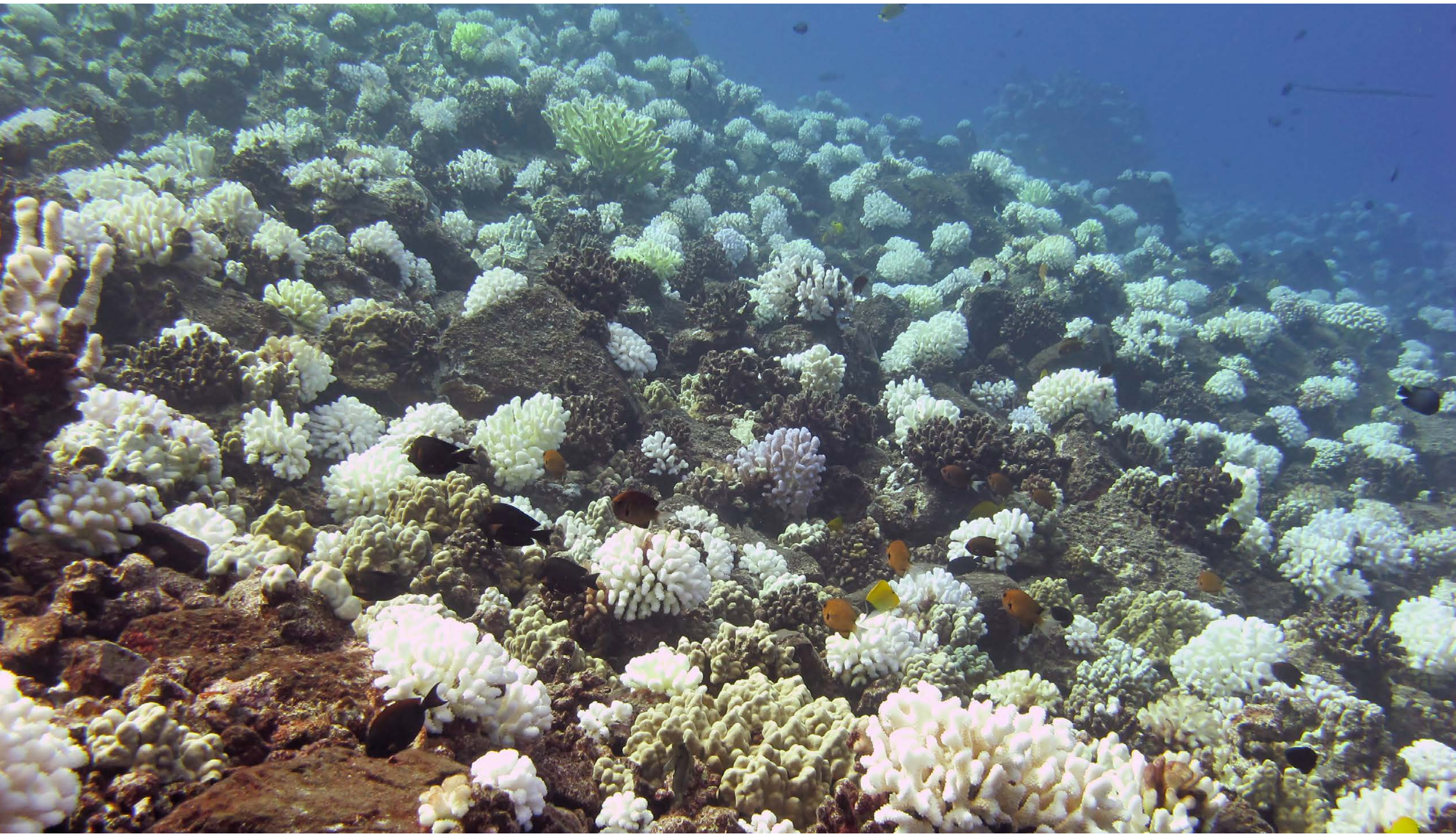
Coral Bleaching Recovery Plan

Identifying Management Responses to Promote Coral Recovery in Hawai‘i



PREPARED FOR

Department of Land and Natural Resources, Division of Aquatic Resources

PREPARED BY

University of Hawai‘i, Social Science Research Institute

MARCH 2017

This report was made possible by:

The NOAA Coral Reef Conservation Program and the
Department of Land and Natural Resources, Division of Aquatic Resources

NA15NOS4820037

Cover image: *Molokini crater at the peak of the coral bleaching event, October 31, 2015.*
Photo credit: *Darla White, Maui Division of Aquatic Resources*

Contents

Executive Summary

GOALS / OBJECTIVES

The goal of the Coral Bleaching Recovery Plan is to promote coral reef recovery following the 2014-2015 global coral bleaching event. Coral bleaching is a stress response, generally induced by high temperature and light levels, where the coral animal expels zooxanthellae, or photosynthetic dinoflagellates that provide coral polyps with energy. Bleached corals are in a weakened state and will eventually die if temperature and light levels remain high. We sought to identify management interventions most likely to promote coral recovery following the mass bleaching event in Hawaiʻi, specifically by synthesizing published information and expert opinions relevant to future policy and rule making by the Department of Land and Natural Resources (DLNR). The Coral Bleaching Recovery Plan summarizes these findings, with the goal of supporting effective capacity to implement management actions to promote coral recovery in Hawaiʻi.

HAWAIʻI'S MASS BLEACHING EVENT (2014/2015)

In August 2014, thermal stress began to cause bleaching throughout the Hawaiian Archipelago. In the main Hawaiian Islands, the majority of bleaching was observed around Kauai, Oahu, and Maui [23]. In 2015, bleaching was severe, with the most extreme bleaching occurring in west Hawaiʻi and Maui. The bleaching event resulted in extensive coral mortality, especially in west Hawaiʻi and Maui. Although mortality varied among sites, overall average coral cover loss at surveyed sites in west Hawaiʻi was 49.7% as a result of the 2015 bleaching event [25]. Bleaching mortality rates were especially catastrophic for important reef-building species; for example, *Porites lobata* mortality was 55%, while for *P. compressa* it was 33% [25]. Coral mortality rate of Maui's corals was estimated at 20-40% following the 2015 bleaching event [27].

DEVELOPING A CORAL BLEACHING RECOVERY STRATEGY

To develop a strategy to promote coral recovery following the mass bleaching event, we synthesized management recommendations in four major steps: 1) define the role of resource managers, 2) collect global expert opinion on ecologically effective management actions, 3) collect Hawaiʻi-based expert opinion on effective management actions, and 4) analyze empirical evidence describing how the top ranked management actions could meet our recovery objectives.

CONCLUSIONS

Establishing a network of permanent no-take Marine Protected Areas (MPAs) and establishing a network of Herbivore Fishery Management Areas (HFMAs) were the top ranked actions arising from the expert judgment assessments and the literature analysis.

Thus, our analysis indicates that spatial management and particularly, herbivore management, will be critical to post-bleaching coral recovery in Hawai'i. These were top ranked actions in both evaluations of global and local expert judgment as well as scientific literature. Additionally, there were some differences between management actions ranked most highly by experts and the evidence derived from the scientific literature. For example, reducing sediment stress was ranked highly by experts but did not come out as an important action from the literature analysis. This may be because the experts that were surveyed in this study were not explicitly asked to consider the feasibility of each management action. Thus, as part of our findings, we discuss the caveats of our analysis, including the limitations associated with the use of expert opinion to inform management decisions. Our evaluations were inherently subjective, as scientific papers tend to focus on research questions rather than feasible management outcome.

The next step in the coral bleaching recovery planning process should be to evaluate where the top-ranked actions including spatial management and perhaps a selection of fisheries rules would have the greatest positive impact in terms of coral reef recovery. This is still an open question because, as the literature emphasized, management actions will not have a consistent effect based on the natural ecological variability among different reef areas. This spatial prioritization should consider minimizing social cost and consider the management feasibility of actions that are seriously being considered for implementation. Finally, an evaluation of how management actions could enhance resiliency to future coral bleaching events is needed. Bleaching events are predicted to increase in both severity and frequency and so a proactive, resilience-based management framework should be considered to support the ability of Hawai'i's reefs to resist frequent climate disturbances.

Section One: Introduction

Coral Bleaching Recovery Steering Committee

All elements of this plan were co-developed and reviewed through an initial scientific steering committee, and then reviewed by the Department of Land and Natural Resources (DLNR), Division of Aquatic Resources (DAR) which also provided input to the initial structure of the plan and the final plan content.

Anne Rosinski
University of Hawai'i (UH), Hawaii Coral Reef Initiative

Charles Birkeland
University of Hawai'i (UH)

Darla White
DAR

Eric Conklin
The Nature Conservancy (TNC)

Ivor Williams
NOAA Pacific Islands Fisheries Science Center (PIFSC)

Jamison Gove
NOAA Pacific Islands Fisheries Science Center (PIFSC)

Kelvin Gorospe
NOAA Pacific Islands Fisheries Science Center (PIFSC)

Tom Oliver
NOAA Pacific Islands Fisheries Science Center (PIFSC)

William Walsh
DAR

Goals & Background

The goal of the Coral Bleaching Recovery Plan is to promote coral reef recovery following the 2014-2015 global coral bleaching event. Coral bleaching is a stress response, most commonly induced by high temperatures and light levels, in which the coral animal expels zooxanthellae, the photosynthetic dinoflagellates that provide coral polyps with much of their energy. Without zooxanthellae, coral becomes more susceptible to diseases and if the stress, in this case a period of high ocean temperatures, is sustained, coral mortality will occur. Coral bleaching events typically occur during the warmest time of year, in Hawai'i this is between August and October.

Coral mortality caused by frequent coral bleaching events leads to systematic changes in the structure of tropical ecosystems [1-6]. Mass coral bleaching events are occurring with more severity and frequency, negatively affecting coral reefs worldwide with both short and long-term impacts [7-11]. Studies of coral bleaching in Hawai'i have mainly focused on physiological processes including acclimation potential [12,13], mechanisms and breakdowns in coral metabolism [14,15], and the role of reef environmental parameters and reef morphology on coral bleaching patterns [16]. Thus, despite the pressing consequences of increasingly frequent coral bleaching events, direct management interventions to promote recovery from a bleaching event have been extremely limited [17-20].

We sought to identify management interventions that could promote coral recovery to Hawai'i's mass bleaching by synthesizing information that could directly support future policy and rule making by the Hawai'i DAR. This process began with an announcement by DAR that they would initiate comprehensive coral reef management planning, prompted by the unprecedented coral bleaching throughout the state (Figure 1). The first step in the planning process was to synthesize peer-reviewed literature to identify the role of resource managers in coral bleaching recovery and to collect case studies of previous management interventions following a mass bleaching event. Then, we collected opinions from global coral bleaching experts on which management interventions they felt would be most ecologically effective in Hawai'i.

Through a workshop with Hawai'i-based coral experts, potential management actions were further prioritized. The workshop group also ranked specific actions that DAR could take in four priority areas: west Hawai'i, Maui, Kāne'ohe Bay, and North Kaua'i. Finally, the top-ranked management interventions were further analyzed in a process to investigate how well each action met our recovery objectives. The Coral Bleaching Recovery Plan synthesizes the information garnered from these steps to support DAR's decision-making process to implement management interventions to promote coral recovery and resiliency throughout the state. Online resources for this plan can be found at **http://dlnr.hawaii.gov/reefresponse/**.

Figure 1. Timeline of planning process steps from announcement of the Coral Bleaching Recovery Plan to public release.

November 2015
DAR announced development of a Coral Bleaching Recovery Plan

January–March 2016
Collect global opinions through the Coral Bleaching Recovery Survey

February–May 2016
Synthesized peer-reviewed literature related to coral bleaching and recovery

August 2016
Analyzed recommendations with local expert researchers and DAR staff at the Coral Bleaching Recovery Workshop

October 2016–February 2017
Writing the Coral Bleaching Recovery Plan

March 2017
The final Coral Bleaching Recovery Plan is released

Hawai'i's Mass Bleaching Event (2014/2015)

2014 Beginning in early spring 2014, NOAA Coral Reef Watch reported the appearance of positive sea surface temperature (SST) anomalies that suggested the development of an El Niño event [21]. The coral bleaching event was specifically triggered by a combination of warming in the North Pacific Ocean, was the Pacific Decadal Oscillation, and "The Blob", a large mass of warm ocean water that developed and stayed in the Pacific Ocean off the coast of North America [21]. By late August 2014, thermal stress began to cause bleaching throughout the Hawaiian Archipelago. The high thermal stress in Hawai'i started in the central portion of the archipelago around the Northwest Hawaiian Islands (NWHI).

The accumulation of thermal stress can be measured in Degree Heating Weeks (DHW). For example, if sea surface temperatures exceed the bleaching threshold for by one degree for one week, that's a DHW value of 1. When the DHW metric reaches 4 °C-Weeks, substantial coral bleaching typically occurs. If DHW values reach 8 °C-Weeks, widespread bleaching is likely and significant coral mortality can be expected. During the 2014 event in the NWHI, certain areas experienced up to 15 °C-Weeks (see **Appendix A** for NOAA Coral Reef Watch satellite data). This marked the third and most severe coral bleaching event on record in the NWHI. Areas severely affected included French Frigate Shoals and Lisianski Island, especially on *Montipora*-dominated reefs [22].

High temperature anomalies then spread both to the west and east, reaching the main Hawaiian Islands in late-September 2014 [21]. In the main Hawaiian Islands, the majority of bleaching was observed around Kaua'i, O'ahu, and Maui [23]. Areas of Kāne'ohe Bay, O'ahu were especially impacted in part because of compounding effects of a flooding event during the bleaching event [24]. DAR surveys indicate that over 10 species of coral were affected by the 2014 bleaching event in Kāne'ohe Bay [23]. On average, three out of four dominant coral species' colonies exhibited some sign of bleaching, with northern areas of Kāne'ohe showing the worst bleaching, while reefs in the central part of the bay exhibiting less bleaching [23].

In Kāne'ohe Bay, the majority of coral colonies tagged by DAR had returning color and were recovering in December 2014, while 12% of colonies had died (Figure 2). Relative to O'ahu, other areas including west Hawai'i and Maui had some moderate to minimal bleaching in 2014.

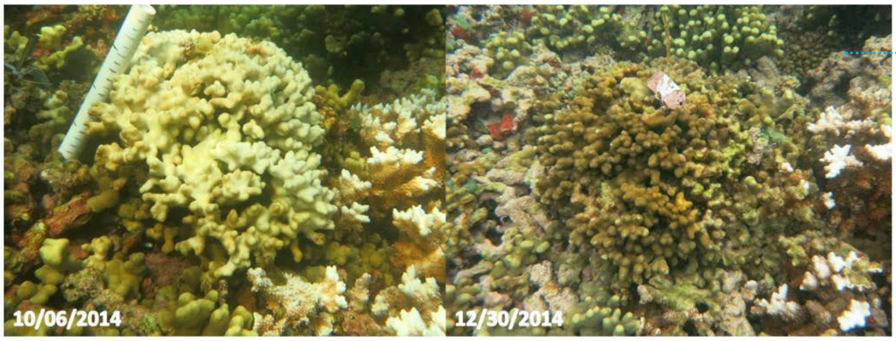
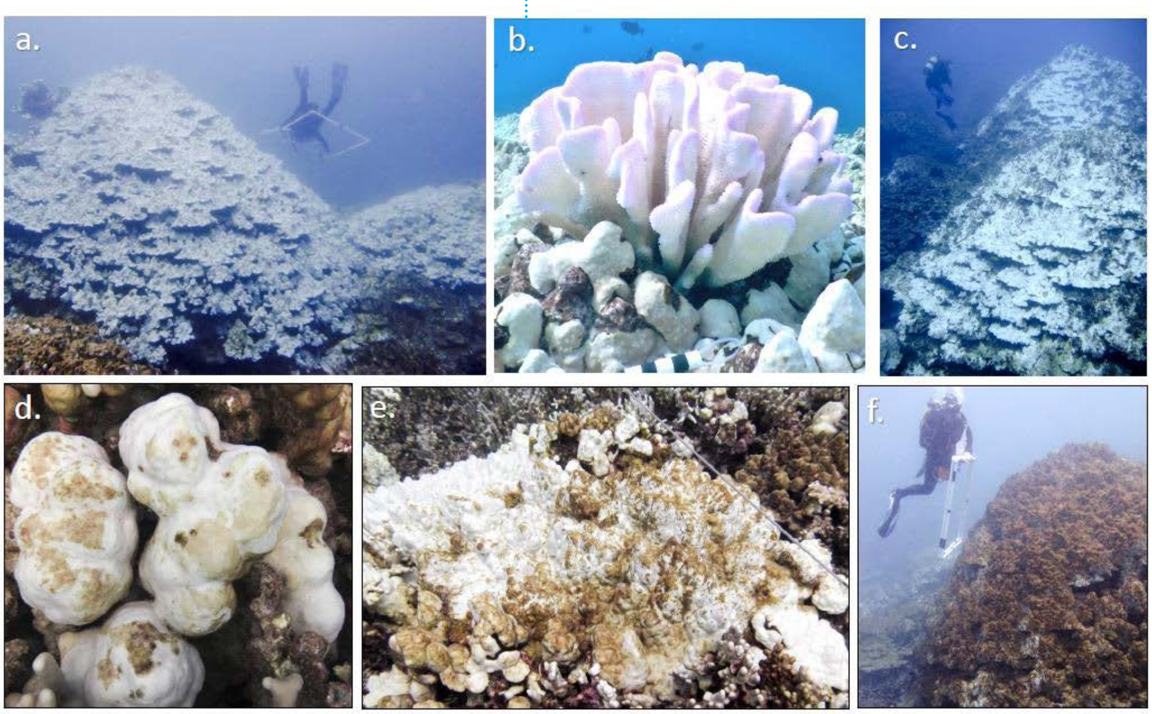


Figure 2.
A coral colony tagged in Kāne'ohe Bay by DAR showing significant bleaching in October 2014 (left) and re-coloring in December 2014 (right). Photos: DAR

Figure 3.
Images from coral bleaching survey sites in west Hawai'i a) severely bleached Porites evermanni at N. Keauhou, b) severely bleached Pocillopora eydouxi and Porites lobata colonies at Honokōhau, c) initial turf colonization on P. evermanni at N. Keahou, d) and e) initial algal turf colonization on P. lobata at Honokōhau, and f) algal turf colonization of recently dead P. evermanni at N. Keauhou (post-bleaching mortality), from Kramer et al. 2016.

2015 Global-scale bleaching occurred again in 2015, and the NOAA Coral Reef Watch program declared the third ever global coral bleaching event based on their suite of satellite monitoring products [25]. This intense temperature anomaly again resulted in coral bleaching throughout the Hawaiian archipelago, this time with higher severity particularly in the southern islands (Figure 3).



The stress exhibited on corals from the 2015 event peaked at 12 °C-Weeks. Severe mass bleaching was observed in west Hawai'i and Maui, with minimal bleaching observed around O'ahu and Kaua'i. In west Hawai'i, there was site-level variation in bleaching prevalence, in South Kohala region averaging 53% but other areas in west Hawai'i reaching up to 93% average bleaching prevalence [26, 27]. Among the most affected sites were shallow regions at Kanekanaka, Kawaihae and 'Ōhai'ula (Spencer Beach) where 80-85% of the corals severely bleached [26]. Bleaching was also observed on Maui, particularly on southern and western-facing shores [28].

West Hawai'i and Maui had the highest levels of mortality following the 2015 bleaching event (Figure 4, Figure 5). Although mortality varied among sites, overall average coral cover loss at surveyed sites in west Hawai'i was 49.7% as a result of the 2015 bleaching event [26]. Bleaching mortality rates were especially catastrophic for important reef-building species; for example, *Porites lobata* mortality was 55%, while for *P. compressa* it was 33% [26]. Coral mortality rate of Maui's corals was estimated at 20-40% following the 2015 bleaching event [28].

Figure 4. Percent change in hard coral cover between 2013/2015 and 2016 NOAA-PIFSC CREP Fish Team visual surveys. Data and graphs by NOAA-PIFSC

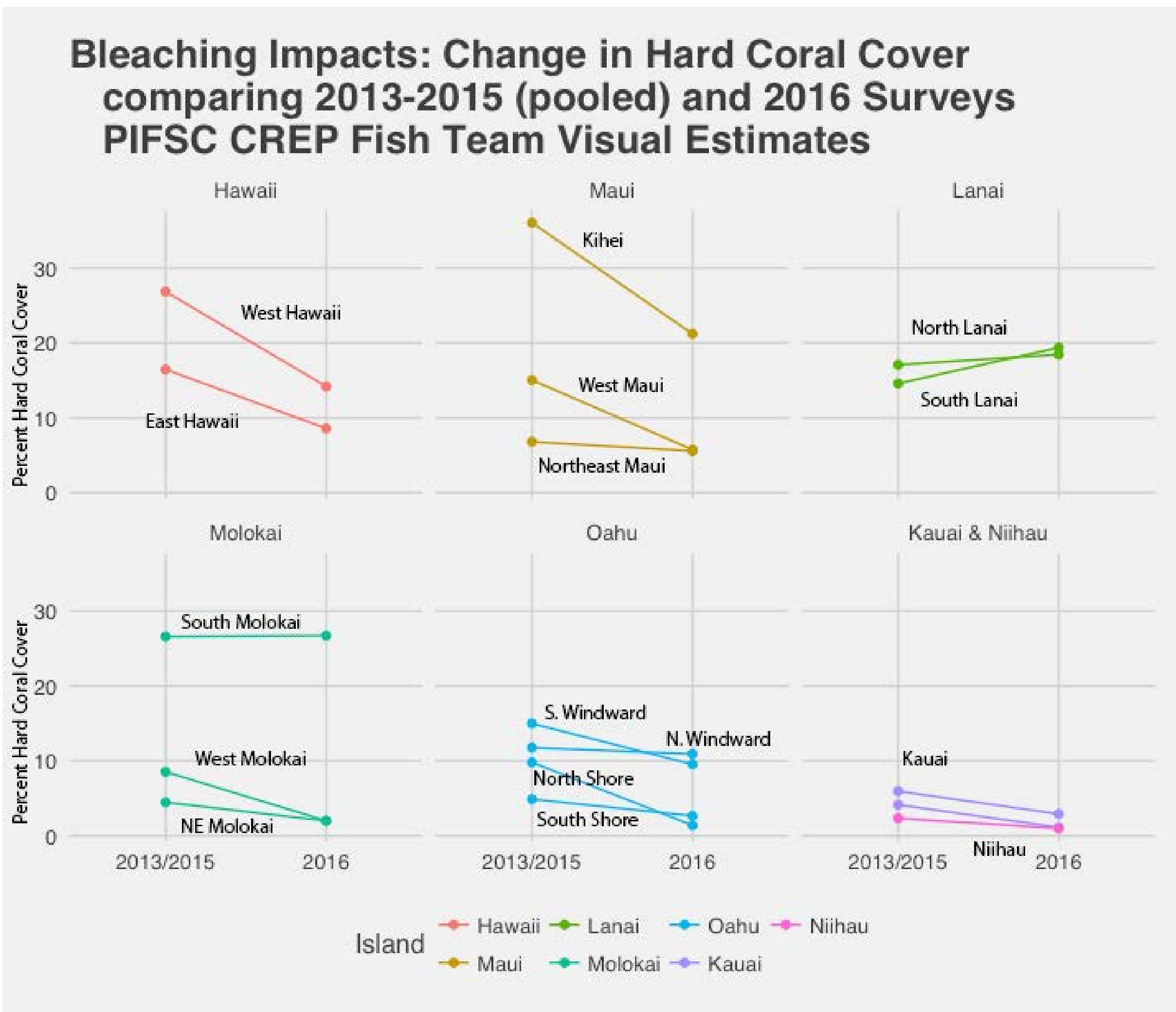


Figure 5a. Percentage of mean bleaching prevalence around the Main Hawaiian Islands in 2014 and 2015 presented at the sector (coastline) scale. Data provided by the Hawai'i Coral Bleaching Collaborative and map made by NOAA-PIFSC.

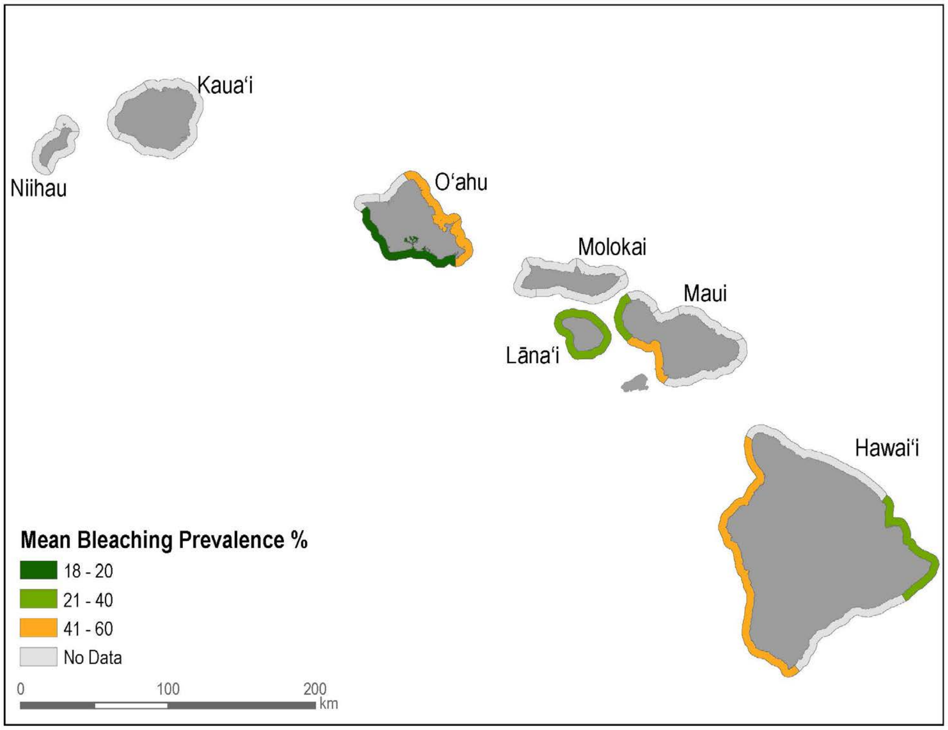
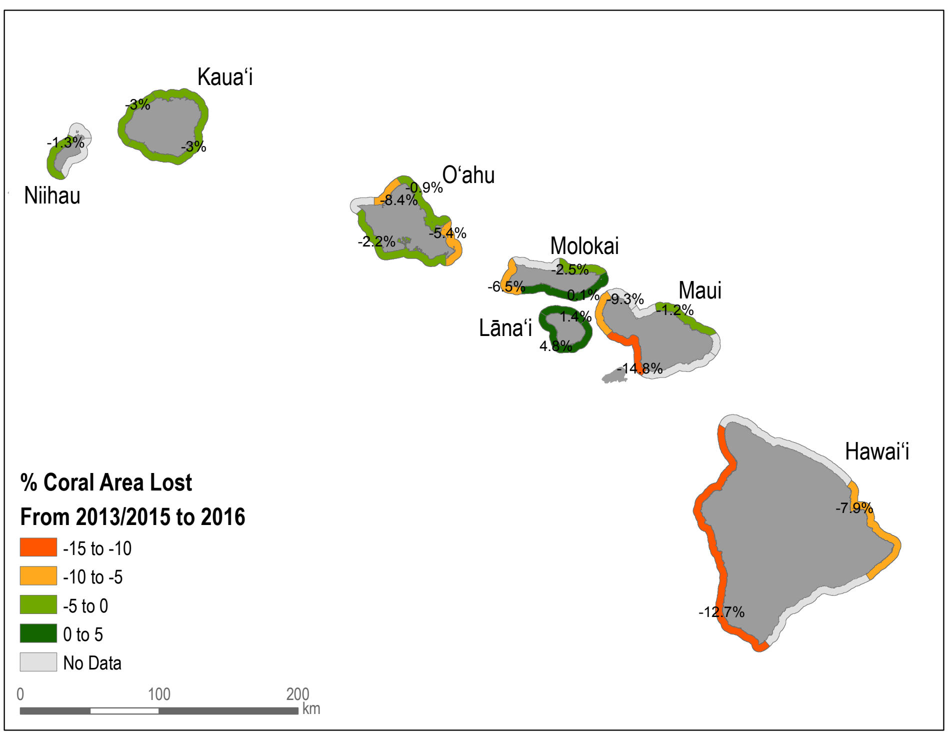
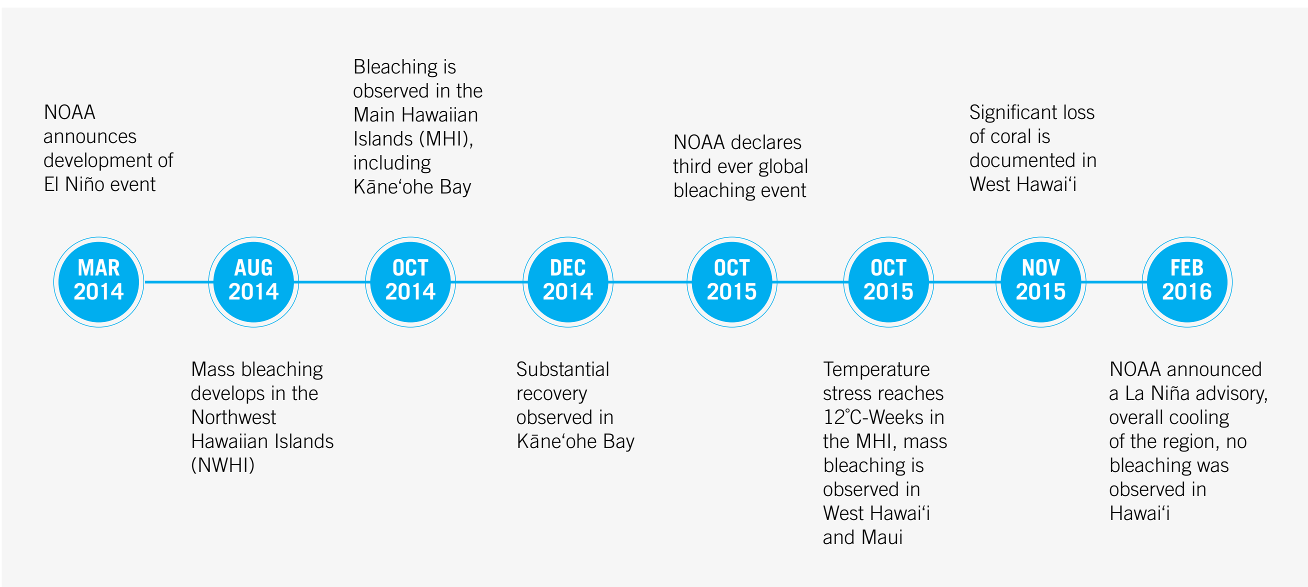


Figure 5b. Percent coral cover lost from 2013/2015 (combined) and 2016 around the Main Hawaiian Islands from visual estimates of % coral area. Data and map by NOAA-PIFSC.



2016 On November 3, 2016 the NOAA Coral Reef Watch program provided an update on the status of the temperature anomaly, which included a La Niña Advisory [29]. Negative SST anomalies were occurring across much of the eastern and central equatorial Pacific Ocean, suggesting an overall cooling of the region. It is thought that La Niña conditions will persist through winter 2016-17 and it is not forecasted that Hawai'i will experience another coral bleaching event during this period (as of February 2017) (Figure 6).

Figure 6. Timeline of important events during the 2014 - 2016 mass coral bleaching event in Hawai'i



Section Two: Developing a Coral Bleaching Recovery Strategy

A bleaching event can lead to a shift in the coral reef ecosystem from a coral-dominated state to an algal-dominated state. This alternative state is less desirable because it is generally less valuable and provides less ecosystem services.

Coral reef decline can be permanent or temporary, depending on its resilience, which is a reef's ability to absorb disturbance (e.g. a bleaching event) and respond to change while maintaining the same function, and thus providing the same ecosystem services[1]. Coral reef resilience has three components: tolerance, or the ability to survive bleaching; resistance, or the ability of corals to withstand high temperatures without bleaching; and recovery, or the ability of coral to be replenished after a significant mortality event [20].

Despite the potential loss of ecosystem services, there have been few examples worldwide of the practical implementation of resilience principles into management action [30, 31]. Recently, a resilience-based management framework has been proposed, which integrates resilience theory into coral reef management through the identification of management 'levers' [32]. Levers are management actions that will have a direct impact on the specific management objective within the resilience framework. However, this process identifies broad suite of actions, or approaches, that managers could implement (e.g. 'reduce fishing of herbivores') and did not a) identify specific actions that managers could take (e.g. bag limits versus size limits, etc.) or b) prioritize these actions on a site-specific level.

The Coral Bleaching Recovery Plan focuses on the third aspect of coral reef resilience–recovery from a significant mortality event. To develop a strategy to promote coral recovery following the mass bleaching event in Hawaii, we developed a strategy which has four steps:

1. **Define the role of resource managers**
2. **Select priority areas for management implementation**
3. **Gather expert judgment on ecologically effective management actions**
4. **Analyze empirical evidence describing how the most highly ranked management actions could meet our recovery objectives**

Defining the role of the resource manager was needed to understand the full array of potential actions managers could take particularly following a mass bleaching event as well as investigate what actions managers have previously taken. Surveying coral bleaching experts on both a global and local scale allowed narrow the possibilities of management action based on expert judgment, which is a method commonly used commonly used in management decisions, especially when there is urgency to the decision-making process or a lack of other credible sources of information [33]. Expert judgment can be particularly useful in situations where certain parameters are not easily assessed (for example future conditions or the effects of hypothetical actions) [34-37]. Despite the usefulness of expert opinion, the use of this approach naturally creates some uncertainty [33, 38]. The use of scientific literature has its own level of uncertainty, as the limitations of individual studies in terms of their wider application, may not be thoroughly discussed [39]. For the purposes of the Coral Bleaching Recovery Plan, we ultimately based our conclusions on management actions that were prioritized in both expert judgment and the literature analyses.

[1] This definition refers to 'resilience' as described in: Holling, C. 1973. Resilience and Stability of Ecological Systems. Annual review of Ecology and Systematics. 4.1: 1-23.

Part 1: Defining the Role of Resource Managers

The first step in the development of the Coral Bleaching Recovery Plan was to review scientific literature to define the potential role of resource managers following a bleaching event. Primary literature and management reports were gathered from the Coral Bleaching Working Group, the Web of Science database, Google Scholar, and the Reef Resilience Network. Database search terms included 'coral bleaching AND management', 'coral bleaching AND recovery', and 'coral bleaching AND intervention.'

We reviewed and analyzed over 200 peer-reviewed articles and reports categorizing management recommendations and looking for intervention case studies[2]. The literature analysis identified five potential goals that resource managers could have when intervening following a bleaching event: 1) prevent additional damage to coral, 2) control algal overgrowth, 3) stimulate new coral settlement, 4) stimulate coral regrowth and 5) replace dead coral (Figure 7). The five goals each link to specific strategies that could be used to achieve the goal, which are additionally linked to the ecological goal through a mechanism.

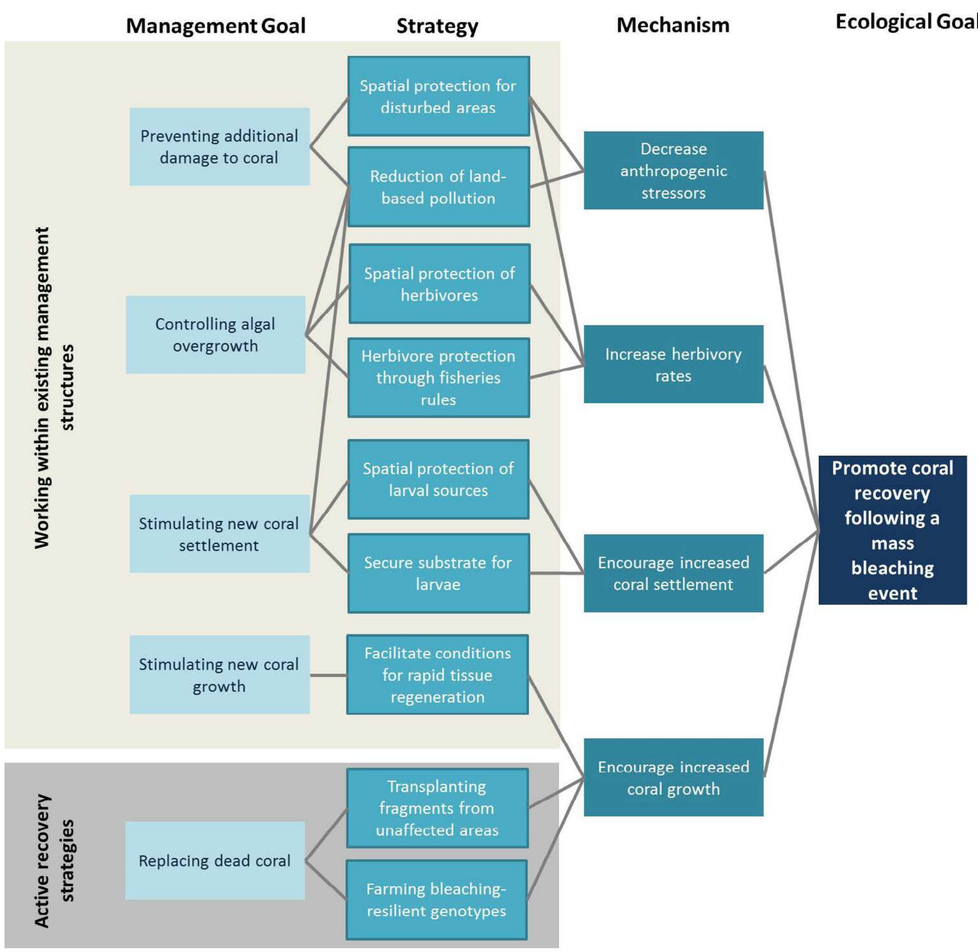


Figure 7. Illustration of the connections between the ecological and management goals following a mass bleaching event based on a review of over 200 peer-reviewed scientific articles and reports. The framework depicts managers intervening in one of two broad categories: either within existing management structures or employing active recovery strategies. Five management goals were identified that would employ a combination of nine strategies. The strategies are linked to the ecological goal of promoting coral recovery through a mechanism.

[2] For a full description of the methods and analysis of coral bleaching literature, as well as detailed descriptions of each case study, please refer to this report: https://dlnr.hawaii.gov/reefresponse/files/2016/09/literature-review_final-report_FINAL.pdf

'Preventing additional damage to coral' refers to the management goal of protecting coral reef areas from stressors which may compound the effect of a bleaching event. Examples of these stressors could include over-fishing, land-based pollution, or physical breakage from boats, trampling, etc. 'Controlling algal overgrowth' refers to the goal of preventing or potentially reversing a phase shift from a coral-dominated system to an algal-dominated system. 'Stimulating new coral settlement' refers to the goal of managers creating conditions which is conducive to coral larvae settling and eventually replacing the dead coral. 'Stimulating coral regrowth' refers to mangers creating conditions under which remnant coral that has survived the bleaching event can rapidly regrow and populate the dead area. These goals all under the overarching category of mangers working within existing management structures, meaning bolstering rules and regulations that are likely ongoing and relying on natural recovery processes. 'Replacing dead coral' refers to managers either by growing replacement corals in a nursery and then transplanting them to a bleaching affected area or by transplanting healthy corals from an unaffected area to the bleached reef. This goal falls under the active recovery category, meaning managers would actively intervene to physically restore bleaching affected areas.

Only a subset of the 200 reviewed papers referred to specific management goal. Of the papers that specifically referred to one of the management goals, the most frequently recommended goals were 'preventing additional damage to coral', which was recommended 42 times and 'controlling algal overgrowth', which was recommended 35 times. The least frequently recommended goal was 'stimulating coral regrowth' (Figure 8). Several papers recommended a combination of these goals.

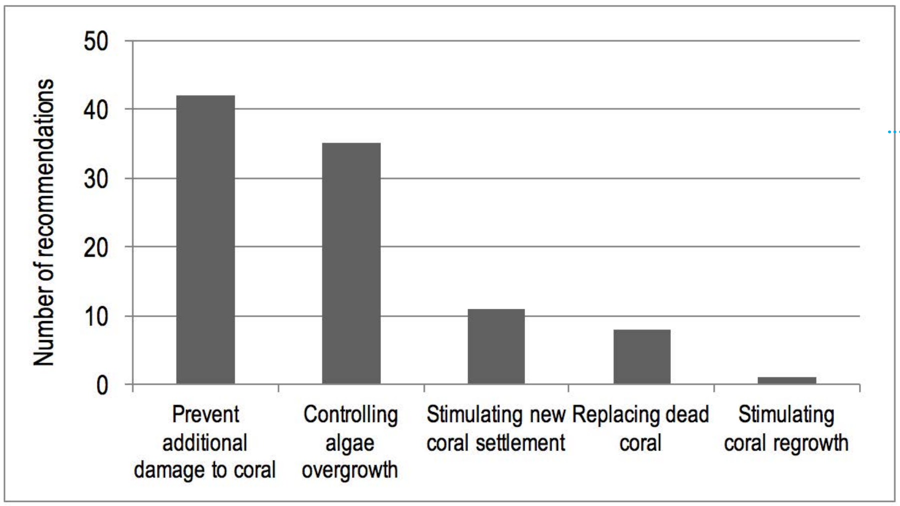


Figure 8.
Number of times management goals were recommended in the reviewed literature. Only a subset of articles addressed a specific management goal and several papers recommended a combination of these goals.

Preventing Additional Damage to Coral

Preventing additional damage to coral allows for the natural recovery of dead or damaged corals. In the literature, the main management action to prevent additional damage to coral reef areas following a bleaching event was the creation of MPAs [18, 40, 41]. The need for new management approaches for exploited areas outside of MPAs was also acknowledged [40, 42]. It was strongly suggested that these protected areas should be placed on and around reefs that have naturally higher resiliency to bleaching events [43-56]. Additional actions to prevent damage included the, reduction of harmful sediment, nutrients, and other pollutants.

Controlling Algal Overgrowth

Controlling algal overgrowth allows for the settlement of new coral recruits and helps to prevent phase shifts excessive algae. Preventing overgrowth prevents reefs from becoming dominated by algae that inhibit coral growth and recruitment (e.g. thick turfs and macroalgae) and increases cover of algae that are benign or inferior competitors to corals (e.g. heavily cropped turfs and crustose coralline algae)–and can therefore lead to substantially better outcomes for resident corals. The majority of such studies have pointed to the protection of herbivores, especially parrotfish, as being critical to effective management. Protection of herbivores from fishing pressure has been projected to delay rates of coral loss even under the most extreme bleaching and other disturbance events [57]. Where fishing pressure on herbivores is high, two main strategies have been suggested: spatial management and the implementation of fisheries restrictions (e.g. bag and size limits). The use of MPAs focusing on the protection of herbivores has been cited in multiple studies as a successful strategy to protect herbivore populations [3, 58-60].

Protecting Herbivores

The literature emphasizes that not all herbivores have equal effects on rates of coral recovery, and that managers should target those species, functional groups, and sizes that have the greatest local impacts [2, 61-63]. Many researchers have focused on parrotfish (*Labridae*, subfamily *Scarinae*) and their role in the removal of algae from coral reefs following disturbance. As with other herbivores, it has been found that their effect differs among species, functional groups, and sizes, with larger individuals having greatest impacts on benthic condition [2, 64]. A recent action to protect parrotfish in Belize through a fishing ban was found to have increased the resilience of surrounding reefs six-fold [64].

Regarding specific fisheries management objectives, a recent study concluded that for Caribbean reefs, the implementation of a harvest limit of 10% of parrotfish biomass and a minimum size of 30cm would greatly increase coral resilience to climate change [65].

Stimulating New Coral Settlement

Stimulating new coral settlement is a recommended strategy for management actions ensuring larval connectivity to the affected area. [51, 66]. It is important to ensure that larval sources maintain a diverse gene pool to the settlement area [67]. Adequate substrate is also imperative; measures should be taken to ensure adequate hard-bottom habitat in the receiving site [78]. There remains a need to bring together connectivity, larval settlement, and post-settlement mortality science to ensure that management targets the most valuable areas [66].

Several strategies have been suggested proposed to encourage settlement of new coral to bleached areas. For example, McLeod et al. (2009) and Magris et al. (2014) discuss the use of MPAs to protect sources of larvae [54, 69]. Amar and Rinkevich (2007) explored the use of active restoration to create coral nurseries as ‘larval dispersion hub.’ These farmed colonies had 35% higher oocytes, or egg cells, per polyp and developed faster than their natural counterparts [70]. A restoration effort in the Philippines following a dynamite blast used plastic mesh to secure loose substrate and found that coral recruitment and percent coral cover increased within 3 years [71]. Lastly, it has been found that early coral life stages are particularly vulnerable to human stressors, so focusing on land-based pollution may also be a strategy to promote settlement of coral larvae [51].

Replacing Dead Coral

Focusing on replacing the coral killed by a bleaching event with new coral from another location is a relatively novel active restoration method. The two main methods mentioned in the literature are: 1) collecting fragments from unaffected areas, and 2) farming bleaching-resilient genotypes to plant in the restoration area. Gomez et al. (2014) collected fragments from unaffected reefs in the Philippines following a bleaching event and transplanted them to the damaged area. After three years, they documented increased coral cover as well as fish becoming attracted to the new reef [72]. This gardening method has been used extensively in the Caribbean for the restoration of staghorn and elkhorn corals [73]. Selecting and farming bleaching-resistant species is also a relatively new phenomenon, but it is gaining momentum for Caribbean corals [66]. The hope is to target genotypes that are also resistant to other stressors such as disease.

Stimulating New Coral Growth

A few papers documented instances where conditions following a coral bleaching event stimulated the rapid recovery from remnant live tissue. On the Great Barrier Reef, areas dominated by Acropora spp. was found to recover quickly (less than one year) due to rapid regeneration and competition with invasive algae (Lobophora variegata) [74]. Roff et al. 2014 described a phenomenon called the 'phoenix effect,' where small, hidden patches of live tissue in a French Polynesia lagoon environment quickly overgrew dead coral and led to rapid recovery of the lagoon area [75]. Finally, Graham 2013 described how if detrimental human impacts could be reduced in the area, pulsed disturbance events could 'jump-start' a return to a coral-dominated state [5]. However, all of these papers describe natural phenomena, lacking direct management intervention. In addition, these are unique and rare case studies and so shouldn't be relied upon by managers as a foundational goal.

Case Studies of Resource Managers Intervening Following a Bleaching Event

Of the 207 papers that were reviewed, only six examples were found of managers directly intervening following a bleaching event to assist in the recovery of those reef areas (Table 1). These efforts fell into two of the management goal categories described above: 1) 'preventing additional damage' to corals and 2) 'replacing dead coral'. It is notable that there are only a hand full of management intervention examples and also that these examples do not align with the majority of recommended actions in the scientific literature (which instead point to 'preventing additional damage' through the implementation of MPAs and controlling algal overgrowth through the effective management of coral reef herbivores). It is currently unknown what prevented managers from developing management goals that were more aligned with the scientific recommendations. Additionally, there was little evidence that these interventions ultimately promoted coral recovery following the bleaching event.

Table 1. Case studies of direct management interventions following a coral bleaching event

PUBLICATION	LOCATION	RESOURCE MANAGER ROLE	SPECIFIC STRATEGY DISCUSSED	OUTCOME	TIME SCALE OF EFFORT
Beeden et al. 2014 [76]	Great Barrier Reef, Keppel Islands	Preventing additional damage	Creation of no-anchor zones	Reduced anchor damage from ~80 to less than 10, coral continued to decline	4 years
Yeemin et al. 2012 [77], Tun et al. 2010 [78]	Malaysia, Thailand	Preventing additional damage	Closure of high-traffic dive sites	No biological outcome could be found, some conflict between managers and dive site users resulted	4-14 months
GBRMPA 2008 [79], Bonin et al. 2016 [80]	Great Barrier Reef, Keppel Islands	Preventing additional damage	Self-moratorium on aquarium collecting	No biological outcome found; MPA network supports larval dispersal	8 years
Gomez et al. 2014 [72]	Philippines, Bolinao	Replacing dead coral	Transplantation of coral fragments to degraded, formerly bleached area	After 12 months, recorded high survivorship (~95%), extensive coral cover; after 16 months more transplanted colonies were fusing and reef fish using the new habitat	3.5 years
Mbije et al. 2013 [81]	Tanzania	Replacing dead coral	Transplantation of coral fragments to degraded, formerly bleached area	After one year, saw high surviorship of transplants, low cost showed that transplantation could maintain ecosystem function	12 months
McClanahan et al. 2005 [82]	Kenya	Replacing dead coral	Transplantation of bleaching-resistant corals to formerly bleached area	Transplantated corals were heavily preyed upon by coral-eating fish, which limited coral recovery	6 months

Part 2: Selecting Priority Areas

Four priority areas for management intervention have been identified, which were chosen because they had the highest levels of either exposure to high ocean temperatures and/or had the highest levels coral mortality following the 2014/2015 bleaching event. The four priority areas are: west Hawai‘i, leeward Maui, Kāne‘ohe Bay (O‘ahu) and North Kaua‘i (Figure 8). The priority areas serve as templates for where management interventions are most needed. Hawai‘i’s coral reef scientists and managers worked collaboratively to identify potential management implementation obstacles and opportunities as well as research needs identified for each of the four areas. These lists which may serve as a guide for future management implementation (see **Appendix B**).

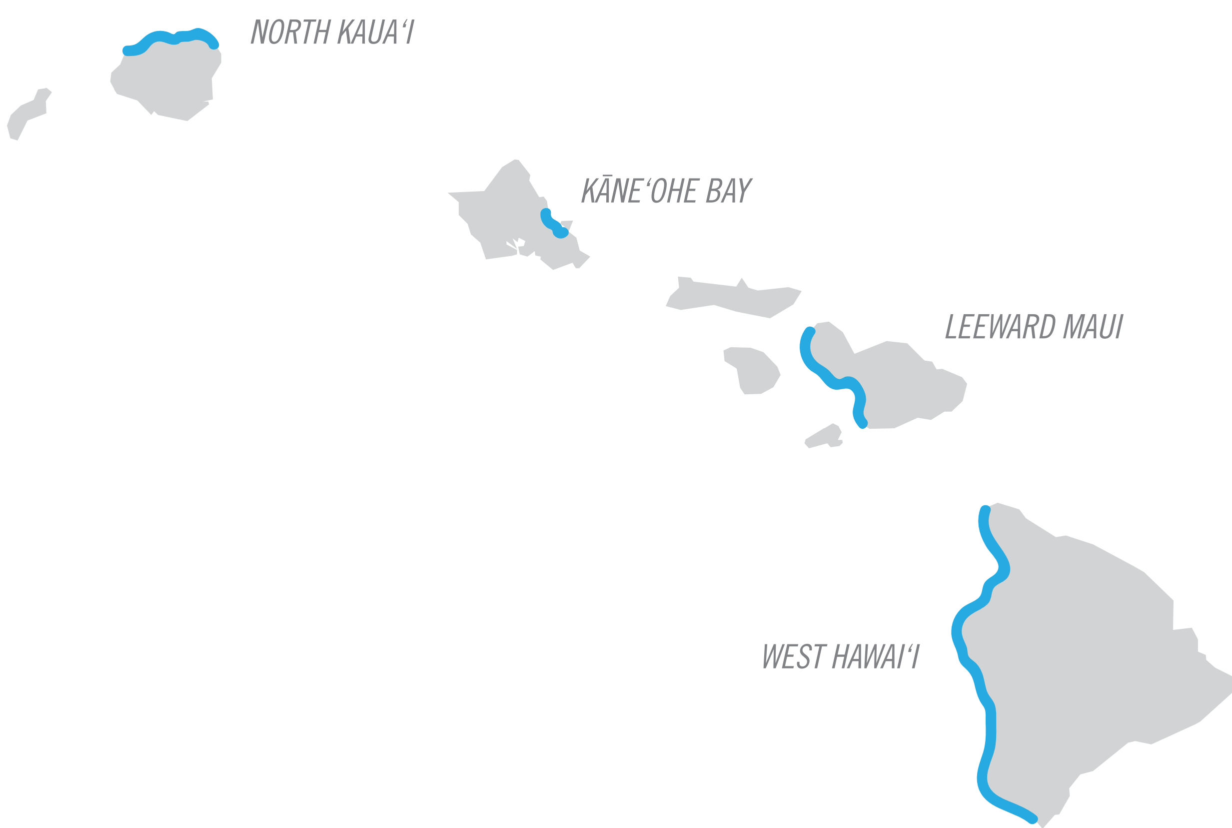


Figure 9. Priority sites for the implementation of management actions to promote coral bleaching recovery, from top left (North Kaua‘i, Kāne‘ohe Bay, west Maui and west Hawai‘i). These sites were chosen because they had the highest levels of exposure to high ocean temperatures and/or the highest rates of coral mortality following the 2014/2015 coral bleaching event.

Part 3: Gathering Expert Opinion of Ecologically Effective Management Actions

Global Scientist Expert Judgement

In addition to understanding the potential roles that resource managers could play and have played in promoting coral recovery following a mass bleaching event, Hawai‘i managers needed information on the perceived ecological effectiveness of specific actions that could be employed to reach their recovery goals. This was accomplished through a DAR online survey to gauge the judgment[1] of global coral bleaching experts[2] as well as an in-person voting exercise with Hawai‘i-based managers and scientists at an August 2016 workshop.

For the DAR online survey, global bleaching experts were defined as meeting at least one of the following criteria:

1. **Lead author on a scientific paper or article dealing with an aspect of coral bleaching or other relevant topic (e.g. herbivory). Only the lead author was included on the contact list if the research was conducted outside of Hawai‘i.**
2. **Author (lead or otherwise) of a paper/article focused on Hawai‘i dealing with an aspect of coral bleaching or other relevant topic (e.g. herbivory).**
3. **Participant in a coral bleaching workshop**
4. **Analyze empirical evidence describing how the most highly ranked management actions could meet our recovery objectives.**

Based on these criteria, a list of 176 experts was developed. Those experts were asked to score the ecological effectiveness of 22 potential management actions to promote the recovery of bleached reefs using a weighted point system ranging from ‘very effective’ to ‘not effective.’ The management actions were derived from a review of the literature described in Part 2, suggestions from local experts, previously identified actions from a 2013 Hawai‘i coral bleaching response workshop of resource managers and scientists, restoration strategies that Hawai‘i DAR already engage in, and actions that had been suggested by stakeholders following the 2015 bleaching event (Table 2). These actions fit into the framework that was developed in Part 2, as practical ways that mechanisms will lead to the ecological goal of promoting coral recovery (Figure 10).

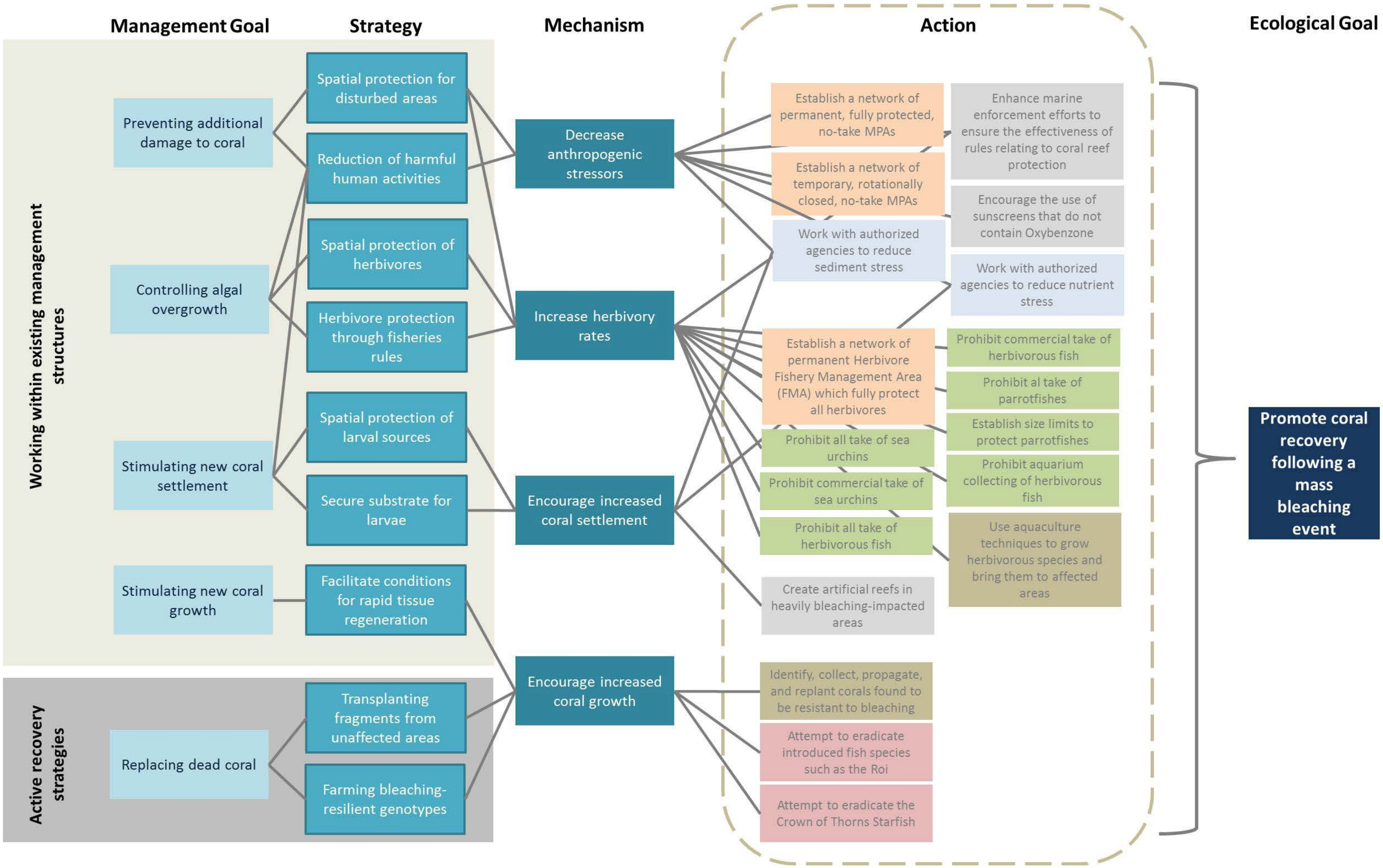
[1] The term ‘expert’ is based on the definition described in: Burgman, M., A. Carr, L. Godden, R. Gregory, M. McBride, L. Flander, and I. Maguire. 2011. Redefining expertise and improving ecological judgment. Conservation Letters. 4: 81-87.

[2] For a full description of the methods and analysis for the Coral Bleaching Recovery Survey, please reference this report: https://dlnr.hawaii.gov/reefresponse/files/2016/09/CoralRecoverySurvey_FINAL.pdf

Table 2. Management actions that were selected to be in the coral bleaching recovery survey. These actions were derived from a review of the literature described in Part 2, suggestions from local experts, previously identified actions from a 2013 Hawai'i coral bleaching response workshop of resource managers and scientists, restoration strategies that Hawai'i DAR already engage in, and actions that had been suggested by stakeholders following the 2015 bleaching event.

Type of action	Management Action
Spatial management	Establish a network of permanent, fully protected no-take MPAs
Spatial management	Establish a network of temporary, rotationally closed, no-take MPAs
Spatial management	Close heavily bleaching-impacted reef areas to all human in-water activities
Spatial management	Establish a network of permanent Herbivore Fishery Management Area (FMA) which fully protect all herbivores
Land-based strategies	Work with authorized agencies to reduce sediment stress on coral reefs by implementing additional land-based mitigation in adjacent watersheds
Land-based strategies	Work with authorized agencies to reduce nutrient/chemical stress on coral reefs by implementing additional land-based mitigation in adjacent watersheds
Fisheries rules	Prohibit all take (commercial and non-commercial) of sea urchins
Fisheries rules	Prohibit only the commercial take of sea urchins
Fisheries rules	Prohibit all take (commercial and non-commercial) of herbivorous fish
Fisheries rules	Prohibit only the commercial take of herbivorous fish
Fisheries rules	Prohibit all take (commercial and non-commercial) of parrotfishes
Fisheries rules	Establish size limits to protect parrotfishes
Fisheries rules	Establish bag limits to protect parrotfishes
Fisheries rules	Prohibit aquarium collecting of herbivorous fishes
Fisheries rules	Establish a temporary moratorium on aquarium collecting
Aquaculture techniques	Use aquaculture techniques to grow herbivorous species and bring them to affected area for biocontrol of macroalgae
Aquaculture techniques	Identify, collect, propagate and replant corals found to be resistant to bleaching
Eradication techniques	Attempt to eradicate introduced fish species such as the Roi, or Peacock Grouper, *Cephalopholis argus*
Eradication techniques	Attempt to eradicate the Crown of Thorns Starfish, *Acanthaster planci*
Other	Enhance marine enforcement efforts to ensure the effectiveness of rules relating to coral reef protection
Other	Encourage the use of sunscreens that *do not* contain the ingredient Oxybenzone, which has been shown to be harmful to corals
Other	Create artificial reefs in heavily bleaching - impacted reef areas

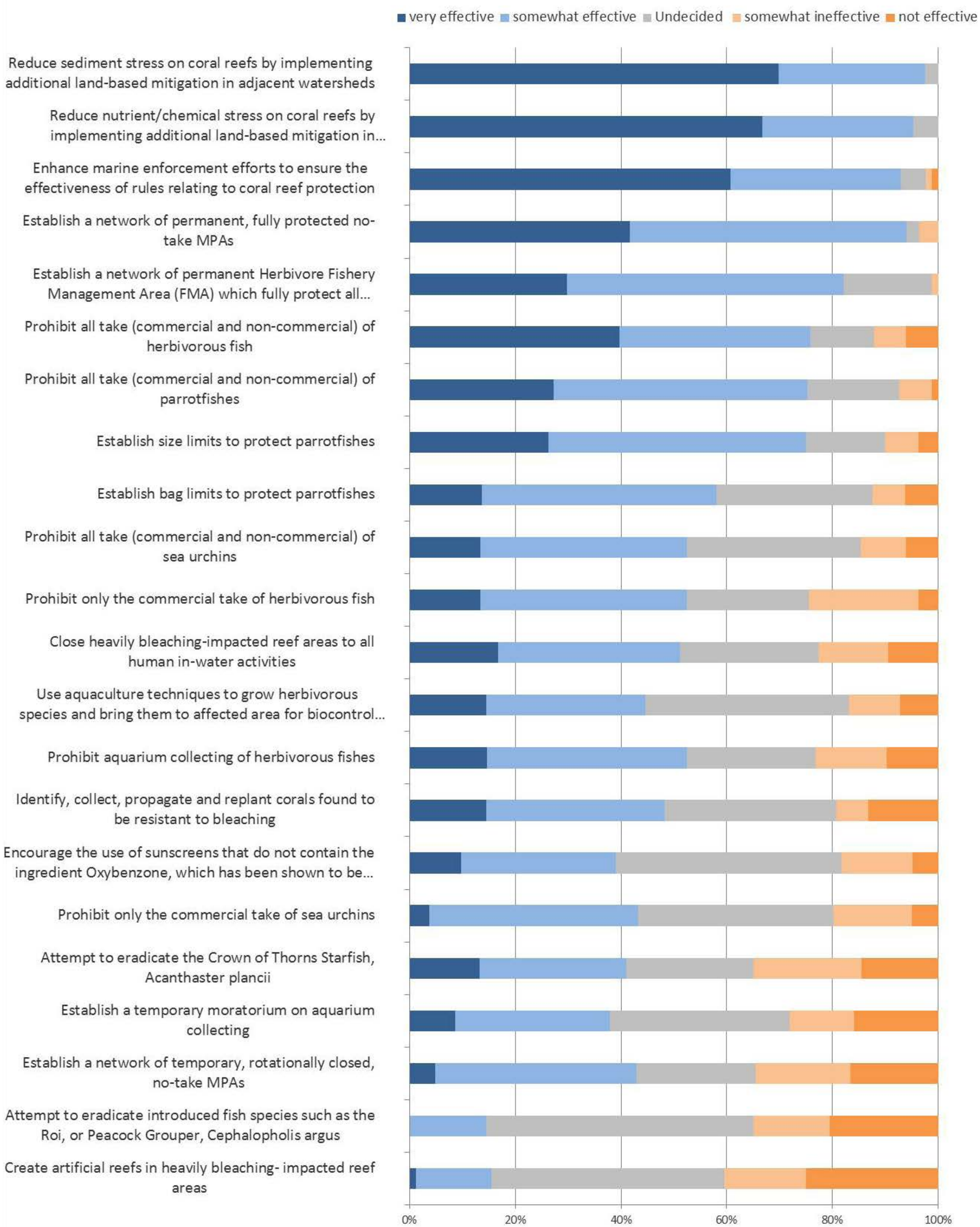
Figure 10. Revised management framework with the inclusion of potential practical actions that could be taken to promote recovery following a mass bleaching event.



The online global survey received 82 complete responses (47% response rate). Respondents were based in 12 countries; the majority being either American or Australian. The majority (52%) had more than 10 publications in the field and 72% had more than 10 years of experience.

We ranked the management actions using their weighted group average score. This simple method provides accurate judgments compared with more complex methods [83]. The management action with the highest average effectiveness score from the survey was ‘reduce sediment stress on coral reefs by implementing additional land-based mitigation in adjacent watersheds’ (Figure 11). The most common comments added by survey takers related to reducing sediment was to emphasize that this was a critical action, but also that it was very complicated to achieve and may only be effective in certain systems. Other of the top five actions were: ‘reducing nutrients’, ‘enhancing enforcement’, ‘creating permanent no-take areas through a network of MPAs’, and ‘creating a network of herbivore protection areas’. Related to MPAs, respondents added comments reflecting that this was only part of the necessary response, and that effective management of these areas would be key to their success. Comments related to spatial management of herbivore populations indicated that managers should look at the success of local herbivore protection areas first and that herbivore management should be prioritized in areas where the threat of algae growth is greatest. The management strategies with the lowest scores were: ‘create artificial reefs in heavily bleaching-impacted reef areas’, ‘attempt to eradicate introduced fish species such as Roi’, ‘establish a network of temporary, rotationally closed, no-take MPAs’, and ‘establish a temporary moratorium on aquarium collecting.’

Figure 11. Management strategies from the global expert survey ranked by ecological effectiveness, showing total of weighted responses.



Hawai'i-based Scientist and Manager Expert Opinion

Hawai'i-based scientist and manager expert opinion was gathered through a workshop in August 2016 in Honolulu. The 44 participants included Hawai'i-based representatives from DAR, NOAA, the Hawai'i Institute of Marine Biology (HIMB), the University of Hawai'i (UH), The Nature Conservancy (TNC), and Conservation International (CI).

To develop a list of ecologically effective statewide management recommendations, the workshop group was provided with the 22 potential management actions from the global survey. Participants were also provided with the results of the global Coral Bleaching Recovery Survey, and summary information on perceived ecological effectiveness of each action. Each participant was then given five points to vote for the most effective actions. Participants could use all five points for one action, or distribute their votes among several actions, but could only use up to five votes.

The management action that received the most points (i.e. "most effective") was 'establish a network of permanent, fully protected no-take Marine Protected Areas (MPAs)', which received 50 points (this action ranked 4 in the global survey). Another top-ranked action was to 'reduce land-based pollution', which the group discussed as encompassing both sediment and nutrient stress on coral reefs. 'Herbivore management' was the third highest prioritized action, which the group decided should encompass a combination of management actions. Lowest ranked actions again included 'create artificial reefs in heavily bleaching- impacted reef areas' and 'attempt to eradicate introduced fish species such as the Roi, or Peacock Grouper, *Cephalopholis argus*.'

Related to herbivore management, the participants could not hone in on one specific management action or list of important species, but deemed it crucial to conduct research to examine the relative influence of herbivores in the affected areas including both fish and invertebrates. The group also felt that adding the development of a strategic communication plan to communicate resilience science and promote individual action should be added. These results concurred with the results from the global survey asking for expert opinion on these same management actions. Although in slightly different order, the reduction of land-based stressors, establishment of MPAs, and focus on herbivore management were consistently cited as ecologically effective actions that managers could take to promote coral recovery and resilience following a bleaching event.

This exercise allowed us to compare the Hawai'i-based expert judgment to the online survey of global expert judgment. Although the two assessments had different methods (a weighted average score versus total number of points), we can compare across methods by looking at how each management action ranked in terms of their overall effectiveness. We did this by giving each rank position a point score. Actions that were in a more highly ranked position received more points. Points were then summed to provide a "combined ranking" based on both the Honolulu workshop and the global survey. This slightly altered the top actions, ultimately providing a succinct list of the top-ranked management actions based on global and Hawai'i-based expert judgment. (Table 3). There were two instances of ties in this process. Actions with tied numbers of points shared that ranking position. Based on this ranking, we honed in on the top ten rated actions (ranked positions 1-9 with a tie for second position).

Table 3. *Ranking of management actions based on expert judgment from a global survey and Hawai'i workshop, indicating the top 10 ranked actions. Actions were compared by giving each rank position a point score, meaning actions that were in a more highly ranked position received more points. Points were then summed to provide a "combined ranking" based on both the Honolulu workshop and the global survey.*

Management Action	Honolulu Workshop	Global Survey	Combined Ranking
Reduce sediment stress on coral reefs by implementing additional land-based mitigation in adjacent watersheds	2	1	**1**
Establish a network of permanent, fully protected no-take MPAs	1	4	**2**
Reduce nutrient/chemical stress on coral reefs by implementing additional land-based mitigation in adjacent watersheds	3	2	
Enhance marine enforcement efforts to ensure the effectiveness of rules relating to coral reef protection	4	3	**3**
Prohibit all take (commercial and non-commercial) of herbivorous fish		6	**4**
Establish a network of permanent Herbivore Fishery Management Area (FMA) which fully protect all herbivores	5	5	**5**
Prohibit all take (commercial and non-commercial) of parrotfishes	6	7	**6**
Establish bag limits to protect parrotfishes	8	9	**7**
Establish size limits to protect parrotfishes	9	8	**8**
Identify, collect, propagate and replant corals found to be resistant to bleaching	7	15	**9**
Prohibit only the commercial take of herbivorous fish	10	11	**10**
Prohibit all take (commercial and non-commercial) of sea urchins	13	10	**12**
Prohibit aquarium collecting of herbivorous fishes	10	14	**13**
Use aquaculture techniques to grow herbivorous species and bring them to affected area for biocontrol of macroalgae	14	13	**14**
Close heavily bleaching-impacted reef areas to all human in-water activities	16	12	**15**
Encourage the use of sunscreens that do not contain the ingredient Oxybenzone, which has been shown to be harmful to corals	15	16	**16**
Prohibit only the commercial take of sea urchins	18	17	**17**
Establish a network of temporary, rotationally closed, no-take MPAs	17	20	**18**
Establish a temporary moratorium on aquarium collecting	19	19	**19**
Attempt to eradicate the Crown of Thorns Starfish, *Acanthaster plancii*	21	18	**20**
Attempt to eradicate introduced fish species such as the Roi, or Peacock Grouper, *Cephalopholis argus*	20	21	**21**
Create artificial reefs in heavily bleaching- impacted reef areas	22	22	**22**

Part 4: Critically Analyzing the Effectiveness of Top-Ranked Management Actions

To strengthen our identification of effective management actions, we further investigated the top ten actions from the expert judgment rankings using scientific literature. This allowed us to minimize the potential biases that could come from each type of analysis and provided us with a final ranking based on both types of analyses. Following the Honolulu workshop, we added two management actions ('prohibit use of laynets statewide' and 'prohibit use of SCUBA spearfishing') because they were continuously raised in workshop discussion and subsequent meetings. However, because these actions were not included in the expert judgment rankings, they were included in the analysis of scientific literature, but not in the final ranking.

To rank the potential management actions, we first collected primary literature and reports using the search format "[management action] AND coral recovery" for each of the twelve actions from Google Scholar as well as the Web of Science databases. Papers were included in the analysis if they were specifically relevant in answering whether each action is effective in terms of a) the action's management objective and b) our overall coral bleaching recovery objective. For example, related to 'reduce sediment stress on coral reefs by implementing additional land-based mitigation in adjacent watersheds', papers were included that described the ability of watershed mitigation to reduce sediment (the management objective) as well as the ability of corals to recover once a reduction in sediment as occurred (the recovery objective).

Once the papers were collected the evidence was categorized into one of six types, which describe whether the evidence was empirical (based on direct observation) or theoretical (based on theories or models), whether the research from inside or outside of Hawai'i, and if it had been assessed at a global scale at multiple sites. The categories were then weighted, which valued empirical evidence over theoretical, research from Hawai'i over research from outside Hawai'i, and highly valued global studies with multiple sites (Table 4).

Empirical/ Theoretical	Scale	Inside/outside of Hawaii	Description of action being effective/ineffective	Point Value
Empirical	Multi-site	Outside	Effective	6
Empirical	Single-site	Inside	Effective	5
Empirical	Single-site	Outside	Effective	4
Theoretical	Multi-site	Outside	Effective	3
Theoretical	Single-site	Inside	Effective	2
Theoretical	Single-site	Outside	Effective	1
Theoretical	Single-site	Outside	Ineffective	-1
Theoretical	Single-site	Inside	Ineffective	-2
Theoretical	Multi-site	Outside	Ineffective	-3
Empirical	Single-site	Outside	Ineffective	-4
Empirical	Single-site	Inside	Ineffective	-5
Empirical	Multi-site	Outside	Ineffective	-6

Table 4.
Point values for categories of evidence describing the ability and limitations of management actions to achieve their management and recovery objectives. This scale was used to categorize and score scientific literature.

Over 100 additional papers were reviewed for this portion of the analysis. Evidence varied by point category and also was variable throughout the management actions **(Appendix C)**. Each piece of evidence from these papers was categorized into one of the evidence categories for both the management and recovery objective. To rank the effectiveness of each management action based scientific evidence, we first calculated the average score of each action's management objective and recovery objective. We then plotted the average score against the number of studies that this average represents, or the literature support for each management action **(Appendix D1)**. We calculated the management and recovery scores for each action by normalizing the number of studies and the mean effectiveness score, then multiplying these metrics **(Appendix D2)**. This allowed us to consider each action's effectiveness and our certainty in this effectiveness, based on the number of studies. Lastly, we summed the management and recovery ranking score to give us our final, combined score for each management action. This produced a quantitative ranking of the management actions considering their management and recovery effectiveness and the certainty of this effectiveness (Figure 12).

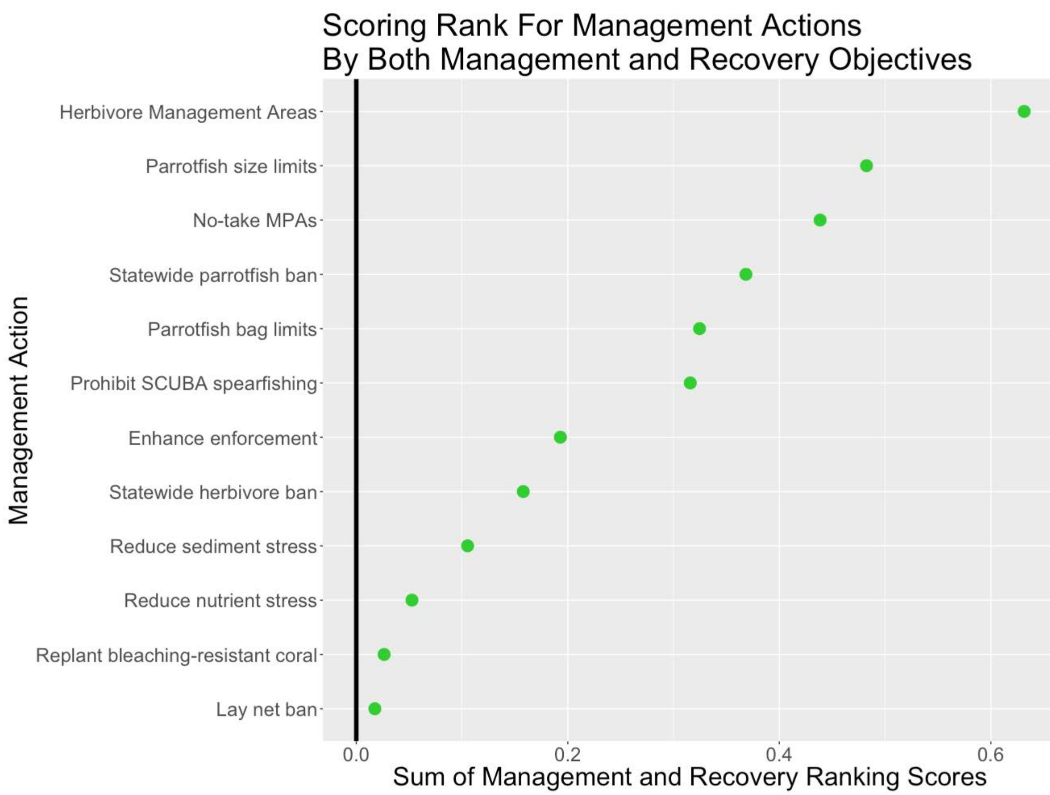


Figure 12. Top-ranked management actions from the expert judgment surveys re-ranked by the sum of management and recovery objective ranking scores. The summed scores take into account the ability of each management action to meet its management and coral bleaching recovery objective as well as the certainty of that effectiveness, based on the number of studies.

Using this method, we found that 'establishing permanent HFMAs' had the highest summed ranking score, followed by 'establish size limits to protect parrotfishes', and 'establish a network of permanent, no-take MPAs.' The lowest ranking actions were 'prohibit all use of lay nets', 'identify, collect, propagate and replant corals found to be resistant to bleaching', and 'reduce nutrient stress.' The next section summarizes the evidence for each management action that was included in this analysis.

A full description of each action's management and recovery objective as well as the categorization of all limiting and supporting evidence can be found in **Appendix E**.

Spatial Management

No-take MPAs

Globally and in Hawai‘i, no-take MPAs have been found to have both fisheries and ecosystem benefits [84-92]. MPAs have been critical in maintaining coral cover over time (but not necessarily increasing it) and in some have prevented cases, preventing algal overgrowth [93-99]. However, MPAs in Hawai‘i have limitations especially when they are too small and don't represent a diversity of habitats ([96]. When MPAs were evaluated against various potential management goals, there is a weak connection specifically between no-take MPAs and coral recovery [92]. Regional environmental and habitat variability also strongly affect the success of an MPA in a given location [100-103] and therefore strategic placement of MPAs is crucial.

Establish HFMAs

HFMAs have been successful in increasing herbivore biomass within their boundaries in Hawai‘i. In the first six years of the Kahekili HFMA (KHFMA), mean parrotfish and surgeonfish biomass both increased within the KHFMA by 139% and 28% respectively, however this was mostly seen in small to medium sized species, whereas large-bodied species have not recovered, likely due to low levels of poaching of preferred fishery targets [60]. Additionally, macroalgal cover has remained low and coral cover stabilized with a slight increase from 2012 through early 2015 (before the bleaching event) [60]. The Redlip Parrotfish (*Scarus rubroviolaceus*), a critically important parrotfish in Hawai‘i has qualities that make them a good candidate for management through MPAs [104]. However, like no-take MPAs there will be variability in its success based on the capacity of individual reef areas to support herbivores [100]. Spatial management has been found to have a strong connection to the mechanism of herbivory and its role in shaping benthic communities, however this role has not been completely shown to lead coral recovery [92]. Like no-take MPAs, regional variability will strongly affect their success [105-107].

Fisheries Rules

Prohibit use of lay nets

Lay nets have been proven to be destructive to benthic environment when they become entangled in coral and cause physical damage [108, 109]. There has only been one study which explored the relationship of lay nets to recovery from coral bleaching events (via their effect on herbivore populations) and found that lay nets were not in the top gear types for herbivore catch [110]. A study from Moloka‘i, Hawai‘i concurred with these findings and found that herbivores only constituted a minimal percentage of the total number of fish caught and therefore banning their use would likely not have a great effect on herbivore populations [111]. It is important to note here that there has been relatively very few studies connecting lay net fishing to herbivores or to coral recovery. It is also possible that the Moloka‘i study captured local-scale patterns and may or may not represent the larger area.

Prohibit all use of SCUBA for spearfishing

Parrotfish management in Hawai‘i could be greatly enhanced by banning spearfishing with SCUBA, especially at night, as herbivores including parrotfishes and surgeonfishes are primary components of the spearfishing catch in Hawai‘i and coral reef fishes, particularly parrotfishes, are more vulnerable at night [96, 116, 117]. Surveyed fishermen in Hawai‘i felt that SCUBA diving allows for inappropriate levels of fishing efficiency [114]. As with laynets, there has only been one study that explored the relationship of fishing gear to recovery from coral bleaching events. In general it is thought that gear restrictions that protect large, grazing species would assist in maximizing algal removal [110]. In addition, spearfishers in Kenya were found to cause the highest rates of physical damage to coral when fishing [108].

Prohibit all take (commercial and noncommercial) of herbivorous fish

There are numerous studies demonstrating the sensitivity of herbivore populations to overfishing [115 - 117]. There is evidence of overfishing of herbivores in Hawaiʻi [96, 116-118]. A parrotfish fishing ban in Belize has reduced herbivorous fish harvest and had a high compliance [119, 120]. Related to coral recovery, fished reefs with fewer herbivores have a greater chance of being overgrown by algae [5]. In addition, the parrotfish ban in Belize resulted in increased coral resilience [64]. However, as with spatial management, it is unlikely that all reef areas will respond similarly to an herbivorous fish ban [105-107, 117]. For example, an assessment in New Caledonia concluded that a ban on herbivore harvesting would be unlikely to improve coral reef resilience based on local conditions [121].

Prohibit all take (commercial and non-commercial) of parrotfish

For parrotfish specifically and especially male fish, there is evidence from Belize that populations can recover quickly from overfishing following a complete ban [122]. Parrotfish play multiple ecological functions in coral recovery, including controlling algal overgrowth and creating new space for coral settlement [123, 124] and these relationships have been identified in Hawaiʻi [125]. Specifically, scrapers (Chlorurus spilurus, Bullethead Parrotfish; Chlorurus perspicillatus, Spectacled Parrotfish; and Scarus rubroviolaceus, Ember parrotfish) were most strongly associated with Hawaiʻi reefs being in a coral-dominated state [126]. However, like the complete ban on herbivorous fishing and spatial management, success will vary depending on geographical factors [105-107, 117].

Establish size limits to protect parrotfishes

Very specific minimum size limits have been identified for Hawaiʻi in order to protect populations from overfishing [127]. Specifically, DeMartini et al. 2016 suggested the minimum legal sizes of parrotfishes in Hawaiʻi should increase to 35.6 cm (14 inches) LF for the two large-bodied species (*Scarus rubroviolaceus* and *Chlorurus perspicillatus*) and 24.3 cm (11 inches) LF for *Calotomus carolinus*. Because the bioerosion abilities of parrotfish increase with size, protecting larger parrotfish will compound their ability to aid in coral recovery processes [65,125, 128]. Because there are natural differences in the capacity of specific reef areas to support herbivores, size limits may not have a consistent effect across all sites [105-107, 117].

Establish bag limits to protect parrotfishes

Bag limits would essentially equate to a partial ban on parrotfish harvest, and therefore have many of the same benefits, but likely with less impact. In Hawaiʻi, it has been suggested that prohibiting the take of blue/green male parrotfishes would be effective at protecting against overfishing of sex-changed male fish [128]. As with total protection, the natural differences in the capacity of different reef areas to support herbivores, will mean that bag limits will not have a consistent effect across all sites [106-108, 118].

Land-based Strategies

Partner with other agencies to reduce sediment stress through land-based watershed mitigation

In general, it is clear that excessive sediment has negative effects on coral, and prevents reefs from returning to pre-impact conditions [129]. Reducing sediment through watershed management has been successful in many island nations and at a large scale in China [130, 131]. However, a global review found only one example of reductions in net fluxes of land-based sediment levels following restoration efforts [132]. There is an established relationship between the health of watersheds and the health of adjacent reefs in Hawaiʻi [133], however if sources of sediment are chronic it is unlikely that corals will be able to rapidly recover after restoration actions [132].

Partner with other agencies to reduce nutrient stress through land-based watershed mitigation

In general, elevated nutrient levels have a negative effect on corals [129]. Diverting nutrients has led to coral reef recovery in Hawai'i (Kāne'ohe Bay) [134], though this is only known example of this type of ecosystem reversal [132]. As with reducing sediment, watershed management has been successful in many island nations [130]. However, also as with reducing sediment, it is unlikely that corals will quickly respond to reductions in nutrients where there remains chronic exposure to other forms of land-based pollution [42, 132].

Aquaculture Techniques

Identify, collect, propagate and replant corals found to be resistant to bleaching

Several coral transplantation efforts have recorded high survivorship of transplanted corals at a relatively low cost to managers, indicating that such an approach may enhance reef recovery [72, 81, 135–137]. A pilot project on the Great Barrier Reef moved corals associated with relatively warm conditions to cooler conditions. This effort proved successful when evidence of recruitment was found, but it was only found at certain locations [138]. There have also been examples of efforts that were not successful in transplanting bleaching-resistant corals, often suffering from logistical challenges [66, 82]. Additionally, one study found corals lost their bleaching resistant 'edge' once they were planted in a new location [139]. Finally, there are some ethical concerns about moving corals including the potential for 'outbreeding depression' and the spread of disease into the receiving area [66,140].

Other

Enhance marine enforcement efforts to ensure the effectiveness of rules relating to coral reef protection

Adequate enforcement is often correlated with high fish biomass and richness on a global scale [141, 142]. In Hawai'i's Community Fishery Enforcement Unit (CFEU)'s first year of operations (2013-2014), officers issued a number of citations including net, diving, lobster, undersized fish, and bag limit violations [143]. Enforcement has been cited as a critical component of MPA management specifically [98, 142, 144, 145] and can prove cost-effective when compared to active restoration [146]. Limiting factors include that levels of enforcement are rarely quantified or reported [98] and the fact that there are a number of specific and distinct actions that could be taken to increase compliance [147], and so a locally-appropriate strategy must be developed.

Section Three: Conclusions

The goal of the Coral Bleaching Recovery Plan is to promote coral reef recovery following the 2014-2015 global coral bleaching event. The bleaching event had effects throughout the state of Hawaiʻi and its severity warranted management intervention. This is especially true in the four priority sites, of north Kauaʻi, Kāneʻohe Bay, leeward Maui, and west Hawaiʻi which had the highest level of either exposure to high ocean temperatures or coral mortality following the bleaching event. This plan will aid managers in implementing effective management actions by prioritizing which potential management actions would be the most ecologically effective in promoting recovery. This was answered by collecting expert judgment from both global and local scientists and managers as well as by critically analyzing the scientific literature on the applications of those actions.

Comparing results from expert judgment and the literature analysis

Although the global online survey, the workshop exercise, and the literature analysis were conducted using different methods, we can compare their results by looking at how management actions were ranked relative to each other across the three activities (Table 5).

We did this by giving each rank position a point value and then summing these values for the three analysis types. Prohibiting SCUBA spearfishing and prohibiting laynets were removed from this comparison because they were not present in the expert judgment assess-

	Based on expert judgment		Based on scientific literature		
Management Action	**Global Survey Rank**	**Hawaiʻi Workshop Rank**	**Literature Analysis Rank**	**Final Ranking**	**Relative Effectiveness**
Establish a network of permanent, fully protected no-take MPAs	4	1	2	**1**	**Very Effective**
Reduce sediment stress on coral reefs by implementing additional land-based mitigation in adjacent watersheds	1	2	9	**2**	
Establish a network of permanent Herbivore Fishery Management Area (FMA) which fully protect all herbivores	5	6	1	**3**	
Enhance marine enforcement efforts to ensure the effectiveness of rules relating to coral reef protection	3	4	7	**4**	**Effective**
Reduce nutrient/chemical stress on coral reefs by implementing additional land-based mitigation in adjacent watersheds	2	3	10	**5**	
Prohibit all take (commercial and non-commercial) of parrotfishes	7	8	4	**6**	
Prohibit all take (commercial and non-commercial) of herbivorous fish	6	5	8		
Establish size limits to protect parrotfishes	8	12	3	**7**	**Moderately Effective**
Establish bag limits to protect parrotfishes	9	9	5	**8**	
Identify, collect, propagate and replant corals found to be resistant to bleaching	15	7	11	**9**	
Prohibit all use of SCUBA for spearfishing			6		
Prohibit all use of laynets			12		

Table 5. Comparison in the relative ranking of management actions between the global online survey, the Hawaiʻi workshop voting exercise, and the literature analysis

ments. It is clear from this comparison that there was a substantial difference in the rankings between the expert judgment and the literature analysis for a portion of the management actions. For example, 'reducing sediment stress' ranked first and second from expert judgments methods. However, it ranked ninth (third to last) in the literature analysis. This may be because experts were asked to not base judgments on the feasibility of a given action. Thus, it is reasonable to conclude that, if it were possible to decrease sediment, that this would be effective-because of the known negative link between sediment and coral survival. However, the literature analysis identified only one example of successful watershed management leading to reduced sediment fluxes on a large scale and ultimately coral recovery. This partly resulted in it receiving a very low rank when using the literature analysis method.

A second example is establishing bag limits for parrotfishes. This ranked 9th (close to the middle of all 22 management action options) in both the global online survey and the Hawai'i workshop but was the top action in the literature analysis. What helped it rise in the literature analysis was the fact that we have very specific information on Hawai'i parrotfish from DeMartini et al. 2016 which describes the positive effect that a partial ban would have on specific species. This can be said for the majority of fisheries rules including parrotfish size limits and the parrotfish ban.

Limitations of this analysis

The limitations of basing policy decisions on expert judgment or scientific literature alone have been discussed in a previous section. To overcome these potential biases, we combined the rankings from both types of analyses and based on conclusions on their collective findings.

Additionally, our evaluation did not consider parameters which are likely to affect the effectiveness of a particular action, for example management feasibility, enforceability, implementation cost, man hours required, sociocultural cost, or public opinion. We assume here that all management actions are equally feasible and enforceable. However, in developing a management strategy, it is critical that these factors be considered. However, beginning with an evaluation based on ecological effectiveness will ultimately strengthen the overall assessment of the potential management actions. Finally, our analysis focused on the ability of management actions to promote coral recovery following a bleaching event. Although there may be some inherent overlap, this analysis did not evaluate how the actions could impact the resistance of Hawai'i's coral reefs to future climatic disturbances. This will be a critical piece of the ultimate recovery strategy.

Management implications and next steps

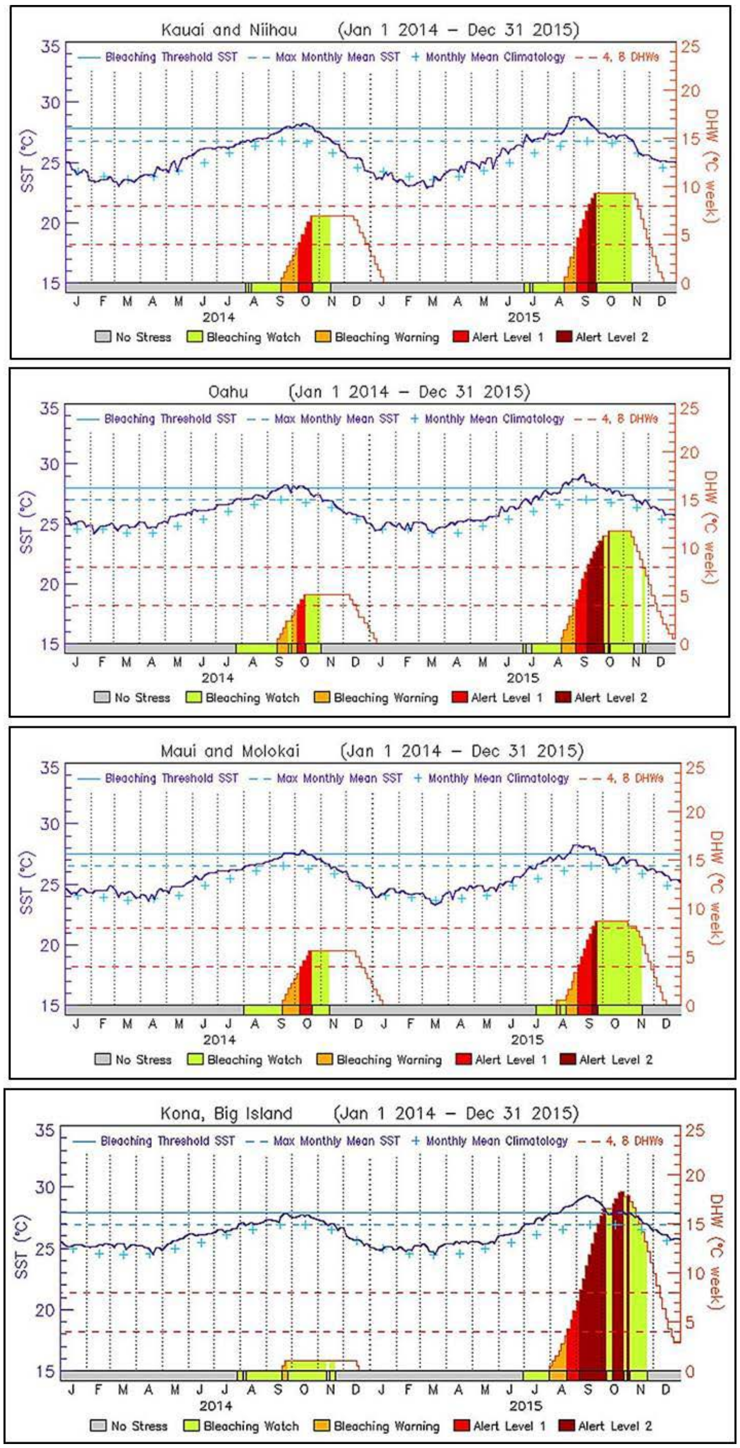
Establishing a network of permanent no-take MPAs and establishing a network of Herbivore Fishery Management Areas (HFMA) were highly ranked actions, which performed well in both the expert judgment assessments and the literature analysis. Our analysis therefore indicates that spatial management, particularly herbivore management, is critical to coral recovery in Hawai'i. Spatial management should also target areas with a high natural resiliency and recovery potential. Enhancing enforcement also scored well across all analyses but additional investigation is needed to inform what type of action (increasing education, increasing penalties, increasing number of officers) would be the most impactful. Lastly, fisheries rules, especially pertaining to parrotfish are particularly important component of any recovery action in Hawai'i, as shown by the detailed information on the contributions of individual species and size classes, and the performance of complete and partial bans in other regions of the world.

The next step in the coral bleaching recovery planning process should be to evaluate where the top-ranked actions including spatial management and perhaps a selection of fisheries rules would have the greatest positive impact in terms of coral reef recovery. This is still an open question because, as the literature emphasized, management actions will not have a consistent effect based on the natural ecological variability among different reef areas. This evaluation should consider minimizing social cost and consider the management feasibility of actions that are seriously being considered for implementation. This exercise should also be extended to consider which management actions are the most effective in enhancing the resiliency of Hawai'i's reefs to future climatic events.

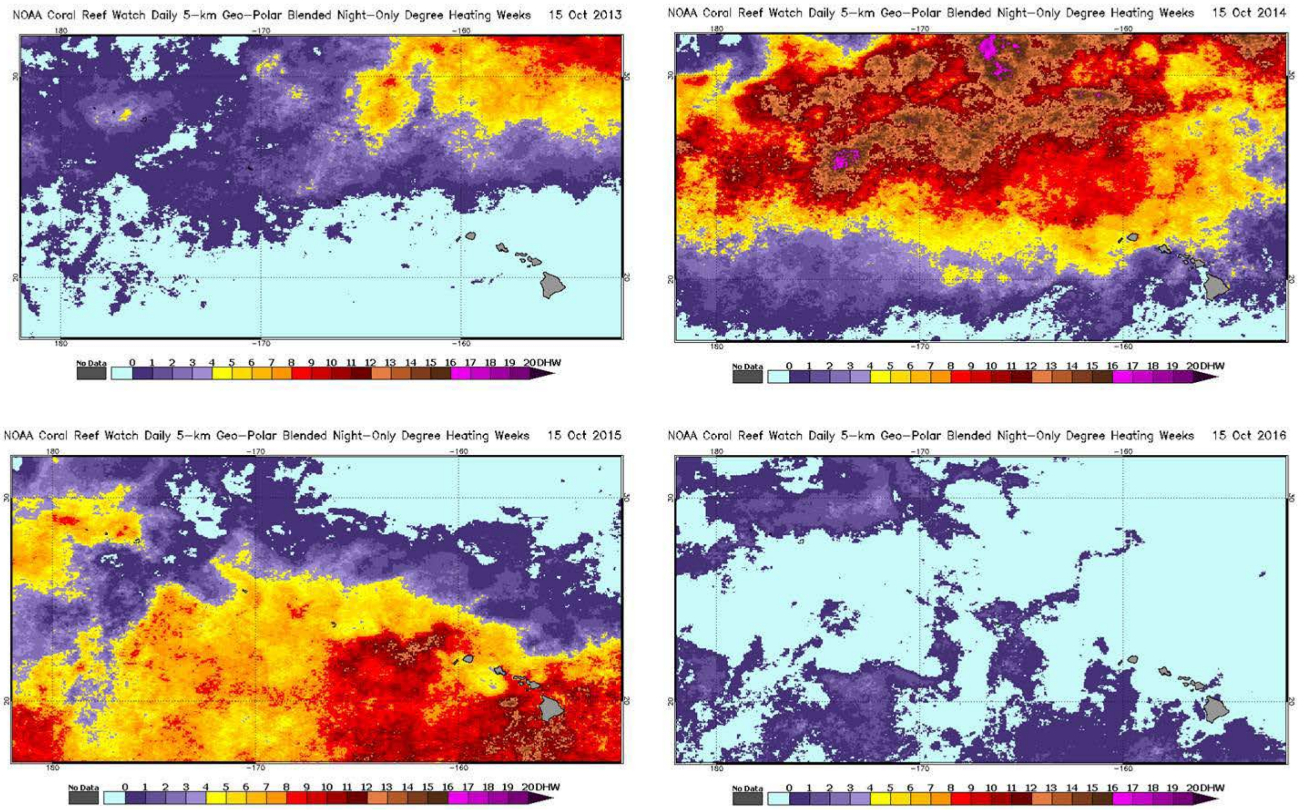
Appendix

Appendix A *NOAA Coral Reef Watch Program a) plots of Sea Surface Temperature (SST), Degree Heating Weeks (DHW), and coral bleaching alerts for 2014 and 2015 in more northerly Main Hawaiian Islands and b) maps of DHW in the Main Hawaiian Islands region.*

a)



b)



Appendix B *a) Management obstacles (in red) and opportunities (in green) identified for implementing management actions in the priority sites. b) Research needs in each priority site for effective management action implementation.*

a)

Management Obstacles and Opportunities for Implementation			
West Hawai'i	West Maui	Kāne'ohe Bay	North Kaua'i
Fish that are fished with nets create an obstacle, easy on enforcement but are these the fish we're going after?	Enforcement	Private landowners	Lack of data/information – few people in the small group had site-based knowledge of areas
How to enable enforcement? Create a rule? Funds from licenses? A new CFEU?	Self-reporting of fishing violations	Effective communication to community (may also be an opportunity)	Makai Watch participation
Needs to be adaptive	Changing current day-to-day practices	NERRS designation	Data available through the Ocean tipping points
Use the existing management regime, nest protection within existing network	Education and outreach, needs to be developed to actually see behavior change	Existing partnerships and management efforts	Haena state park management plan – catalyst to managing this area and crowding issues
Create general area rules, then focus on individual site-based rules	Coral bleaching events as a call to action	Decent enforcement in the bay	
Resurface the previous rule package	We already have a good rule for Maui – ban take on terminal male uhu		
	Education and outreach perceived as important for future generations.		
	Urchins not broadly harvested so a ban on their take would not be too difficult		
	Use new technology		

b)

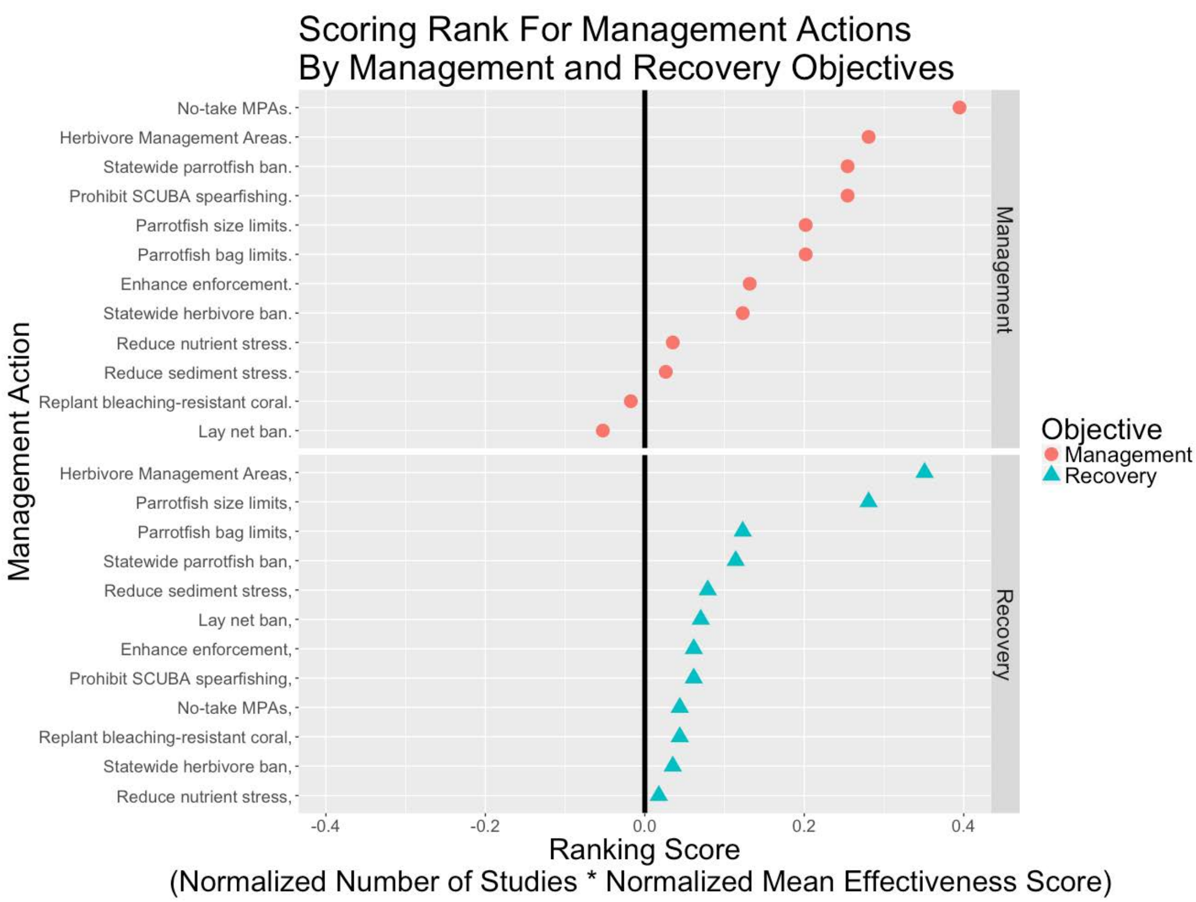
Site-based Research Needs			
West Hawaii	**West Maui**	**Kaneohe Bay**	**North Kauai**
Decision support tools, specifically those that have a spatial analysis element and allow for stakeholder engagement	Define and defended "important herbivores"	Identify best areas for MPA network	Where are nutrients coming from and how impactful are they?
What other herbivores (besides fish) are important?	Gather more life history info to help with modeling efforts	ID existing datasets useful to monitoring effectiveness of implemented management action	Ecological resilience of the area, what makes the most sense to protect?
Consistent, statewide metrics of coral "health"	Gather fishing pressure data on the important herbivores	Distribution of herbivores – what happened to the post-recruit parrotfish?	How effective is education?
What combinations of gear, size, and bag limits on herbivores would be most effective?	Determine economic demand on the important herbivores – what is the social impact of regulations?	Boat strikes – effectiveness of markers before and after intervention; is reattachment of coral effective?	What are the impacts of sunscreen, does it get flushed out in this area?
What areas are likely to resist bleaching?	Set management criteria for suitability of particular forms of management	Tracer study to understand relative impacts of cesspools versus other stressors	Where to put a no take MPA? What are the criteria?
What areas are sources of larvae?	Synthesize large body of available data of on parrotfish to show current status and variability between areas	Prioritize watershed areas/streams	
Synthesize biophysical data for the region – freshwater inputs?	Identify the stressors for each area (spatially) and quantify relative importance of each to that area		
Need method to share data and synthesize metadata			

Appendix C *The distribution of evidence in the literature analysis in each point value category and for each management action.*

	Limiting Evidence						Supporting Evidence						
Management Action	*-6*	*-5*	*-4*	*-3*	*-2*	*-1*	*1*	*2*	*3*	*4*	*5*	*6*	**Total number of studies**
Enhance marine enforcement efforts to ensure the effectiveness of rules relating to coral reef protection				2					5	2	2		11
Reduce sediment stress on coral reefs by implementing additional land-based mitigation in adjacent watersheds	2						2			4	1		9
Establish a network of permanent, fully protected no-take MPAs	2	4	1	3			1		7	3	6	5	32
Establish a network of permanent Herbivore Fishery Management Area (FMA) which fully protect all herbivores	1	1		3			2		3	4	7	5	26
Reduce nutrient/chemical stress on coral reefs by implementing additional land-based mitigation in adjacent watersheds	3	1					3			4	2		13
Prohibit all take (commercial and non-commercial) of herbivorous fish		1				1	2	1		2	2		9
Establish size limits to protect parrotfishes		1	1				1		1	3	7	3	17
Prohibit all take (commercial and non-commercial) of parrotfishes	1	1		3			1		1	5	4	3	19
Establish bag limits to protect parrotfishes		1		3			1	1	1	3	4	3	17
Identify, collect, propagate and replant corals found to be resistant to bleaching	2		2			1				6			11
Prohibit all use of SCUBA for spearfishing						1				4	2	1	8
Prohibit all use of laynets		1				1				2			4

Appendix D.1 *The literature support for the top-ranked management actions based on their mean effectiveness score and the number of studies.*

Appendix D.2 *The scoring rank for the top-ranked management actions based on their ranking score.*



Appendix E *Summary of evidence related to the ability of each action to meet its management objectives (in dark blue) and the recovery objective of promoting its recovery objective (in light blue).*

	Point Value	-6	-5	-4	-3	-2	-1		1	2	3	4	5	6
Management Action	**Objective**	*Empirical multi-site evidence this method is not effective*	*Empirical ineffectiveness of this method in Hawaiʻi*	*Empirical ineffectiveness of this method outside Hawaiʻi*	*Theoretical multi-site evidence this method is not effective*	*Theoretical ineffectiveness of this method in Hawaiʻi*	*Theoretical ineffectiveness of this method outside Hawaiʻi*		*Theoretical effectiveness of this method outside Hawaiʻi*	*Theoretical effectiveness of this method in Hawaiʻi*	*Theoretical multi-site evidence this method is effective*	*Empirical effectiveness of this method outside Hawaiʻi*	*Empirical effectiveness of this method in Hawaiʻi*	*Empirical multi-site evidence this method is effective*
A network of permanent, no-take MPAs	Increase in fish abundance within and around areas closed to all take of marine resources		Heenan et al. 2016, Williams et al. 2015, Williams et al. 2015	Williams et al. 2015					Magris et al. 2015		Beverton and Holt 1957, Polacheck 1990, DeMartini 1993, Sladek et al. 1999, Bellwood et al. 2004	McClanahan 2009	Friedlander et al. 2007, Christie et al. 2010, Wedding and Friedlander 2008, Friedlander and DeMartini 2002	McClanahan and Kaunda-Arara 1996, Roberts et al. 2001, Russ et al. 2004, Abesamis and Russ 2005
	Coral recovery due to an increase in all fish within no-take MPA areas	Graham et al. 2011, Mumby and Steneck 2008		Stockwell et al. 2009	McCook et al. 2001, Knowlton 2004, Bellwood and Fulton 2008						Graham et al. 2013, Bohnsack 1998	Mumby et al. 2007, Ledlie et al. 2007	Stockwell et al. 2009, Friedlander et al. 2007	Selig and Bruno 2010
Establish permanent Herbivore Fishery Management Areas, protecting all herbivores	Increase in herbivore abundance within and around areas closed to all take of marine resources		Heenan et al. 2016								McLoed et al. 2009, Graham et al. 2011	McClanahan et al. 2007	Howard et al. 2013, Williams et al. 2016, Friedlander and DeMartini 2002	Bellwood et al. 2012, Edwards et al. 2014
	Coral recovery due to an increase in herbivorous fish because of Herbivore Fishery Management Areas	Graham et al. 2011			McCook et al. 2001, Knowlton 2004, Bellwood and Fulton 2008				Edwards et al. 2011, Rogers et al. 2015		Graham et al. 2013	Nash et al. 2016, Holbrook et al. 2016, Cramer et al. 2017	Jaywardene 2009, Williams et al. 2016, Hixon et al. 1996, Smith et al. 2010	Bellwood et al. 2004, Hughes et al. 2004, Marshall and Schuttenberg 2004

Prohibit all use of lay nets	Increase in herbivorous fish targeted by lay nets statewide		Puleloa 2012				Cinner et al. 2009							
	Coral recovery due to an increase in herbivorous fish because of a laynet ban											Mangi and Roberts 2006, McClanahan and Cinner 2008		
Prohibit all take of herbivorous fish statewide	Increase in herbivorous fish statewide		Heenan et al. 2016						Mumby et al. 2014			O'Farrell et al. 2016, Cox et al. 2013	Heenan et al. 2016, Friedlander et al. 2007	
	Coral recovery due to increase in herbivorous fish because of a herbivorous fishing ban						Carassou et al. 2013		Mumby et al. 2014	Smith et al. 2002, Friedlander et al. 2007				
Enhance marine enforcement efforts to ensure the effectiveness of rules relating to coral reef protection	Increase in compliance to coral reef-related rules				Kaplan et al. 2015, Selig and Bruno 2010						Edgar et al. 2014, McClanahan et al. 2006, Crawford et al. 2004, Kaplan et al. 2015	Pollnac et al. 2010	DLNR 2015	
	Coral recovery due to increased compliance because of enhanced enforcement										Selig and Bruno 2010	Haisfield et al. 2010		
Prohibit all use of SCUBA for spearfishing	Increase in biomass of herbivorous fish targeted by SCUBA spearfishing											Cinner et al. 2009, Lindfield et al. 2014	Meyer 2006, Howard et al. 2013, Stoffle and Allen 2012	Gillet and Moy 2006
	Coral recovery due to an increase in herbivores because of a SCUBA spearfishing ban						Cinner et al. 2009					Nash et al. 2016, Mangi and Roberts 2006		

Prohibit all take (commercial and recreational) of parrotfishes	Increase in biomass of parrotfish statewide		Heenan et al. 2016									O'Farrell et al. 2015, Cox et al. 2012, O'Farrell et al. 2016	Friedlander et al. 2007, Heenan et al. 2016	Bellwood et al. 2012, Edwards et al. 2014
	Coral recovery due to a complete ban of parrotfishes	Graham et al. 2011			McCook et al. 2001, Knowlton 2004, Bellwood and Fulton 2008				Bozec et al. 2016		Graham et al. 2013	Bellwood et al. 2006, Ledlie et al. 2007	Jaywardene 2009, Jouffray et al. 2014	Mumby et al. 2006
Establish size limits to protect parrotfishes	Increase in biomass of parrotfish statewide		Heenan et al. 2016	Kuempel and Altieri 2017									Friedlander et al. 2007, Heenan et al. 2016, DeMartini et al. 2016, DAR 2009, Ong and Holland 2010	Bellwood et al. 2012, Edwards et al. 2014
	Coral recovery due to an increase in large parrotfish because of size limits								Bozec et al. 2016		Graham et al. 2013	Bellwood et al. 2006, Ledlie et al. 2007, Lokrantz et al. 2008	Jaywardene 2009, Ong and Holland 2010	Mumby et al. 2006
Establish bag limits to protect parrotfishes	Increase in biomass of parrotfish statewide		Heenan et al. 2016							DeMartini 2016		O'Farrell et al. 2015	Friedlander et al. 2007, Heenan et al. 2016	Bellwood et al. 2012, Edwards et al. 2014
	Coral recovery due to an increase in parrotfish because of bag limits				McCook et al. 2001, Knowlton 2004, Bellwood and Fulton 2008				Bozec et al. 2016		Graham et al. 2013	Bellwood et al. 2006, Ledlie et al. 2007	Jaywardene 2009	Mumby et al. 2006
Prohibit all take of sea urchins	Increase in biomass of sea urchins statewide	Graham et al. 2011	Williams et al. 2016	McClanahan and Shafir 1990, Sweatman 2008, Harborne et al. 2009										
	Promote coral bleaching recovery		Conklin and Smith 2005, Stimson 2005	Ogden 1977; McClanahan & Muthiga 1988; Bak 1990; McClanahan 1997; Griffin et al. 2003	McCook et al. 2001, Knowlton 2004, Bellwood and Fulton 2008							Kuempel and Altieri 2017	Vermeij et al. 2009, Neilson et al (in prep), Conklin and Smith 2005	

Partner with other agencies to reduce sediment stress through land-based watershed mitigation	Decrease in sediment levels adjacent to watershed management	Kroon et al. 2014							Richmond et al. 2005			Richmond et al. 2007, Chu et al. 2009		
	Coral recovery due to decrease in sedimentation becasue of watershed mitigation	Kroon et al. 2014							Richmond et al. 2005; Zimmer et al. 2006			Jokiel et al. 2006, Gil et al. 2016	Rodgers et al. 2012	
Partner with other agencies to reduce nutrient stress through land-based watershed mitigation	Decrease in nutrient levels adjacent to watershed management		Hunter and Evans 1995						Richmond et al. 2005			Richmond et al. 2007, Kroon et al. 2014		
	Coral recovery due to a decrease in nutrients because of watershed mitigation	Kroon et al. 2014, Risk et al. 2014, Mumby and Steneck 2011							Richmond et al. 2005; Zimmer et al. 2006			Jokiel et al. 2006, Gil et al. 2016	Smith et al. 1981, Rodgers et al. 2012	
Identify, collect, propagate and replant corals found to be resistant to bleaching	Successful transplantation of bleaching-resistant corals	Aswani et al. 2015		McClanahan et al. 2005, D'Angelo et al. 2015								Mbije et al. 2013, Gomez et al. 2014, van Oppen et al. 2011		
	Coral recovery because of the planting of bleaching-resistant corals	Aswani et al. 2015					Cremieux et al. 2010					Rinkevich 2005, 2006, 2008		

Literature Cited

1. Bellwood, D., T. Hughes, C. Folke, and M. Nyström. 2004. Confronting the Coral Reef Crisis. Nature. 429.6994: 827–833.
2. Bellwood, D., T. Hughes, and A. Hoey. 2006. Sleeping Functional Group Drives Coral-Reef Recovery. Current Biology. 16.24: 2434–39.
3. Hughes, T., M. Rodrigues, D. Bellwood, D. Ceccarelli, O. Hoegh-Guldberg, L. McCook, N. Moltschaniwskyj, M. S. Pratchett, R. S. Steneck, and B. Willis. 2007. Phase Shifts, Herbivory, and the Resilience of Coral Reefs to Climate Change. Current Biology. 17.4: 360–65.
4. Hughes, T., N. Graham, J. Jackson, P. Mumby, and R. Steneck. 2010. Rising to the Challenge of Sustaining Coral Reef Resilience. Trends in Ecology & Evolution. 25.11: 633–42. doi:10.1016/j.tree.2010.07.011.
5. Graham, N., D. Bellwood, J. Cinner, T. Hughes, A. Norström, and M. Nyström. 2013. "Managing Resilience to Reverse Phase Shifts in Coral Reefs." Frontiers in Ecology and the Environment . 11.10: 541–48. doi:10.1890/120305.
6. Ainsworth, C. and P. Mumby. 2015. Coral-Algal Phase Shifts Alter Fish Communities and Reduce Fisheries Production. Global Change Biology. 21.1
7. Hoegh-Guldberg, O. 1999. Climate Change, Coral Bleaching and the Future of the World's Coral Reefs. Marine and Freshwater Research. 50. 8: 839.
8. Baker, A., P. Glynn, and B. Riegl. 2008. Climate Change and Coral Reef Bleaching: An Ecological Assessment of Long Term Impacts, Recovery Trends and Future Outlook. Estuarine, Coastal and Shelf Science. 80. 4: 435–71.
9. Ateweberhan, M., D. Feary, S. Keshavmurthy, A. Chen, M. Schleyer, and C. Sheppard. 2013. Climate Change Impacts on Coral Reefs: Synergies with Local Effects, Possibilities for Acclimation, and Management Implications. Marine Poll tion Bulletin. 74: 526–39.
10. Frieler, K., M. Meinshausen, A. Golly, M. Mengel, K. Lebek, S. Donner, and O. Hoegh-Guldberg. 2012. Limiting Global Warming to 2 °C Is Unlikely to Save Most Coral Reefs. Nature Climate Change 3.2: 165–70.
11. Ateweberhan, M., D. Feary, S. Keshavmurthy, A. Chen, M. Schleyer, and C. Sheppard. 2013. Climate Change Impacts on Coral Reefs: Synergies with Local Effects, Possibilities for Acclimation, and Management Implications. Marine Pollution Bulletin 74.2: 526–39. doi:10.1016/j.marpolbul.2013.06.011.
12. Coles, S., and P. Jokiel. 1978. Synergistic Effects of Temperature, Salinity and Light on the Hermatypic Coral Monitpora Verrucossa. Marine Biology. 49: 187–95.
13. Putnam, H., and R. Gates. 2015. Preconditioning in the Reef-Building Coral Pocillopora Damicornis and the Potential for Trans-Generational Acclimatization in Coral Larvae under Future Climate Change Conditions. Journal of Experimental Biology. 218.15: 2365–2372.
14. Gates, R., G. Baghdasarian, and L. Muscatine. 1992. Temperature Stress Causes Host Cell Detachment in Symbiotic Cnidarians: Implications for Coral Bleaching. The Biological Bulletin. 182. 3: 324–332.
15. Grottoli, A., L. Rodrigues, and J. Palardy. 2006. Heterotrophic Plasticity and Resilience in Bleached Corals. Nature. 440.7088: 1186–89.
16. Jokiel, P., and E. Brown. 2004. Global Warming, Regional Trends and Inshore Environmental Conditions Influence Coral Bleaching in Hawaii. Global Change Biology. 10.10: 1627–41.
17. McClanahan, T., S. Donner, J. Maynard, M. MacNeil, N. Graham, J. Maina, A. Baker, J. Alemu, M. Beger, S. Campbell, E. Darling, C. Eakin, S. Heron, S. Jupiter, C. Lundquist, E. McLeod, P. Mumby, M. Paddack, E. Selig, R. Woesik. 2012. Prioritizing Key Resilience Indicators to Support Coral Reef Management in a Changing Climate. Edited by Richard K. F. Unsworth. PLoS ONE. 7.8: e42884. doi:10.1371/journal.pone.0042884.
18. Aeby, G., M. Hutchinson, and P. MacGowan. 2009. Hawaii's Rapid Response Contingency Plan for Events of Coral Bleaching, Disease or Crown-of-Thorns Starfish Outbreaks. The Division of Aquatic Resources, Department of Land and Natural Resources.

19. Baker, A., P. Glynn, and B. Riegl. 2008. Climate Change and Coral Reef Bleaching: An Ecological Assessment of Long-Term Impacts, Recovery Trends and Future Outlook. Estuarine, Coastal and Shelf Science. 80.4: 435–71.
20. Marshall, P., and H. Schuttenberg. 2004. A Reef Manager's Guide to Coral Bleaching. Townsville, Qld.: Great Barrier Reef Marine Park Authority.
21. NOAA, Coral Reef Watch. 2014. Pacific Climate Update: Coral Bleaching Thermal Stress Analysis and Seasonal Guidance through February 2015. https://coralreefwatch.noaa.gov/satellite/analyses_guidance/pacific_climate_updates/pacific_climate_update_coral_reef_watch_20141103.pdf.
22. Couch, C., J. Burns, K. Steward, T. Gutlay, G. Liu, E. Geiger, C. Eakin, R.K. 2016. Causes and consequences of the 2014 mass coral bleaching event in Papahānaumokuākea Marine National Monument. Technical Report for NOAA Papahānaumokuākea Marine National Monument. 28pp.
23. DAR (Division of Aquatic Resources). 2014. Coral Bleaching 2014: Important Findings. http://dlnr.hawaii.gov/reefresponse/current-rapid-responses/coral-bleaching-2014/.
24. Bahr, K., P. Jokiel, and K. Rodgers. 2015. The 2014 Coral Bleaching and Freshwater Flood Events in Kāne'ohe Bay, Hawai'i. PeerJ. 3: e1136. doi:10.7717/peerj.1136.
25. NOAA, Coral Reef Watch. 2015. NOAA Declares Third Ever Global Coral Bleaching Event. http://www.noaanews.noaa.gov/stories2015/100815-noaa-declares-third-ever-global-coral-bleaching-event.html.
26. Kramer, K., S. Cotton , M. Lamson , W. Walsh. 2016. Bleaching and catastrophic mortality of reef-building corals along west Hawai'i island: findings and future directions. Proceedings of the 13th International Coral Reef Symposium, Honolulu: 229-241.
27. TNC (The Nature Conservancy). 2015. Summary of Findings: 2015 Coral Bleaching Surveys: South Kohala, North Kona.
28. Sparks, R. 2016. Department of Land and Natural Resources, Division of Aquatic Resources. Unpublished data.
29. NOAA, Coral Reef Watch. 2016. Pacific Climate Update: Coral Bleaching Thermal Stress Analysis and Seasonal Guidance through February 2017. https://coralreefwatch.noaa.gov/satellite/analyses_guidance/pacific_climate_updates/pacific_climate_update_coral_reef_watch_20161103.pdf
30. Heller, N., and E. Zavaleta. 2009. Biodiversity Management in the Face of Climate Change: A Review of 22 Years of Recommendations. Biological Conservation 142, no. 1: 14–32.
31. Maynard, J., P. Marshall, J. Johnson, and S. Harman. 2010. Building Resilience into Practical Conservation: Identifying Local Management Responses to Global Climate Change in the Southern Great Barrier Reef. Coral Reefs 29.2: 381–91. doi:10.1007/s00338-010-0603-8.
32. Anthony, K., P. Marshall, A. Abdulla, R. Beeden, C. Bergh, R. Black, M. Eakin, E. Game, N. Graham, A. Green, S. Heron, R. Hooidonk, C. Knowland, S. Mangubhai, N. Marshall, J. Maynard, P. McGinnity, E. McLeod, P. Mumby, M. Nystrom, D. Obura, J. Oliver, H. Possingham, R. Pressey, G. Rowlands, J. Tamelander, D. Wachenfeld, S. Wear. 2015. Operationalizing Resilience for Adaptive Coral Reef Management under Global Environmental Change. Global Change Biology. 21.1: 48–61.
33. Martin, T., M. Burgman, F. Fidler, P. Kuhnert, S. Low-Choy, M. Mcbride, and K. Mengersen. 2012. Eliciting Expert Knowledge in Conservation Science: Elicitation of Expert Knowledge. Conservation Biology. 26.1:29–38. doi:10.1111/j.1523-1739.2011.01806.
34. Crome, F., M. Thomas, and L. Moore. 1996. A novel Bayesian approach to assessing impacts of rain forest logging. Ecological Applications. 6:1104–1123.
35. Marcot, B. 2006. Characterizing species at risk I: modeling rare species under the northwest forest plan. Ecology and Society. 11: http://www.ecologyandsociety. org/vol11/iss12/art12/. (accessed November 2011).
36. Griffiths, S., P. Kuhnert, W. Venables, and S. Blaber. 2007. Estimating abundance of pelagic fishes using gillnet catch data in data-limited fisheries: a Bayesian approach. Canadian Journal of Fisheries and Aquatic Sciences. 64:1019–1033.
37. 37. Rothlisberger, J., D. Lodge, R. Cooke, and D. Finnoff. 2010. Future declines of the binational Laurentian Great Lakes fisheries: the importance of environmental and cultural change. Frontiers in Ecology and the Environment. 8:239–244.

38. Morgan, M. Granger. 2014. Use (and Abuse) of Expert Elicitation in Support of Decision Making for Public Policy. Proceedings of the National Academy of Sciences. 111.20: 7176–7184.

39. Ioannidis, J. 2007. Limitations Are Not Properly Acknowledged in the Scientific Literature. Journal of Clinical Epidemiology. 60.4: 324–29. doi:10.1016/j.jclinepi.2006.09.011.

40. Dodge, R., and C. Birkeland. 2008. A Call to Action for Coral Reefs. Science. 322.5899: 189.

41. Rogers, A., A. Harborne, C. Brown, Y. Bozec, C. Castro, I. Chollett, K. Hock, C. Knowland, A. Marshell, J. Ortiz, T. Razak, G. Roff, J. Samper-Villarreal, M. Saunders, N. Wolff, P. Mumby. 2015. Anticipative Management for Coral Reef Ecosystem Services in the 21st Century. Global Change Biology 21.2: 504–14.

42. Mumby, P., and R. Steneck. 2008. Coral Reef Management and Conservation in Light of Rapidly Evolving Ecological Paradigms. Trends in Ecology & Evolution. 23.10: 555–63.

43. Wilkinson, C. 1992. Coral Reefs of the World Are Facing Widespread Devastation: Can We Prevent This through Sustainable Management Practices? Proceedings of the Seventh International Coral Reef Symposium, Guam. Vol 1.

44. Westmacott, S., ed. 2000. Management of Bleached and Severely Damaged Coral Reefs. Gland; Cambridge: IUCN.

45. Done, Terence T., and others. 2001. "Scientific Principles for Establishing MPAs to Alleviate Coral Bleaching and Promote Recovery." In Coral Bleaching and Marine Protected Areas. Proceedings of the Workshop on Mitigating Coral Bleaching Impact through MPA Design. Bishop Museum, Honolulu, Hawaii, 29-31 May 2001. Asia Pacific Coastal Program Report #0102-Pages: 53-59. http://epubs.aims.gov.au/handle/11068/6542.

46. West, J., and R. Salm. 2003. Resistance and Resilience to Coral Bleaching: Implications for Coral Reef Conservation and Management." Conservation Biology. 17.4: 956–67.

47. Hansen, L. 2003. Buying Time: A User's Manual for Building Resistance and Resilience to Climate Change in Natural Systems. Chapter 6: Tropical Marine. WWF Climate Change Program.

48. Obura, D. 2005. Resilience and Climate Change: Lessons from Coral Reefs and Bleaching in the Western Indian Ocean." Estuarine, Coastal and Shelf Science 63.3: 353–72.

49. McClanahan, T., M. Ateweberhan, C. Muhando, J. Maina, and M. Mohammed. 2007. Effects of Climate and Seawater Temperature Variation on Coral Bleaching and Mortality." Ecological Monographs. 77.4: 503–525.

50. Keller, B., D. Gleason, E. McLeod, C. Woodley, S. Airamé, B. Causey, A. Friedlander, R. Grober-Dunsmore, J. Johnson, S. Miller, R. Steneck. 2009. Climate Change, Coral Reef Ecosystems, and Management Options for Marine Protected Areas. Environmental Management. 44.6: 1069–88.

51. Baskett, M., R. Nisbet, C. Kappel, P. Mumby, and S. Gaines. 2010. Conservation Management Approaches to Protecting the Capacity for Corals to Respond to Climate Change: A Theoretical Comparison. Global Change Biology 16. 4: 1229–46.

52. Ban, N., V. Adams, G. Almany, S. Ban, J. Cinner, L. McCook, M. Mills, R. Pressey, and A. White. 2011. Designing, Implementing and Managing Marine Protected Areas: Emerging Trends and Opportunities for Coral Reef Nations. Journal of Experimental Marine Biology and Ecology. 408.1.2: 21–31.

53. 53. Maynard, J., S. McKagan, S. Johnson, P. Houk, G. Ahmadia, R. van Hooidonk, L. Harriman, and E. McLeod. 2012. Coral Reef Resilience to Climate Change in Saipan, CNMI; Field-Based Assessments and Implications for Vulnerability and Future Management. Prepared for CNMI DEQ and NOAA as part of the Northern Mariana Islands Coral Reef Initiative with The Nature Conservancy, Pacific Marine Resources Institute and the CNMI Division of Fish and Wildlife as collaborating agencies.

54. Magris, R., R. Pressey, R. Weeks, and N. Ban. 2014. Integrating Connectivity and Climate Change into Marine Conservation Planning. Biological Conservation. 170: 207–21.

55. Magris, R., S. Heron, and R. Pressey. 2015. Conservation Planning for Coral Reefs Accounting for Climate Warming Disturbances. Edited by Bayden D Russell. PLOS ONE. 10.11: e0140828.

56. Pandolfi, J. Ecology: Deep and Complex Ways to Survive Bleaching. 2015. Nature. 518.7537: 43–44.

57. Edwards, H., I. Elliott, M. Eakin, A. Irikawa, J. Madin, M. Mcfield, J. Morgan, R. Woesik, and P. Mumby. 2011. How Much Time Can Herbivore Protection Buy for Coral Reefs under Realistic Regimes of Hurricanes and Coral Bleaching?: CORAL AND CLIMATE CHANGE." Global Change Biology . 17.6: 2033–48.

58. Game, E., M. Bode, E. McDonald-Madden, H. Grantham, and H. Possingham. 2009. Dynamic Marine Protected Areas Can Improve the Resilience of Coral Reef Systems: Dynamic MPAs in Coral Reef Systems." Ecology Letters. 12.12: 1336–46.
59. McClanahan, T. 2014. Recovery of Functional Groups and Trophic Relationships in Tropical Fisheries Closures. Marine Ecology Progress Series. 497: 13–23.
60. Williams I., D. White, R. Sparks, K. Lino, J. Zamzow, E. Kelly, H. Ramey. 2016. Responses of herbivorous fishes and benthos to 6 years of protection at the Kahekili Herbivore Fisheries Management Area, Maui. PLoS ONE. 11, e0159100. (doi:10.1371/journal.pone.0159100).
61. Bonaldo, R., A. Hoey, and D. Bellwood. 2014. The Ecosystem Roles of Parrotfishes on Tropical Reefs. Oceanography and Marine Biology: An Annual Review. 52: 81–132.
62. Adam, T., D. Burkepile, B. Ruttenberg, and M. Paddack. 2015. Herbivory and the Resilience of Caribbean Coral Reefs: Knowledge Gaps and Implications for Management. Marine Ecology Progress Series. 520: 1–20.
63. Cernohorsky, N., T. McClanahan, I. Babu, and M. Horsak. 2015. Small Herbivores Suppress Algal Accumulation on Agatti Atoll, Indian Ocean. Coral Reefs. 34: 1023–35.
64. Mumby, P., N. Wolff, Y. Bozec, I. Chollett, and P. Halloran. 2014. Operationalizing the Resilience of Coral Reefs in an Era of Climate Change: Mapping Resilience. Conservation Letters. 7.3: 176–87.
65. Bozec, Y., S. O'Farrell, J. Bruggemann, B. Luckhurst, and P. Mumby. 2016. Tradeoffs between Fisheries Harvest and the Resilience of Coral Reefs. Proceedings of the National Academy of Sciences.
66. Aswani, S., P. Mumby, A. Baker, P. Christie, L. McCook, R. Steneck, and R. Richmond. 2015. Scientific Frontiers in the Management of Coral Reefs. Frontiers in Marine Science 2.
67. Hansen, L. 2003. Buying Time: A User's Manual for Building Resistance and Resilience to Climate Change in Natural Systems. Chapter 6: Tropical Marine. WWF Climate Change Program.
68. Arnold, S., R. Steneck, and P. Mumby. 2010. Running the Gauntlet: Inhibitory Effects of Algal Turfs on the Processes of Coral Recruitment." Marine Ecology Progress Series. 414: 91–105.
69. McLeod, E., R. Salm, A. Green, and J. Almany. 2009. Designing Marine Protected Area Networks to Address the Impacts of Climate Change. Frontiers in Ecology and the Environment. 7.7: 362–70.
70. Amar, K. and B. Rinkevich. 2007. A Floating Mid-Water Coral Nursery as Larval Dispersion Hub: Testing an Idea. Marine Biology. 151.2: 713–18.
71. Raymundo, L., A. Maypa, E. Gomez, and P. Cadiz. 2007. Can Dynamite-Blasted Reefs Recover? A Novel, Low-Tech Approach to Stimulating Natural Recovery in Fish and Coral Populations. Marine Pollution Bulletin. 54.7: 1009–19.
72. Gomez, E., P. Cabaitan, H. Yap, and R. Dizon. 2014. Can Coral Cover Be Restored in the Absence of Natural Recruitment and Reef Recovery?: Restoring Coral Cover. Restoration Ecology. 22.2: 142–50.
73. Lirman, D., T. Thyberg, J. Herlan, C. Hill, C. Young-Lahiff, S. Schopmeyer, B. Huntington, R. Santos, and C. Drury. 2010. Propagation of the Threatened Staghorn Coral Acropora Cervicornis: Methods to Minimize the Impacts of Fragment Collection and Maximize Production. Coral Reefs. 29.3: 729–35.
74. Diaz-Pulido, G., and L. McCook. 2002. The Fate of Bleached Corals: Patterns and Dynamics of Algal Recruitment. Marine Ecology Progress Series. 232: 115–128.
75. Roff, G., S. Bejarano, Y. Bozec, M. Nugues, R. Steneck, and P. Mumby. 2014. Porites and the Phoenix Effect: Unprecedented Recovery after a Mass Coral Bleaching Event at Rangiroa Atoll, French Polynesia. Marine Biology. 161.6: 1385–93.
76. Beeden, R., J. Maynard, J. Johnson, J. Dryden, S. Kininmonth, and P. Marshall. 2014. No-Anchoring Areas Reduce Coral Damage in an Effort to Build Resilience in Keppel Bay, Southern Great Barrier Reef. Australasian Journal of Environmental Management. 21.3: 311–19.
77. Yeemin, T., V. Mantachitra, S. Plathong, P. Nuclear, W. Klinthong, and M. Sutthacheep. 2012. Impacts of Coral Bleaching, Recovery and Management in Thailand. In Proc. 12th Int. Coral Reef Symp., Cairns, Australia. http://www.icrs2012.com/proceedings/manuscripts/ICRS2012_17D_5.pdf.

78. Tun, K., L. Ming Chou, J. Low, T. Yeemin, N. Phongsuwan, N. Setiasih, J. Wilson, et al. 2010. 1.1 A Regional Overview on the 2010 Coral Bleaching Event in Southeast Asia. Global Coral Reef Monitoring Network, Ministry of the Environment, Japan.

79. GBRMPA (Great Barrier Reef Marine Park Authority). 2008. Aquarium Collectors' World First Climate Change Initiative. SeaRead.

80. Bonin, Mary C., H. Harrison, D. Williamson, A. Frisch, P. Saenz-Agudelo, M. Berumen, and G. Jones. 2016. The Role of Marine Reserves in the Replenishment of a Locally Impacted Population of Anemonefish on the Great Barrier Reef. Molecular Ecology. 25.2: 487–99. doi:10.1111/mec.13484.

81. Mbije, N., E. Spanier, and B. Rinkevich. 2013. A First Endeavour in Restoring Denuded, Post-Bleached Reefs in Tanzania. Estuarine, Coastal and Shelf Science. 128 (August): 41–51. doi:10.1016/j.ecss.2013.04.021.

82. McClanahan, T., J. Maina, C. Starger, P. Herron-Perez, and E. Dusek. 2005. Detriments to Post-Bleaching Recovery of Corals. Coral Reefs. 24.2: 230–46. doi:10.1007/s00338-004-0471-1.

83. Armstrong, J. S. 2001. Combining forecasts. Pages 417–440 in J. S. Armstrong, editor. Principles of forecasting: a handbook for researchers and practitioners. Kluwer Academic Publishers, Norwell, Massachusetts.

84. Beverton, R., & S. Holt. 1957. On the dynamics of exploited fish populations, Fishery Investigations Series II, Vol. XIX, Ministry of Agriculture. Fisheries and Food. 1: 957.

85. Polacheck, T. 1990. Year around closed areas as a management tool. Natural Resource Modeling, 4.3, 327-354.

86. DeMartini, E. 1993. Modeling the potential of fishery reserves for managing Pacific coral-reef fishes. Fishery Bulletin, 91.3: 414-427.

87. McClanahan, T., & B. Kaunda-Arara. 1996. Fishery recovery in a coral-reef marine park and its effect on the adjacent fishery. Conservation Biology, 10.4: 1187-1199.

88. Nowlis, J., & C. Roberts. 1999. Fisheries benefits and optimal design of marine reserves. Fishery Bulletin, 97.3: 604-616.

89. Roberts, C., J. Bohnsack, F. Gell, J. Hawkins, & R. Goodridge. 2001. Effects of marine reserves on adjacent fisheries. Science: 294.5548: 1920-1923.

90. Russ, G., & C. Alcala. 2004. Marine reserves: long-term protection is required for full recovery of predatory fish populations. Oecologia. 138.4: 622-627.

91. Abesamis, R., & G. Russ. 2005. Density–dependent spillover from a marine reserve: Long–term evidence. Ecological applications. 15.5: 1798-1812.

92. Graham, N., T. Ainsworth, A. Baird, N. Ban, L. Bay, J. Cinner, D. De Freitas, et al. 2011. From Microbes to People: Tractable Benefits of No-Take Areas for Coral Reefs. Oceanography and Marine Biology-an Annual Review. 49: 105.

93. Bohnsack, J. A. 1998. Application of marine reserves to reef fisheries management. Austral Ecology. 23.3: 298-304.

94. Roberts, C., J. Hawkins, & F. Gell. 2005. The role of marine reserves in achieving sustainable fisheries. Philosophical Transactions of the Royal Society of London B: Biological Sciences. 360.1453: 123-132.

95. Mumby, P., A. Harborne, J. Williams, C. Kappel, D. Brumbaugh, F. Micheli, K. Holmes, C. Dahlgren, C., and P. Blackwell. 2007. Trophic Cascade Facilitates Coral Recruitment in a Marine Reserve. Proceedings of the National Academy of Sciences. 104.20: 8362–8367.

96. Friedlander, A., E. Brown, and M. Monaco. 2007. Defining Reef Fish Habitat Utilization Patterns in Hawaii: Comparisons between Marine Protected Areas and Areas Open to Fishing. Marine Ecology Progress Series. 351 (December): 221–33. doi:10.3354/meps07112.

97. Stockwell, B., C. Jadloc, R. Abesamis, A. Alcala, and G. Russ. 2009. Trophic and Benthic Responses to No-Take Marine Reserve Protection in the Philippines. Marine Ecology Progress Series. 389 (September): 1–15. doi:10.3354/meps08150.

98. Selig, E.., and J. Bruno. 2010. A Global Analysis of the Effectiveness of Marine Protected Areas in Preventing Coral Loss. PLoS One. 5.2: e9278.

99. Graham, N., D. Bellwood, J. Cinner, T. Hughes, A. Norström, and M. Nyström. 2013. Managing Resilience to Reverse Phase Shifts in Coral Reefs." Frontiers in Ecology and the Environment. 11.10: 541–48.

100. Heenan, A., R. Pomeroy, J. Bell, P. Munday, W. Cheung, C. Logan, R. Brainard, et al. 2015. A Climate-Informed, Ecosystem Approach to Fisheries Management. Marine Policy. 57 (July): 182–92. doi:10.1016/j.marpol.2015.03.018.

101. Williams G., Gove J., Eynaud Y., Zgliczynski B., Sandin S.. 2015. Local human impacts decouple natural biophysical relationships on Pacific coral reefs. Ecography. 38: 751–761. (doi:10.1111/ecog.01353)

102. Williams I., Baum J., Heenan A, Hanson K., Nadon M., Brainard R. 2015. Human, oceanographic and habitat drivers of central and western Pacific coral reef fish assemblages. PLoS ONE. 10, e0120516. (doi:10.1371/journal.pone.0120516).

103. Williams S., Chollett I., Roff G., Corte´s J., Dryden C., Mumby P. 2015. Hierarchical spatial patterns in Caribbean reef benthic assemblages. J. Biogeogr. 42: 1327–1335. (doi:10.1111/jbi.12509).

104. Howard, K., J. Claisse, T. Clark, K. Boyle, and J. Parrish. 2013. Home Range and Movement Patterns of the Redlip Parrotfish (Scarus Rubroviolaceus) in Hawaii. Marine Biology 160.7: 1583–95. doi:10.1007/s00227-013-2211-y.

105. McCook, L., J. Jompa, and G. Diaz-Pulido. 2001. Competition between Corals and Algae on Coral Reefs: A Review of Evidence and Mechanisms. Coral Reefs.19. 4: 400–417. doi:10.1007/s003380000129.

106. Knowlton, N. 2004. Multiple “stable” states and the conservation of marine ecosystems. Progress in Oceanography. 60.2: 387-396.

107. Bellwood D., C. Fulton. 2008. Sediment-mediated suppression of herbivory on coral reefs: decreasing resilience to rising sea-levels and climate change? Limnol. Oceanogr. 53. 2695–2701. doi:10.4319/lo.2008.53.6.2695.

108. Mangi, S., & C. Roberts, C. M. 2006. Quantifying the environmental impacts of artisanal fishing gear on Kenya’s coral reef ecosystems. Marine pollution bulletin. 52. 12: 1646-1660.

109. McClanahan, T., and J. Cinner. 2008. A Framework for Adaptive Gear and Ecosystem-Based Management in the Artisanal Coral Reef Fishery of Papua New Guinea. Aquatic Conservation: Marine and Freshwater Ecosystems. 18.5: 493–507. doi:10.1002/aqc.874.

110. Cinner, J., T. McClanahan, N. Graham, M. Pratchett, S. Wilson, and J. Raina. 2009. Gear-Based Fisheries Management as a Potential Adaptive Response to Climate Change and Coral Mortality. Journal of Applied Ecology. 46.3: 724–32. doi:10.1111/j.1365-2664.2009.01648.x.

111. Puleloa, W. Moloka‘i Island Gill-net Project. 2012. Department of Land and Natural Resources.

112. Meyer, Carl G. 2007. The Impacts of Spear and Other Recreational Fishers on a Small Permanent Marine Protected Area and Adjacent Pulse Fished Area. Fisheries Research. 84.3: 301–7. doi:10.1016/j.fishres.2006.11.004.

113. Lindfield, S., J. McIlwain, and E. Harvey. 2014. Depth Refuge and the Impacts of SCUBA Spearfishing on Coral Reef Fishes. PloS One. 9.3: e92628.

114. Stoffle, B., S. Allen. 2012. The Sociocultural Importance of Spearfishing in Hawai‘i. US Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Pacific Islands Fisheries Science Center.

115. Bellwood, D., A. Baird, M. Depczynski, A. González-Cabello, A. Hoey, C. Lefèvre, and J. Tanner. 2012. Oecologia. 170: 567–573.

116. Edwards, C., A. Friedlander, A. Green, M. Hardt, E. Sala, H. Sweatman, & J. Smith. 2014. Global assessment of the status of coral reef herbivorous fishes: evidence for fishing effects. Proceedings of the Royal Society of London B: Biological Sciences. 281.1774: 20131835.

117. Heenan, A., A. Hoey, G. Williams, and I. Williams. 2016. Natural Bounds on Herbivorous Coral Reef Fishes. Proceedings of the Royal Society B: Biological Sciences 283.1843: 20161716. doi:10.1098/rspb.2016.1716.

118. Nadon, M. O. 2017. Stock assessment of the coral reef fishes of Hawaii, 2016. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-PIFSC-60, 212 p. doi:10.7289/V5/TM-PIFSC-60.

119. Cox, C., C. Jones, J. Wares, K. Castillo, M. McField, and J. Bruno. 2013. Genetic Testing Reveals Some Mislabeling but General Compliance with a Ban on Herbivorous Fish Harvesting in Belize: Genetic Testing on Coral Reef Fish in Belize. Conservation Letters 6.2: 132–40. doi:10.1111/j.1755-263X.2012.00286.x.

120. O'Farrell, S., B. Luckhurst, S. Box, and P. Mumby. 2016. Parrotfish Sex Ratios Recover Rapidly in Bermuda Following a Fishing Ban. Coral Reefs. 35.2: 421–25. doi:10.1007/s00338-015-1389-5.

121. Carassou, L., M. Léopold, N. Guillemot, L. Wantiez, and N. Kulbicki. 2013. Does Herbivorous Fish Protection Really Improve Coral Reef Resilience? A Case Study from New Caledonia (South Pacific). Edited by Richard KF. Unsworth. PLoS ONE. 8.4: e60564. doi:10.1371/journal.pone.0060564.

122. O'Farrell, S., A. Harborne, Y. Bozec, B. Luckhurst, and P. Mumby. 2015. Protection of Functionally Important Parrotfishes Increases Their Biomass but Fails to Deliver Enhanced Recruitment. Marine Ecology Progress Series. 522 (March): 245–54. doi:10.3354/meps11134.

123. Mumby, P. 2006. Fishing, Trophic Cascades, and the Process of Grazing on Coral Reefs. Science. 311. 5757: 98–101. doi:10.1126/science.1121129.

124. Ledlie, M., N. Graham, J. Bythell, S. Wilson, S. Jennings, N. Polunin, and J. Hardcastle. 2007. Phase Shifts and the Role of Herbivory in the Resilience of Coral Reefs. Coral Reefs. 26. 3: 641–53. doi:10.1007/s00338-007-0230-1.

125. Jayewardene, D. 2009. A Factorial Experiment Quantifying the Influence of Parrotfish Density and Size on Algal Reduction on Hawaiian Coral Reefs. Journal of Experimental Marine Biology and Ecology. 375.1–2: 64–69. doi:10.1016/j.jembe.2009.05.006.

126. Jouffray, J., M. Nystrom, A. Norstrom, I. Williams, L. Wedding, J. Kittinger, and G. Williams. 2014. Identifying Multiple Coral Reef Regimes and Their Drivers across the Hawaiian Archipelago. Philosophical Transactions of the Royal Society B: Biological Sciences. 370.1659: 20130268–20130268. doi:10.1098/rstb.2013.0268.

127. DeMartini, E., and K. Howard. 2016. Comparisons of Body Sizes at Sexual Maturity and at Sex Change in the Parrotfishes of Hawai'i: Input Needed for Management Regulations and Stock Assessments: Comparative Maturation of Parrotfishes. Journal of Fish Biology. 88.2: 523–41. doi:10.1111/jfb.12831.

128. Ong, L., and K. Holland. 2010. Bioerosion of Coral Reefs by Two Hawaiian Parrotfishes: Species, Size Differences and Fishery Implications. Marine Biology. 157.6: 1313–23. doi:10.1007/s00227-010-1411-y.

129. Gil, M., S. Goldenberg, A. Bach, S. Mills, and J. Claudet. 2016. Interactive Effects of Three Pervasive Marine Stressors in a Post-Disturbance Coral Reef. Coral Reefs. 35.4: 1281–93. doi:10.1007/s00338-016-1489-x.

130. Richmond, R., T. Rongo, Y. Golbuu, S. Victor, N. Idechong, G. Davis, W. Kostka, L. Neth, M. Hamnett, and E. Wolanski. 2007. Watersheds and Coral Reefs: Conservation Science, Policy, and Implementation. BioScience. 57.7: 598–607.

131. Chu, Z., S. Zhai, X. Lu, J. Liu, J. Xu, K. Xu, 2009. A quantitative assessment of human impacts on decrease in sediment flux from major Chinese rivers entering the western Pacific Ocean. Geophys. Res. Lett. 36: 1–5.

132. Kroon, F., B. Schaffelke, and R. Bartley. 2014. Informing Policy to Protect Coastal Coral Reefs: Insight from a Global Review of Reducing Agricultural Pollution to Coastal Ecosystems. Marine Pollution Bulletin. 85.1: 33–41. doi:10.1016/j.marpolbul.2014.06.003.

133. Rodgers, K., M. Kido, P. Jokiel, T. Edmonds, and E. Brown. 2012. Use of Integrated Landscape Indicators to Evaluate the Health of Linked Watersheds and Coral Reef Environments in the Hawaiian Islands. Environmental Management. 50.1: 21–30. doi:10.1007/s00267-012-9867-9.

134. Smith, S., W. Kimmerer, E. Laws, R. Brock, T. Walsh. 1981. Kaneohe Bay sewage diversion experiment–perspectives on ecosystem responses to nutritional perturbation. Pac. Sci. 35: 279–402.

135. Rinkevich, Baruch. 2005. Conservation of Coral Reefs through Active Restoration Measures: Recent Approaches and Last Decade Progress. Environmental Science & Technology. 39.12: 4333–42. doi:10.1021/es0482583.

136. Rinkevich, B. 2006. The Coral Gardening Concept and the Use of Underwater Nurseries: Lessons Learned from Silvics and Silviculture. In Coral Reef Restoration Handbook, edited by William F. Precht.

137. Rinkevich, B. 2008. Management of Coral Reefs: We Have Gone Wrong When Neglecting Active Reef Restoration. Marine Pollution Bulletin. 56. 11: 1821–24. doi:10.1016/j.marpolbul.2008.08.014.

138. Van Oppen, M., P. Bongaerts, J. Underwood, L. Peplow, and T. Cooper. 2011. The Role of Deep Reefs in Shallow Reef Recovery: An Assessment of Vertical Connectivity in a Brooding Coral from West and East Australia: vertical connectivity in a brooding coral. Molecular Ecology. 20.8: 1647–60. doi:10.1111/j.1365-294X.2011.05050.x.

139. D'angelo, C., B. Hume, J. Burt, E. Smith, E. Achterberg, and J. Wiedenmann. 2015. Local Adaptation Constrains the Distribution Potential of Heat-Tolerant Symbiodinium from the Persian/Arabian Gulf. The ISME Journal. 9.12: 2551–2560.

140. Cremieux, L., A. Bischoff, H. Muller-Scharer, and T. Steinger. 2010. Gene Flow from Foreign Provenances into Local Plant Populations: Fitness Consequences and Implications for Biodiversity Restoration. American Journal of Botany. 97.1: 94–100. doi:10.3732/ajb.0900103.

141. Pollnac, R., P. Christie, J. Cinner, T. Dalton, T. Daw, G. Forrester, et al., Marine reserves as linked social–ecological systems. 2010. Proc.Natl.Acad.Sci. 107: 18262–18265. http://dx.doi.org/10.1073/pnas.0908266107.

142. Edgar, G., R. Stuart-Smith, T. Willis, S. Kininmonth, S. Baker, S. Banks, et al. 2014. Global conservation outcomes depend on marine protected areas with five key features, Nature. 50: 216–220. http://dx.doi.org/10.1038/ nature13022.

143. DLNR. 2015. North Maui Community Fisheries Enforcement Unit Update: Educate, Outreach, and Enforcement Leads to Healthier Resources. http://dlnr.hawaii.gov/blog/2016/08/25/nr16-166/.

144. Crawford, B., A. Siahainenia, C. Rotinsulu, and A. Sukmara. 2004. Compliance and enforcement of community-based coastal resource management regulations in North Sulawesi, Indonesia. Coastal Management. 32.1: 39-50.

145. McClanahan, T., M. Marnane, J. Cinner, and W. Kiene. 2006. A Comparison of Marine Protected Areas and Alternative Approaches to Coral-Reef Management. Current Biology. 16.14: 1408–13. doi:10.1016/j.cub.2006.05.062.

146. Haisfield, K., H. Fox, S. Yen, S. Mangubhai, & P. Mous. 2010. An ounce of prevention: cost-effectiveness of coral reef rehabilitation relative to enforcement. Conservation Letters. 3.4: 243-250.

147. Kaplan, K., G. Ahmadia, H. Fox, L. Glew, E. Pomeranz, and P. Sullivan. 2015. Linking Ecological Condition to Enforcement of Marine Protected Area Regulations in the Greater Caribbean Region. Marine Policy . 62 (December): 186–95. doi:10.1016/j.marpol.2015.09.018.