INDICATOR SPECIES / ECOLOGY GROUP SUMMARY

I. Background [1]

At many sites along the coast of the Keauhou Aquifer System Area (KASA), groundwater feeds springs, anchialine pools, fishponds, offshore seeps, near shore estuaries, and reef life from tidal benches to great distances off-shore. These groundwater dependent ecosystems (GDEs) are important sites for biodiversity and Native Hawaiian biocultural practices which include, among others, food and resource collection, aquaculture production, water gathering, food preservation, medicine production, traditional ceremonies and bathing (Gibson et. al 2022). The Commission on Water Resource Management (CWRM) is obligated to protect these as part of its responsibilities under the public trust doctrine.

In preparation of a first generation Keauhou Aquifer System Groundwater Adaptive Management Plan (AMP) that will eventually inform permit and groundwater pumpage decisions, CWRM convened three different groups of experts. The Indicator Species / Ecology expert group focused on GDEs, specifically the organisms that rely on fresh water and how those species may be impacted by groundwater withdrawals in the KASA. Three initial meetings with biological and ecological experts were held in August and September of 2025. The meetings were convened by CWRM Planning Branch manager Katie Roth and facilitated by consultant Peter Adler. Invited experts included:

- Celia Smith - The Wilder Chair and Professor of Botany, School of Life Sciences, University of Hawaiʻi at Mānoa
- Diamond Tachera - Project Scientist I, Mesoscale & Microscale Meteorology Laboratory, NSF National Center for Atmospheric Research (NCAR)
- Henrietta Dulai – Professor, Department of Earth Sciences, School of Ocean Earth Science and Technology, University of Hawaiʻi at Mānoa
- Ryan Okano - Aquatic Biologist, DLNR, Division of Aquatic Resources
- Troy Sakihara - Aquatic Biologist, DLNR, Division of Aquatic Resources
- Veronica Gibson – Postdoctoral wetland researcher, Heʻeia National

[1] A few citations are included in this summary but a more extended list of references is at Section-2 of https://dlnr.hawaii.gov/cwrm/files/2025/07/AMP-Literature-Gathering-07_07_25.pdf.

Estuarine Research Reserve, Hawaiʻi Institute of Marine Biology, University of Hawaiʻi at Mānoa

Also participating in most of the discussions were Water Commissioner, Hannah Springer (who noted that her participation was more as a practitioner and person of that place rather than as a commissioner), AMP Advisor Charles Young, Hawaiʻi Island ʻAhā Moku, AMP Advisor Leah Bremer, County Department of Water Supply Manager-Chief Engineer Keith Okamoto, and other CWRM and DWS staff members including Ryan Quitoriano and Shari Uyeno. Each meeting lasted approximately two hours.

II. Initial Goals

The meetings sought to foster a comfortable consensus-seeking exchange of ideas with five aspirations:

(a) Identify not more than three possible specific Adaptive Management Plan (AMP) baseline monitoring indicators regarding <u>native species</u> found in the GDEs;

(b) Identify not more than three possible specific <u>non-native, invasive, or disruptive species</u> found in the GDEs;

(c) Articulate the current assumptions behind each recommended indicator;

(d) Design a preliminary monitoring program to accompany the AMP baseline monitoring indicators, including what to monitor for, frequency of monitoring, and monitoring (sentinel) sites; and

(e) Prioritize a short list of specific additional future research questions that will improve a second-generation AMP.

III. Take Aways from Expert Discussions

A. **The Delicate Balance: Groundwater's Role in Ecosystem Resilience**. Despite natural fluctuations from tides, seasons, sea level, and rainfall, there is a delicate balance over widespread coastal regions, that allows native species to thrive. However, persistently reduced groundwater quantity or quality can tip the balance in favor of invasive and non-native aquatic and terrestrial species (including plants, algae, parasites, diseases, and animals across a range of ecosystems). Some Hawaiian limu, for example, are adapted to thrive under low-salinity, high-nutrient conditions created by Submarine Groundwater Discharge, or "SGD" (Dulai et. al., 2021). If groundwater pumping reduces the volume of freshwater discharge, coastal salinity and temperature can rise, nutrient levels can drop, and habitat parameters can shift away from the groundwater affected conditions in which native species thrive. Reduced freshwater discharge may also impact other water quality parameters, including pH, dissolved oxygen, and turbidity. The habitat essentially is no longer a native habitat and becomes favorable for invasive species, several of which are poised to outcompete and overgrow native species. This creates a "perfect storm" scenario where reduced fresh water flow and excessive increases in nutrient influx above ambient levels can lead to blooms of invasive algae~~.~~

Native species will decline or cease to grow if their habitat needs are not met, even without the proliferation of invasive species. Thus, the occurrence and growth rates of some limu such as limu pālahalaha (*Ulva lactuca*) emerge as good indicators of groundwater health. Limu pālahalaha has long been established as a biocultural indicator by cultural practitioners and resource managers of the Kona region (Gibson et al. 2022), and the positive impacts of protecting SGD on limu pālahalaha habitat are well studied (Okuhata et al. 2023, Richards-Donà et al. 2023).

B. **The Role of Herbivores**. Some invasive algae such as *Acanthophora spicifera* are present in Kona but seem to be controlled outside of fishponds by healthy populations of diverse, native grazing fish. The continued survival of these fishes, such as manini, pualu, palani, ʻamaʻama and āholehole, which prefer brackish water habitats particularly as juveniles, make them good potential indicators of groundwater health. Particularly, ʻama'ama (*Mugil cephalus*) and aholehole (*Kuhlia xenura* and *Kuhlia sandvicensis*) are well studied and have narrow salinity tolerance ranges for juvenile phases and will be unable to reproduce without the lowered salinities produced by SGD inputs (see Gibson et. al. appendix, 2022).

This is likely also true for other juvenile fish species for which the salinity requirements have not yet been measured. Again, native species tend to be resilient under the ranges of water quality and quantity of groundwater found in a wide spectrum of native coastal habitats. If the quantity of freshwater discharged in groundwater dependent regions is reduced, populations are likely to change away from the presence of native species. If we increase nutrient concentrations even moderately, coupled with a decline in native grazers, invasive algae may overgrow these once-native habitats.

C. **Potential Indicators.** Beyond limu pālahalaha (see Section A above) other species warrant consideration as indicator species. Because of their cultural importance and complex behaviors, including their use of subsurface water conduits to move between ponds, ʻōpaeʻula (*Halocardinia rubra*) may be an especially significant indicator to track. It may reveal not just the presence of brackish groundwater but also the subsurface water connections and flow paths.

The hesitation in using ʻōpaeʻula is that they have a broad salinity tolerance and are resilient to natural changes, making them more of a reactive rather than proactive indicator. Dragonflies and damselflies may also be important indicators because they require much lower salinity than the aforementioned coastal fish species (~ 10 parts per thousand (ppt)), making them relatively more sensitive to changes in anchialine pool chemistry. Damselflies are also an endemic, endangered species. Dragonflies and damselflies are also found within the anchialine pool habitat, rather than the coastal habitat in which the aforementioned fish species are found. The hau tree (*Hibiscus tiliaceus*) was proposed as a terrestrial plant that acts as a "water seeker." Changes in the health or location of hau could signal a shift in the freshwater-saltwater interface.

Guppies (*Gambusia affinis* and *Poecilia reticulata*) and mosquito fish were proposed as good indicators of changing water conditions in anchialine pools because they are less tolerant of high salinity than other invasives such as mollies or tilapia. Their absence can indicate a reduction in groundwater, leading to higher salinities. In reference to invasive algae, experts advocated for monitoring for the arrival of any new threats (e.g., *Hypnea musciformis*) and tracking the abundance of established species. Reductions in SGD have been shown to expand habitat and invasion potential for the invasive algae *Hypnea musciformis* (Okuhata et al 2023, Richards-Donà et al. 2023). Further work is needed to demonstrate how reduced SGD may expand habitat for other invasive species and reduce native species habitat within this region.

A complete list of all possible indicators is attached (see Appendix 1 and 2) but the following top three in each category seem to have potential for a first-generation AMP. However, we also think more diverse subcategories may ultimately be needed because of the varieties of coastal features and creatures. This would allow limu pāhalaha to be a major primary indicator for coastal regions that would quickly ʻreportʻ changes in large coastal regions such as tidal benches versus anchialine pools.

Native species	Invasive / non-native species

Limu pālahalaha *(Ulva lactuca)* **ʻŌpae ʻula** *(Halocardinia rubra)* **Damselflies** *(Megalagrion)*	**Guppies** *(Gambusia affinis* and *Poecilia reticulata)* **Macro or micro algae** *(e.g., Hypnea musciformis)* **Non-native damselflies**

Other taxa to be considered include mollusks, especially hapawai (*Neritina vespertina*) and pīpīwai (*Neritina spp.,* especially *Neritina granosa*) and, most importantly, microbial communities which may be the fastest and best indicators of change before more cascading impacts are seen. Practitioners and resource managers know what "color" ponds should be, and this could be a powerful first alert.[2] Opelu were also mentioned as an important biocultural species and food source for the region (Gibson et al. 2022), that should be considered for monitoring.

D. Sentinel Sites.

Three specific sites were mentioned as possible sentinel sites: Queen Liliʻuokalani Trust (QLT) at Keahuolū, Kaloko Honōkohau National Historic Park, and Kahaluʻu Bay. These initial sites were suggested based on their inclusion of diverse GDE habitats, active fisheries, existing community monitoring efforts, and may represent a variety of landowners. Other possible sentinel sites include the Honokōhau Harbor and Keauhou Harbor due to their role as vectors of significant SGD.

It should be noted that many of the experts thought studying whole sentinel sites and using eDNA and DNA metabarcoding methods which account for the diversity of species found within the site might be better than only focusing on individual species. Their reasoning was that an ecosystem-level approach would better capture the complex interactions between species and be more effective at detecting unpredictable new invasives or parameters wherein natives act invasively.

Experts emphasized that a suite of indicators covering a range of hydrological parameters (i.e., temperature, salinity, nutrients) would be most effective and that limiting indicators to 3 native and 3 invasive / non-native seemed arbitrary. The

[2] See research by Dr. Kiana Frank

importance of selecting biocultural indicators—locally and culturally relevant metrics that combine social, cultural, and ecological information to assess the health and resilience of a community and its environment—was also stressed. It was noted that, to be more effective, indicator species need to be place-based and informed by cultural practitioners and resource managers of the place.

Experts recommended the inclusion of "control" sites, where localized impacts within the KASA would not be expected. This is critical in separating outside drivers from drivers directly related to parameters within the KASA. The scientific control provides a reliable basis for comparison that is essential to distinguish between localized impacts (like groundwater pumping) and broader, coastline-wide changes (such as sea-level rise), thereby minimizing misinterpretation of data trends.

D. **Further Research and the Challenge of Linking Hydrology and Biology.** The experts acknowledge the immense difficulty in drawing a direct, causal line from specific pumping wells to a specific biological outcome, in part because of the lag time between groundwater pumping and depletion in submarine groundwater discharge (SGD). For example, isotopic analysis of water emerging as SGD in the Kīholo and Keauhou aquifer systems shows that it originated as rain at an elevation higher than the summit of Hualālai. To account for these isotopic compositions, water might be coming from Mauna Loa or Mauna Kea through complex and interconnected subsurface features, traveling for thousands of years underground before emerging at the coast. This complex hydrogeology makes it difficult to predict the response time to changes in groundwater pumping.

In addition, the KASA consists of three distinct aquifer bodies (the high level, the basal, and the deep confined). More research is needed to better understand how these 3 aquifer bodies are connected and how groundwater withdrawals from one could impact another and subsequently impact fresh water discharge at the coast. Additionally, experts mentioned new confirmation of a massive, deep offshore freshwater reservoir containing an estimated 4 cubic kilometers of fresh water, known to local practitioners for generations. This system is actively discharging nutrient-rich fresh water up to 2 kilometers offshore, supporting a previously unconfirmed by modern scientific methods deep-water, offshore GDE. While likely separated from the shallow GDEs by confining layers, the deep system is under immense hydrostatic pressure, and any connection would likely involve deep water flowing upward to feed the upper basal aquifer fresh water lens.

Tapping into high-level fresh water that feeds this deep system cannot be ruled out as having a potential impact on the shallower GDEs that are the focus of this effort.

This finding also raises the question of whether the definition of a GDE should be expanded to include our diverse mesophotic communities of algae, corals, and black corals as well as pelagic fisheries. This is an important point due to the biocultural value of these ecosystems along the Kona coast, which support important commercial and sport fishing, diving, and marine tourism industries. Finally, another challenge is that fluctuations in salinity and temperature could be the result of changes in sea level and saltwater intrusion into the basal aquifer rather than changes in fresh water inputs from the aquifers as demonstrated in Kīholo Bay.

Appendix 1: Proposed Indicators for Native and Endemic Flora and Fauna

Limu (e.g. pālahalaha, ʻakiʻaki)

Amplified by several experts, limu and other marine plants are valuable indicators due to their critical role as the foundation of all marine / coastal ecosystems as primary producers and their accessibility to sampling. Often attaching to a site and spreading in place, these plants allow for consistent monitoring across specific sites. They generally exhibit a much faster response to environmental changes compared to corals, making them effective early warning indicators. Changes in occurrence of native limu (e.g., limu pālahalaha, ʻeleʻele, ʻakiʻaki, and paheʻe) may indicate changes in SGD. Limu pālahalaha, in particular, thrives in the low-salinity, high-nutrient conditions characteristic of healthy groundwater influence. A decline in its population may suggest a disruption in SGD flow, while an increase could indicate elevated nutrient levels. Other native limu genera like *Cladophora, Dictyosphaeria*, *Rhyzoclonium*, and cyanobacteria are also useful indicators of increased nutrient concentrations. For instance, Limu manauea requires specific salinities (27% minimum 35%), and its disappearance from previously observed locations can signify a reduction in spring flow.

Challenges/Considerations: Preliminary research indicates that the relationship between limu and SGD can be complicated by exceptionally high nutrient levels, particularly from concentrated sources of wastewater, which might allow invasive species like *Hypnea* to outcompete native limu even in low-salinity environments. Further research is necessary to fully understand these complex interactions, especially concerning the distinction between natural and anthropogenic nutrient sources. Studies, such as that by Okuhata et al. (2023), demonstrate that pālahalaha can either expand with wastewater presence or shrink with decreasing SGD and/or increased salinity. Modeling techniques, such as "hindcasting" its pristine distribution, could establish a baseline for monitoring.

Limu ʻakiʻaki can be an important indicator especially in basaltic areas, offering a different sensitivity and vulnerability profile compared to other limu species. It would require significant research as its salinity tolerance is unknown, however redundancy in selecting indicators could be a useful strategy. More work is needed to identify specific salinity thresholds for diverse limu species along the Kona coast. See Gibson et al. 2022, appendix 1 for a more complete list of GDE associated limu species.

ʻŌpaeʻula (*Halocardinia rubra*)

Culturally, historically vital and a key biological indicator. Also proposed as a hydrological tool: genetic population testing between ponds could reveal subsurface water connections and flow paths. The presence of this species in anchialine pools typically indicate a relatively healthy ecosystem, and the absence or minimal presence of invasive fish and invertebrates.

Challenges/Considerations: Its tolerance to a broad range in salinity, water temperature and other natural variations in habitat conditions may make it a less sensitive, "reactive" indicator.

<u>Damselflies (*Megalagrion*)</u>

Damselflies, particularly the *Megalagrion* species, are considered highly sensitive, or "finicky sentinel species." Their immature larvae are intolerant of salinities exceeding 15 PSU, and their eggs have a very narrow temperature and salinity range for successful hatching. As an endangered species, their presence and health are critical indicators of pristine groundwater-dependent habitats.

<u>Terrestrial, Emergent and Aquatic Plants (e.g., hau, ʻulu)</u>

Practitioners have observed that native plants such as hau exhibit changes in health or distribution, including dying off, when springs shift spatially or dry up. The presence of these "water seeking" plants indicates the presence of water, making areas suitable for the creation or restoration of anchialine ponds. These species are selected as potential indicators for the migration of the freshwater-saltwater interface. Changes in the health or location of these trees could signal shifts in groundwater due to factors like sea-level rise or increased pumping. Additionally, hau possesses numerous utilitarian uses, further emphasizing its biocultural significance.

The die-off of ʻulu trees in other Pacific regions due to saltwater intrusion highlights their potential as indicators of environmental change, especially given their importance as a food staple and their low salinity tolerance. Such die-offs can signal a loss of submarine spring flow. Another water-seeking species is the niu or coconut tree. .. For example, the historic niu grove at Mahaiʻula north, which is spring-fed. Other emergent and aquatic plants associated with springs and anchialine pools, including Makaloa, *Pritchardia*, ʻaeʻae, ʻōhelo kai, *Ruppia*, and ʻakaʻakai, are also sensitive to salinity changes.

<u>eDNA</u>

Environmental DNA (eDNA) is a modern tool capable of detecting a wide range of organisms, including microbes, plants, and fish, from a single water sample. This method allows for the early detection of species changes within an ecosystem or the detection of species that may be difficult to observe through other means. When combined with other techniques including conventional sampling and surveying methods, eDNA can provide a more comprehensive and accurate assessment of species present in a habitat. CWRM already incorporates eDNA into some of their monitoring partnerships. It is proposed as an enhancement tool to capture the presence of all species in a given area, offering a broad snapshot of biodiversity and ecosystem health. NOAA has results from an eDNA and benthic surveys from 80 reefs along the Kona coast conducted in 2022, which could serve as a good baseline for comparison

<u>Loss of ʻamaʻama (*Mugil cephalus*) and āholehole (*Kuhlia xenura, Kuhlia*</u>

sandvicensis)

ʻAmaʻama (striped mullet) and āholehole are key biocultural species whose reproduction and specific life history phases are intrinsically linked to particular salinity conditions in nearshore environments. A decline in the recruitment of pua ʻama and āholehole in areas previously known for submarine groundwater discharge (SGD) seeps could indicate a loss of lower salinity conditions. For ʻamaʻama, eggs require 30-32‰, larvae 26-28‰, and juveniles less than 15‰. Conversely, in Heʻeia, the expansion of āholehole habitat has been observed with the restoration of spring flow. Other species, such as moi, weke, awa and awaʻawa, ʻōpae huna and ʻōpae ʻoehaʻa, while not extensively studied for salinity tolerance, are known to be associated with springs and could also serve as indicators. (Note: combined with above)

Decline in recruitment of amphidromous/diadromous species (e.g., 'o'opu, pua'ama, āhole hole)

A variety of native fishes and crustaceans in Hawaiʻi have an amphidromous life cycle where eggs hatch in fresh or brackish water, larvae drift out to sea to develop, then return to fresh and brackish inshore habitats as small juveniles. These animals key in on signals of freshwater to find these brackish habitats. For regions without perennial streams, SGD is the primary source providing the freshwater signal. Because of this, a reduction in SGD may result in a reduction in recruitment of native amphidromous species in these areas. Challenges/considerations: many other factors can influence recruitment of amphidromous species.

Hapawai, Pī pīwai

This indicator combines the monitoring of snails, specifically hapawai and pīpīwai, whose salinity tolerance is lower than that of ʻamaʻama. For these species, including fish and snails, there is a strong potential for them to serve as subtidal indicators of salinity when take together as a subrtidal community assemblage. Hapawai, in particular, is valued for both food and adornment, highlighting its biocultural significance.

Coral

Increasing coral bleaching events may be linked to rising and lasting elevated temperatures resulting from declining submarine groundwater discharge (SGD). Resource managers at Kīholo perceive this connection. The mitigation in temperature, influenced by SGD, plays a crucial role in coral health.

Birds

The loss of shorebird nesting habitats due to a decrease in fresh drinking water is a significant concern. The Kaloko-Honokōhau National Historical Park (KHNHP) possesses data on bird distribution correlated with available salinities. Species such as Aeʻo, nēnē, Koloa maoli, ʻuaʻu, ‘auku‘u, koloa mōhā, ‘akeke, and lesser caup are among those whose populations are affected by changes in freshwater availability.

Meiofauna

Meiofauna are small invertebrate animals typically less than 1 mm in size that are common in aquatic environments including anchialine pools. Their high abundance, diversity, short lifespans and sensitivity to environmental changes can serve as a good early indicator of changes to habitat conditions. **Challenges/considerations:** a unique knowledge base, skill sets and experience is required for studying meiofauna, which may be more limited than other disciplines and fields of study.

Community Composition/Benthic Microbial Community

Alterations in the benthic microbial community within anchialine pools or nearshore intertidal habitats can be the "fastest and best indicator of change" before more significant cascading impacts become apparent. Changes in these communities are often visible as shifts in water color or clarity, allowing practitioners to observe and respond to early signs of environmental stress. Challenges/considerations: expertise in microbiology and microbial ecology with specific technical skillsets and knowledge is required.

Tissue N and Stable Isotopes

Analysis of tissue nitrogen (N; usually on macroalgal tissue) and stable isotopes can be a valuable tool for detecting pollution in coastal environments. These analyses help in identifying and quantifying nutrient loads, including total nitrogen, total phosphorus, nitrate, silicate, and phosphate, providing insights into the sources and impacts of nutrient enrichment on groundwater-dependent ecosystems.

Appendix 2: Proposed Indicators Invasive and Non-native Flora and Fauna

Fish (e.g., guppies, mosquitofish)

The absence of certain invasive fish species, such as guppies and mosquitofish, in anchialine ponds can be a strong indicator of salinity levels being too high for their tolerance. These species are considered better indicators than mollies or tilapia, which possess a much wider range of salinity tolerances, making them less sensitive to subtle changes in groundwater-dependent ecosystems. The presence or absence of guppies and other salinity-limited invasive species in anchialine pools can therefore provide valuable insights into the hydrological conditions

Limu and macroalgae

Monitoring for the arrival and occurrence of invasive macroalgae like *Hypnea musciformis* is important especially since it is not yet believed to be present on Hawaiʻi Island. Its detection would signal significant environmental reductions in SGD in the Kona region. *Acanthophora spicifera,* an already established invasive red alga, can serve as an inexpensive proxy for local herbivory pressure due to its high palatability to reef fish. Any rapid expansion of bloom-forming macroalgae, including *Cladophora, Ulva, Dictyosphaeria,* and *Caulerpa*, could indicate increased nutrient levels or shifts in salinity that disadvantage native competitors. Similarly, the rapid expansion of *A. spicifera, Cladophora, Ulva, Cyanobacteria (microalgae), Caulerpa*, or other limu, or the occurrence of *G. salicornia*, could signal reductions in herbivory as well as increased nutrients / salinity changes that enhance invasive over native competitors. The presence or absence of invasive salinity-tolerant macroalgae, and whether their occurrence is permanent or episodic, provide important data.

Challenges/Considerations: The utility of *Acanthophora* as an indicator is complicated by its strong confounding with herbivory, making it difficult to isolate the signal of water quality changes. Effective monitoring would necessitate concurrent monitoring of herbivores in the same area. Furthermore, it is challenging to predict which invasive macroalgae species will arrive next. Therefore, a comprehensive approach that monitors for all invasive macroalgae, and even native limu (like Pālahalaha) that can exhibit invasive behavior during nutrient-fueled blooms, is often advocated

Tissue analysis of Limu via δ15N and %N: Tissue analysis for percentage nitrogen (%N) and δ^{15}N (delta-^{15} nitrogen) is proposed to be included as a standard component of monitoring protocols for the detection of wastewater as well as agricultural fertilizers.. This method offers a direct way to monitor the primary driver of many invasive algal blooms. By analyzing the tissue of algae, a nitrogen content of 1 - 4% or more serves as a clear, low-cost (approximately $20 per sample) indicator of nutrient pollution (wastewater and ag fertilizes), which is a significant factor in fueling the growth of some invasive species.

Systemic Literature Review: A systematic literature review and/or meta-analysis is an effective method of identifying habitat parameters, especially for globally distributed and aquacultured species. This involves systematically reviewing existing global scientific literature on known invasive and native species, such as *Hypnea musciformis*, to understand their preferred growth parameters (e.g., salinity, nutrients, light). This process helps in building "habitat parameters" that can inform monitoring strategies and predict where these species are most likely to thrive.

eDNA

Amplified by several experts, eDNA (Environmental DNA) is proposed as a modern tool for early detection. While it requires an initial investment to create species-specific primers (to distinguish invasives from similar native species), it becomes a cost-effective and easy way to monitor for the presence of an invasive species just by sampling the water. Early detection facilitated by eDNA allows for rapid response and removal efforts, complementing ongoing monitoring. This approach would be particularly useful for detecting *Hypnea musciformis* if saltier, more nutrient-rich conditions develop in coastal regions.

Challenges/Considerations: The development of species-specific primers for detecting individual species through eDNA work requires significant time and initial financial investment. However, once developed, these tools are powerful for ongoing monitoring.

Bacteria

An increase in bacterial presence, such as fecal indicator bacteria, could signal a decline in groundwater quality or quantity, potentially leading to increased coral disease where SGD is impacted. Any rapid increase in disease among any species within groundwater-dependent ecosystems would be a cause for concern, indicating broader environmental stress.

Terrestrial Plants (e.g. Mangroves, Kiawe)

Invasive terrestrial plants can also serve as indicators. Mangroves, for instance, often indicate the presence of springs and can, in some areas, clog spring outflows. While not prevalent in Kona, they represent a type of terrestrial invasive plant that can significantly alter hydrological systems. Other examples include Tropical Almond (also known as false kamani or Indian almond, *Terminalia catappa*), an invasive tree that frequently grows near water sources, whose leaf litter can negatively impact the water body's health. Pluchea is another invasive shrub with similar implications. Kiawe stands, as deep-rooted phreatophytes, directly access groundwater, making their biological condition a monitorable indicator of groundwater availability and quality.

Non-native Damselflies / Dragonflies

It is assumed that non-native damselflies and dragonflies would exhibit similar salinity tolerances to their native counterparts, making their presence or absence a potential indicator of changes in salinity within GDEs.

Invasive Grasses

Seashore Paspalum, an invasive grass, can escape from managed areas like golf courses and have detrimental effects on natural environments. Other invasive grass species that could be a good indicator of salinity changes.