implementation must occur in order to determine if progress is being made towards meeting the goals and objectives of the NRMP. The NRM Program will be monitored annually, with annual progress reports issued as described in Section 5.2.2.1. A major review and revision of the NRMP will occur every five years, as described in Section 5.2.2.2.

Monitoring of a natural resources management program requires collection of concrete data that can be objectively analyzed and compared between years. This requires preparation at the beginning of each year, to determine the performance measures by which the year will be judged, followed by collection of data throughout the year on progress made toward meeting these measures. Preferably, the NRC will conduct brief monthly progress checks, to ensure that management activities are begun at appropriate times, that nothing is forgotten, and that projects are progressing as scheduled. Good notes taken throughout the year on the causes of delays or concerning unrealistic scheduling will enable the NRC to more thoughtfully analyze annual progress and determine course-corrections for the following year. The annual monitoring program should occur as follows:

1. At the beginning of each year, the NRC will establish a list of priority management actions to occur that year, along with a realistic schedule. These actions should be based on the components developed in the NRMP, along with any new pressing issues that may have come to light since the last update of the NRMP.
    a. The NRC should take care that the schedule is realistic and that there are not more tasks than can be completed in the number of man-hours available in the year. If it is consistently found that there are more tasks that must be completed than there are man-hours to complete them, staffing needs should be reviewed and new staff added, as needed.
    b. Management actions and projects that require a great deal of field labor (e.g., invasive weed control on a large scale), or expertise that the NRC and field biologist(s) do not have (e.g., invertebrate surveys if the NRC or field biologist is not an entomologist) should be contracted out, to ensure that they are conducted on schedule.
2. When the list of priority management actions and the schedule is completed, the NRC should create a progress tracking datasheet, using the listed actions, and begin tracking progress towards meeting the actions.
    a. It is useful to break up larger actions into smaller components that can be individually tracked and checked off when complete. This will give a sense of progress for some of the larger items that may be complete only at the end of the year, or even after several years. Ongoing projects should be broken into monthly components, or as appropriate.
    b. As each action is completed, the NRC should enter the date of completion into the datasheet. It is easy to forget when projects were completed if you are attempting to recall this information at the end of a busy year.
    c. Notes on problems encountered during management actions, interesting outcomes, successes, and ideas for improving management actions in the future should be kept on a linked document, to allow for easy cross-reference. This will help when writing the progress report at the end of the year.
    d. The progress tracking datasheets and schedule should be referenced at the beginning of each month, and updated as appropriate.
3. At the end of each year, the NRC should review the progress of that year's management-program activities by reviewing the progress-tracking datasheet. This datasheet will provide information on the percentage of management actions completed during the year and can reveal patterns in the strengths and weaknesses in the management program. The notes will provide helpful information on how best to improve the management actions, if they are to be continued the next

year. Comparison of the projected schedule with the actual schedule will enable the NRC to better estimate timelines for future projects and will help determine if the scale and scope of the actions slated for the following year(s) are appropriate for the staffing level.

4. After the progress tracking forms are analyzed, the NRC should produce an annual report, as described in Section 5.2.2.1.

5.2.2 Review and Revision

The principles of adaptive management require regular review of the program and revision of management goals, objectives, actions, and techniques, to improve the performance of the program. Two review processes, an annual progress report and a five-year management outcome assessment, are recommended to assess the success of the NRM Program and to enable revision of the NRMP.

5.2.2.1 Annual Progress Report

At the end of each year the NRC should produce an annual progress report describing in detail the management goals, objectives, and actions for the year and what progress was made towards meeting them. The report should also describe actions to be taken to improve the program for the next year(s). This report is not intended to be a status report on the natural resources in UH Management Areas,[17] rather it is meant to inform management and stakeholders of the progress of the program and direction it is to take in the future.

This progress report should be presented at an annual meeting, to be held before the following year's management priorities and schedule are set. This will allow for input into the NRM Program by OMKM, MKMB, the MKMB Environment Committee, DLNR, and other agencies, as deemed appropriate (see Section 5.1.3.2).

5.2.2.2 Five-Year Management Outcome Analysis and NRMP Revision

The NRM Program should be subjected to a major review every five years, and the NRMP should be revised, as necessary. This process should involve input from state and federal agencies and the public.

5.2.2.2.1 Management Outcome Analysis

Determination of the outcome of management activities on the natural resources and of the success of the management program will be accomplished through a report summarizing the state of natural resources on Mauna Kea and the progress of the NRM Program over the preceding five years.

The first section of the report will discuss the state of the natural resources in UH Management Areas. This section will summarize data collected during monitoring, research, restoration, and threat prevention and control activities conducted over the preceding five years (See Section 4).[18] This portion of the report will analyze trends in natural resources, and the impacts (positive, negative, or neutral) that management actions have had on them. It will also summarize what future management actions are needed to protect, enhance, or restore Mauna Kea's natural resources.

[17] The status of natural resources in UH Management Areas will be tracked during annual natural resources monitoring and will be presented in the annual Natural Resources Monitoring Report. See Section 4.1 for information on natural resources monitoring.

[18] The source of the data will be the annual reports produced as part of the various component plans.

The second section of the Five-Year Management Outcome Analysis should include a summary of the progress of the NRM Program towards meeting management goals, objectives, and actions, as outlined in the NRMP and in the annual listing of priority management actions (see 5.2.1). The source of information for this section of the report will be the annual progress reports from the last five years. Additionally, the NRC should review the NRMP and determine if any goals or objectives were not addressed during the preceding five years, and if so, why not. This section will discuss strengths and weaknesses of the NRMP and the NRM Program and ways to improve them.

The purpose of the Management Outcome Analysis is to provide analysis of both the condition of the natural resources in UH Management Areas and the status of the NRM Program and Plan. This information will be used to update the NRMP, so that it better addresses the needs of the natural resources, and to improve management activities through adaptive management.

A draft of this report should be submitted for review and comment to OMKM, MKMB, the MKMB Environment Committee, and state and federal agencies, as deemed necessary or appropriate. This will provide a mechanism for the interested parties to provide input into the direction the NRM Program and suggestions for changes to the NRMP. A final version of the report can then be presented to the public for comments and suggestions to be used in revising the NRMP.

5.2.2.2.2 Revising the Natural Resources Management Plan

Following the production of the Five-Year Management Outcome Analysis, and after input from appropriate stakeholders, the NRMP should be revised and updated to incorporate new management goals, objectives, and actions. This major review and revision process should occur on the sixth year (to allow for time to process the five-year review). If it is determined that the five-year cycle is too short to show real changes in resource conditions, then after two five-year review and revision cycles, the frequency of the process can be lengthened, as needed.

It should be noted that as of the first draft of this NRMP, no quantitative baseline inventories of the natural resources on UH Management Areas have been conducted. Therefore, the true state of the natural resources is currently unknown, and completion of the baseline inventories will necessitate a re-evaluation of the management actions recommended in the component plans in Section 4. It may be necessary to complete one or more in-house reviews and revisions of the NRMP and management priorities during the first several years of the program, to determine impediments to successful management of natural resources, develop realistic timelines for projects, and make necessary changes to the structure of the program. This can be done on an as-needed basis, to be determined by the NRC, OMKM director, and MKMB Environment Committee.

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8 Glossary

Aa: Common type of basalt lava with rough broken surface; from Hawaiian word ʻaʻā.

Adaptive management: Systematic process for continually improving management policies and practices by learning from the outcomes of past and current management activities. Adaptive management recognizes that there is a level of uncertainty about the "best" policy or practice for a particular management issue, and therefore requires that each management decision be revisited in the future to determine if it is providing the desired outcome.

Aeolian: Process pertaining to the wind in which particles are detached, transported and deposited. On Mauna Kea the aeolian processes are integral to at least one endemic arthropod due to the import of food resources transported from lower slopes of Mauna Kea to its highest elevations.

Albedo: Ratio of the amount of sunlight that is reflected and absorbed by a surface; 1.0 is a completely reflective surface.

Alien: When used in reference to a plant or animal species, alien means that the species was introduced (accidentally or on purpose) by mankind, and does not naturally occur in the location.

Alkalic: Igneous rock chemical classification based on total alkali (Na_2O+K_2O) vs. silca (SiO_2) content; alkalic rocks have greater total alkali than tholeiitic rocks at the same silica content.

Alpine: Living or growing on mountains above the timberline. On Mauna Kea alpine ecosystems occur above the nocturnal ground frost line, which is found at 9,800 ft (3,000 m).

Alteration: Change in character, appearance, direction, or status.

Anthropogenic: Relating to or resulting from the influence humans have on the natural world.

Aquifer: Water bearing geological layer. Aquifers are often used to provide water for human needs.

Arthropods: Organisms with jointed appendages and exoskeletons, including insects, spiders, and crustaceans.

Baseline inventory: Initial survey establishing the status of natural resources (population sizes, distributions, and biological diversity). Conducted at the beginning of a natural resources management program.

Bedload: Particles of sand, gravel, or soil moved by water along the bottom of a stream, gulch or river.

Biodiversity: Full range of natural variety and variability within and among living organisms, and the ecological and environmental complexes in which they occur.

Candidate species: Species that is possibly declining in population and that is being considered for threatened or endangered status under the Endangered Species Act.

Cesspool: Underground reservoir for liquid waste.

Cinder: Fragment of cooled pyroclastic lava material, typically very porous and with low particle density, making them light for their size. Also called tephra and scoria.

Cinder cone: Conical hill formed by the accumulation of volcanic ash or cinder around a vent.

Climate: Long term average of meteorological variables representative of the geographic area where the variables have been collected.

Community: In ecology, a community is an assemblage of populations of different species, interacting with one another.

Control: When used in reference to invasive species, control is the long-term reduction of invasive species density and abundance to an acceptable threshold.

Decommission: To remove from service.

Dike: Mass of intrusive igneous rock that has been injected into a fissure while molten, usually vertically aligned to the ground surface.

Dormant: Marked by a suspension of activity; temporarily devoid of identifiable activity.

Ecosystem: Dynamic system of living organisms (plants, animals, and microorganisms) within an area, the environment sustaining them, and their interactions. An ecosystem can range in size from a tiny site containing only a few species, such as an isolated lake, to a huge area containing thousands of species, such as a tropical rainforest.

Ecosystem health: Condition of an ecosystem in which its dynamic attributes are expressed within the range of activity normal for its stage of development.

Ecosystem integrity: Achieved when an ecosystem has the biodiversity characteristics of a reference ecosystem such as species composition and community structure, and is fully capable of sustaining normal ecosystem functioning.

Ecosystem restoration: The process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed.

Endemic: Native to, and restricted to, a particular geographical region. Highly endemic species are those with very restricted natural ranges; they are especially vulnerable to extinction if their natural habitat is eliminated or significantly disturbed.

Ephemeral: Description of stream or gulch hydrology in which surface water flow occurs only following periods of rainfall or snow melt.

Eradicate: To completely remove or destroy the entire population. When used in reference to invasive species, it refers to removal of the invasive species from an entire landmass, such as the entire Island of Hawai'i. Eradication is extremely rare in the case of invasive species, and generally occurs only on very small islands and in isolated locations, or with very small populations.

Erodibility: Potential of soil to be eroded or physically altered by the action of water or wind.

Erosion hazard: Rating or classification of the potential of a surface to erode; used to identify areas to avoid developing or take special precautions.

Erosivity: Potential of water and wind to detach and transport soil or rock.

Evapotranspiration: Loss of water from the combined effects of evaporation and transpiration from plants.

Evaporation: Phase change of water from liquid to vapor; classified as a loss in the hydrologic cycle.

Exclosure: Limited area from which animals such as sheep, pigs, or cattle are excluded by fencing. Fencing, and subsequent removal of non-native mammals, is a habitat management technique used in areas containing native plants or animals that are susceptible to grazing or predation by non-native mammals.

Exotic: Introduced from another part of the world; not native to the place where found.

Fauna: Animals or animal life of a region or environment.

Fissure: Narrow opening or crack of considerable length and depth, usually occurring from some breaking or forced parting.

Flora: Plants or plant life of a region or environment.

Geographic Information System (GIS): Computer software used to store, view, and analyze geospatial information. Outputs include analysis, maps and images.

Glacial member: Layers of glacial deposit used to describe the three glacial episodes that occurred on Mauna Kea.

Gully: Trench originally worn in the earth by running water and through which water often runs after rain.

Headcut: Location where a sudden change in ground elevation occurs, usually at the leading edge of a gully. Headcuts often result in rapid erosion and incision of the runoff channel.

Hydraulic conductivity: Quantification of the transmission rate of a liquid. Movement of water through soil or rock is a function of the materials conductivity.

Incidental take: Unknown or accidental killing or removing of an organism.

Incipient invasive species: Invasive species that has not yet become established. For this plan, refers to known invasive species found in Hawai'i that are not currently on UH Management Areas but that are thought to pose a threat to subalpine or alpine communities.

Indigenous: Native to a given region or ecosystem. An indigenous species differs from an endemic species in that it may occur in several locations in the world, while an endemic species is limited to one area or region.

Interstitial pores: Openings or voids contained in a soil or rock.

Invasive species: Non-native (alien) species whose introduction does or is likely to cause economic or environmental harm or harm to human health.

Introduced: When used in reference to a plant or animal species, the term means that the species was brought to a new location by man (either purposefully or accidentally).

In-situ: In the natural or original position or place.

Isotopic analysis: The analysis of the isotope composition of a sample.

Leachate: Solution or product that gradually moves through a matrix to a new location.

Leach field: The soil surrounding and immediately down gradient of a septic tank used to absorb leached septic liquids.

Lichen: Symbiotic associations of a fungus with a photosynthetic partner (either green alga or cyanobacterium) that can produce food for the lichen from sunlight. Usually found growing on rocks or trees.

Lithology: Character of a rock or rock formation as described by its components.

MKSR: Mauna Kea Science Reserve. An 11,288 ac (4,568 ha) parcel of state land above 11,500 ft (3,505 m) elevation on Mauna Kea, leased by the University of Hawai'i.

Mauna Kea Forest Reserve: Approximately 448,000 acre forest reserve and part of the State of Hawai'i Forest Reserve System. Circles Mauna Kea, and is found directly below the MKSR.

Metadata: Data that provides descriptive information about other data.

Mitigation: Elimination, reduction or control of the adverse environmental effects of a project. Mitigation includes restitution for any damage to the environment caused by such effects through replacement, restoration, compensation or any other means.

Monitoring: Recording changes to an entity over time in order to understand how actions, activities and ecosystem processes affect it. Monitoring is conducted as part of a plan to evaluate management prescriptions.

Natural Area Reserve (NAR): Part of DLNR, the reserves are created to preserve and protect representative samples of Hawaiian biological ecosystems and geological formations. The Ice Age Natural Area Reserve is located on Mauna Kea.

Native: Naturally occurring in a given area. When used in reference to plants and animals in Hawai'i, the term native means species that were not brought to the islands by mankind.

NRCS soil survey: Scientific document describing the physical and chemical attributes of soil.

Nunatak: Areas of cinder cones that remained ice-free by being above the surrounding glacier during the previous glaciation period.

Orographic: Associated with or induced by the presence of mountains, e.g., cloud lift and development.

Outcrop: To project from the surrounding soil.

Outplanting: Planting of greenhouse or pot-grown plants into an area.

Paleosol: Soil horizon from the geologic past; usually buried beneath other rocks or recent soil horizons.

Percolate: Movement of liquid through a permeable substance.

Permafrost: Layer of ice usually located beneath the ground surface, which is maintained year round.

Pu'u: Hawaiian name for hill. With respect to Mauna Kea, pu'u refers to the volcanic cinder cones found at the summit.

Rare: Occurring at low densities, or in limited locations.

Rehabilitation: Repair of habitat following a disturbance. Rehabilitation emphasizes the repair of ecosystem processes, productivity, and services, rather than reestablishment of historical plant and animal communities (which is the focus of restoration).

Relic: Something that has survived the passage of time.

Restoration: The actions or activities implemented in order to return damaged or altered habitat or a component of the ecosystem to a historical condition, including physical habitat attributes as well as community composition and native species abundance.

Rill: Small erosion feature created by water flow. With time rills can either join together to form a gully or expand into a gully.

Ruderal: Plants that colonize disturbed sites, bare soil, or waste piles.

Seep: Spot where water trickles out of the ground.

Segetal: Plants that grow inter-mixed with crop species.

Sensitive area: Area that is deemed in need of protection. Sensitive areas may include areas with a rare, Threatened, or Endangered species; a unique native community; or physical resources. Sensitive areas may also be areas prone to disturbance such as erosion or crushing of cinder.

Septic tank: Tank used in the collection of human waste and gray water in which solid materials settle to the bottom and liquid waste is discharged onto a leach field (an area lined with highly porous materials allowing effluent to seep into the ground).

Site recycling: Reuse of a previously developed site. In the case of the observatories, refers to removal of an old observatory and replacement with a new one.

Snowpack: Accumulation of naturally formed, packed snow over an area that usually melts during the warmer months.

Species of Concern: Those species that might be in need of conservation action, but that are not currently Listed or Candidate species. Species of Concern receive no legal protection and use of the term does not necessarily imply that a species will eventually be proposed for listing.

Spring: Ground water discharging out of the earth where the water table meets the ground surface.

Stratigraphy: Geology discipline dealing with the origin, composition, distribution, and succession of strata (layers of sedimentary rock); the arrangement of strata.

Subalpine: Of, relating to, or inhabiting high upland slopes and especially the zone just below the timberline. On Mauna Kea, the subalpine region occurs from approximately 5,600 ft to 9,800 ft (1,700 m to 3,000 m) elevation.

Sublimation: Process by which water in its solid phase is transformed directly to vapor phase without first passing through the liquid phase. Sublimation rates are highest in areas where relative humidity is low, dry winds are present, and at high elevations where atmospheric pressure is low and sunlight is strong.

Subsidence: To sink; to tend downward. Refers to the slow process of volcanic island sinking due to the continued accumulation of extruded material and associated weight.

Tephra: Fragments of volcanic rock and lava regardless of size that are blasted into the air by explosions or carried upward by hot gases in eruption columns or lava fountains. Tephra includes large dense blocks and bombs, and small light rock debris that have usually solidified prior to hitting the ground.

Tholeiitic: Igneous rock chemical classification based on total alkali (Na_2O+K_2O) vs. silica (SiO_2) content; tholeiitic rocks have less total alkali than alkalic rocks at the same silica content.

Threatened and Endangered Species: Plant or animal that is in danger of extinction throughout all, or a significant portion, of its range. Federally listed threatened and endangered species are those species that the US Fish and Wildlife Service has determined require federal action to protect them. Protection of Federally listed threatened and endangered species is mandated by the United States Endangered Species Act, 1973.

Ungulate: Hoofed, typically herbivorous, quadruped mammal.

Upwelling: Process or an instance of rising or appearing to rise to the surface.

Vascular plant: Plant with water and fluid conductive tissue (xylem and phloem); includes seed plants, ferns, and fern allies. Does not include fungus, lichens or mosses.

Weathering: Physical disintegration and chemical decomposition of earth materials at or near the earth's surface.

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