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Pa'akai Overload: Potential Consequences of Over-mixing Brackish Water Ecosystems in Keaukaha, Hawaii

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Abstract: On the east side of Moku o Keawe (Hawaii Island), along the Keaukaha coastline, there is a valuable and critical resource known for its brackish water habitat. The ecosystem occurs in the near shore zones where upwelling groundwater and marine seawater meet at the shoreline. This study assesses the potential impacts of climate change on the coastline of Keaukaha in the Hilo district of Hawaii Island where I have lived all my life. Sea-level rise in particular is of growing concern for the community because of its low-lying coastal zone that relies on a sustainable brackish water ecosystem. Saltwater intrusion could drastically alter the habitat and interfere with Kanaka Maoli (native Hawaiian) cultural practices associated with these environments. In this study, I will be investigating the impacts of sea-level rise on the brackish ecosystem of Keaukaha, and the cultural implications of these impacts. Brackish water habitats serve as a sustainable food source for coastal communities and as a result, the health of these systems is closely tied to the survival of many Kanaka Maoli cultural practices. Sea-level rise may impact cultural practices as gathering traditions dependent on *lokoi'a* (Hawaiian fishponds), and storytelling that teaches to those practices. My investigation asks: Is Hawaiian fishpond restoration an advantageous response to environmental changes of the brackish water ecosystems of Keaukaha, Hawaii?

Key words: Sea-level rise, Keaukaha, HI, brackish water, *lokoi'a* (Hawaiian Fishponds), Kanaka Maoli (native Hawaiian)

1. Introduction

On the east side of Moku o Keawe (Hawaii Island) in the district of Hilo along the coastline of Keaukaha, an extraordinary ecosystem of fresh ground water from the upland flows down to the ocean and meets at the shoreline. This pristine ecological community with its brackish water habitats is home to many endemic species not found anywhere else in the world. For generations, the ecosystem has also facilitated foraging traditions of Hawaiian communities through cultural gathering practices and storytelling associated with *lokoi'a*. In fact, in the last decade, there has been a resurgence of the customary practice of fishpond culture [1]. A steady effort to restore the traditional Hawaiian fishpond back to its productive use again is evident on the islands of Molokai, O'ahu, and Moku o Keawe.

However, since global climate change looms more critically over island nations, this poses an immediate threat to Keaukaha's coastline and its brackish water fishponds. Studies show that "impacts on coastal systems are among the most costly and most certain consequences of climate change" [2]. Burkett emphasizes sea-level rise, inundation, and salinity increase as a result of climate change that will be most striking in low-lying island coastal zones [Ibid]. If this is the case, then native species in brackish water habitats are potentially at risk because "habitat

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alteration and climate change affect species richness or composition in many coastal environments" [3]. Levin also explains, "ecosystem function in marine critical transition zones because high diversity maintains positive interactions among species (facilitation and mutualism), promoting stability and resistance to invasion or other forms of disturbance" [Ibid]. In the most probable sense, a shift in the composition of brackish water habitats can affect the community in several ways: lost of interaction with and understanding of brackish water ecology, and the depletion of a critical cultural practice and sustainable food source.

For Hawaii, Kanaka Maoli likely will be the most affected by such threats. Jan Salick and AnjaByg [4] note in their publication of *Indigenous People and Climate Change*, "their [indigenous people] livelihoods depend on natural resources that are directly affected by climate change, and they often inhabit economically and politically marginal areas in diverse, but fragile ecosystems." If climate change is a threat, what actions can we take to adapt to the environment at risk? For the Keaukaha coastline, *lokoi'a* maintenance as a common cultural practice, mentioned earlier, could act as primary component to relieve a stressed ecosystem. For this reason, I propose to "shift the focus to indigenous people as primary actors in terms of global climate change monitoring, adaptation, and innovation" [Ibid]. This study examines the principal outcomes of global climate change on brackish water ecosystems of Keaukaha, Hawaii, and proposes Kanaka Maoli to lead in the restoration and maintenance of *lokoi'a*. I ask: Is Hawaiian fishpond restoration and advantageous response to the environmental changes in the brackish water ecosystems of Keaukaha, Hawaii?

2. Brackish Water Ecosystem

Brackish water in Hawaii is a combination of a particular element consisting of two main characteristics including salt water from the ocean and fresh water fed through aquifers formed by volcanic rock. Rainfall, fog drip, and irrigation water that is not lost to runoff or evapotranspiration or stored in the soil, is released into the volcanic aquifers from the uplands, and travels to the ocean coastline where the two waters communicate [5]. The aquifers formed by volcanic rock is the most extensive and productive aquifer in the Hawaiian Islands and is found throughout the eight major Islands [Ibid]. On these Islands, freshwater commonly occurs as a body of water called a freshwater lens that floats on saltwater and is separated from the saltwater by a transition zone of brackish water. These brackish water ecosystems are present throughout the Hawaiian Islands along the coastline. In the creation story of Hawaii called the Kumulipo, it describes Kane (god of fresh water) and Kanaloa (god of the ocean) as being the same or identical [6]. I understand this concept as being exactly that of the brackish water because freshwater and the ocean water is made up of the same thing but they just have different functions. Also Kane and Kanaloa must have a symbiotic relationship in order to create this balanced ecosystem of the brackish water habitat.

3. Keaukaha Coastline and *Lokoi'a*

From the Hilo Breakwater to Leleiwi, the Keaukaha coastline extends approximately five miles. Keaukaha's coastline is a low coastal zone area consisting of volcanic rock along the shoreline. The community is known for its nutrient rich brackish water ecosystem linking together the "land, fresh water inhabitants, and the sea" [3] shown in Figure 1. The volcanic mountains, Mauna a Wakea and Mauna Loa feed the aquifers at the uplands producing groundwater that bursts through the lava rocks at the shoreline of Keaukaha [5]. Many groundwater sockets along the coastline bubble out of the lava rock especially as the tide rises, introducing a force of seawater inland where the two waters meet. The

mixing of the two waters represents the brackish water ecosystem that provides a habitat for a very particular biodiversity of aquatic life. Additionally, this unique habitat provided Kanaka Maoli with an opportunity to establish a sustainable food source for the community. The practice was the development of the *lokoi'a* kuapa (seawall fishpond), which consisted of the construction of a wall facing the ocean, enclosing the brackish water habitat while still allowing for a direct fluctuation with the sea. An all-natural form of aquaculture supported the needs of the people and a nursery for various native species at the immediate ocean coastline.

Fig. 1 Sea water and fresh groundwater interaction along the coast in *lokoi'a Honokea* at Waouli, Hawai'i. IS: Kamala Anthony.

4. Habitat

Amongst the many habitats of Hawaii, a brackish water ecosystem can be distinguished by the species that live within it or by its surrounding environment. The Keaukaha brackish water habitat has a variety of species that are key contributors to the health of the ecosystem. Some of the species are migrators from the ocean while others are endemic and restricted to the brackish water habitat. This is because within these ecosystems "extreme fluctuations often occur in salinity, temperature, water level, and dissolved oxygen within any single locale, restricting the number of species in these environments" [3].

Some of the identified brackish water fish and invertebrates of Keaukaha include aholehole (*Khuliaxenura*) shown in Figure 4, *uouoa* (*Neomyxuschaptalii*), opae oeha'a (*Macrobrachiumgrandimanus*) shown in Figure 3, hapawai (*Theodoxusvespertinus*), and o'opuakupa (*Eleotrissandwicensis*) shown in Figure 2. The o'opuakupa or goby for example, is a common endemic fish that is a bottom dweller in the ecosystem. Most relatives of the o'opuakupa have fused pelvic fins that help to climb the fresh water streams, but this particular goby does not [7]. The o'opuakupa are also poor continuous swimmers and have a tendency to be ambush predators (Ibid). Such characteristics make small brackish water ecosystems ideal homes for them.

The goby is also a desired food source for many people. Another pond species is the aholehole, a reef fish that is a primary predator on the post larvae of the goby. The aholehole are usually found in large schools in brackish water environments during their juvenile stages, utilizing the habitat as a nursery. Large abundances allow for a primary food source for coastal fishermen and their families. With access to the brackish habitat, juvenile aholehole are able to be safe with a greater chance of surviving to adulthood. Finally, the opaeoeha'a, is one of the first organisms I learned to catch as a child with a scoop net. Families of the community often use this native shrimp as bait. These brackish water shrimp feed on plant matter and microscopic algae assisting in breaking down organic matter [8]. Interestingly, the shrimp need stream or groundwater flow to release their eggs, and one will

find them most likely within the brackish water ecosystem where there is fresh spring flow. A study by Shokita (1985) reports the larvae of the opaeaeha'a can only withstand water with salinity levels of 17.5 to 35 parts per thousand, meaning it could be problematic if the environment is altered out of the salinity range.

The few aforementioned species play a critical role in the brackish water habitats of the Keaukaha coastline both for the health of the ecosystem and the people who utilize it as a resource. The Keaukaha community consists of many families who have a direct relationship to the coastline ecosystem because of its ability to sustain the practices that provide a suitable livelihood for its residents. In the past and up to the present, and in hopes for the future, Kanaka Maoli have adapted to create this valuable habitat as a sustainable food source and cultural practice in their immediate community.

Fig. 2 *'O'opuakupa*. IS: Daniele J-Kam.

Fig. 3 'Opaeoeha'a. IS: Daniele J-Kam.

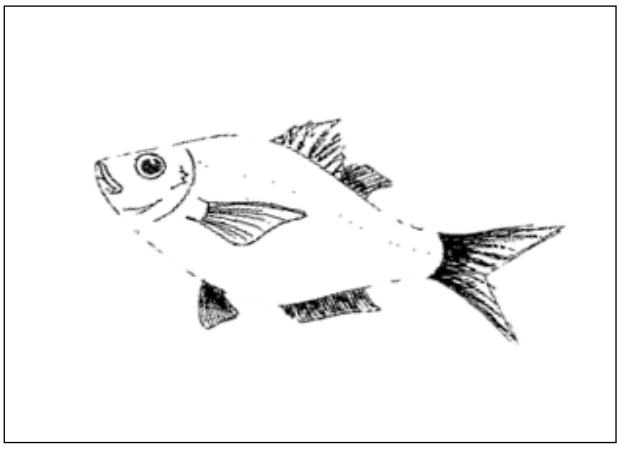

Fig. 4 'Aholehole. IS: Lauren Kapono.

Historically and traditionally, Kanaka Maoli developed a sophisticated strategy for a sustainable lifestyle from brackish water habitats of Hawaii [1]. These ecosystems facilitate a cultural resource known as the *lokoi'a* or Hawaiian fishpond. A *lokoi'a* is considered an integrated farming system that includes massive fresh water and seawater [Ibid]. Of the four different types of *lokoi'a* found in Hawaii, the lokokuapa or seawater ponds are those that exist along the shoreline where brackish water habitats occur. It was once a critical component of Hawaii's sustainable natural resource management system and "the ultimate aquaculture achievement of the native Hawaiians and a valuable contribution to native engineering and subsistence food production" [9]. These systems are found nowhere else in Polynesia [10]. The *lokoi'a* kuapa is identified by its main feature, a seawall made of coral or lava rock facing the ocean, thus creating a brackish water pond on the shoreline side. An additional feature of the *lokoi'a* kuapa is the auwai (canals) constructed into the walls of the fishpond for stocking, harvesting, and cleaning (water circulation) of the *lokoi'a*, allowing it to be directly connected to the sea. A single stationary gate, the makaha (sluice gate) made of dense branches is constructed in a manner that only water and very small fish can pass freely in and out of the pond. Therefore, the pond was automatically stocked from the sea. Two main

species, the mullet and milkfish were originally cultured in these fishponds. These species are catadromous, meaning they spawn at sea but spend their juvenile stages in brackish water habitats.

Traditional stories tell of a certain time of the season or migration period when "the keepers of the fishpond would joyously watch hundreds of fish swim into the canal in futile attempt to reach the sea" [9]. At that time, nets would be set on the pond side near the makaha to close off the migratory route. This practice was a method developed for efficient use of the resource by the "use of keen observational skills and knowledge of fish behavior and allowing the fish to harvest themselves" (Ibid). Aside from being a valuable food source, *lokoi'a* are the nurseries of the coastline, especially in Keaukaha. Today, one can see juvenile reef fish in large schools roaming about in the near shore brackish water ponds of Keaukaha.

Lokoi'a are culturally and historically significant to Kanaka Maoli for its sustainable natural resource management system. As part of Hawaii's living treasures, fishponds provide an avenue for practitioners to actively perpetuate their culture and also pass on this knowledge to future generations.

Fig. 5 Modern makaha constructed with waiwi wood. IS: O kaaina.

5. Global Climate Change

Without doubt, climate change presents island nations and their coastlines with immense challenges [11, p. 145]. Global climate is defined as a long-term change in the earth's climate dominated by human influences, which have reached a stage that exceeds the bounds of natural variability [Ibid, p. 13]. This overuse of human activity has led to changes in atmospheric composition resulting from emissions associated with energy use, urbanization, and land use changes [Ibid]. Although it is not certain the rates of change to be expected, there have been many studies that indicate the particular effects of climate change throughout the globe. The consequences include, extreme temperature and precipitation, decreases in seasonal and perennial snow and ice extent, and sea level rise amongst many other factors. Climate change impacts can vary depending on location and threaten some places more frequently than others. These places tend to be those that are isolated and have unique ecosystems such as small Islands. Their low elevation and small sizes make them extremely vulnerable to the negative changes of the environment due to climate change (IPCC[1], 2014). Pacific and Indian Ocean Islands are amongst the most vulnerable to climate change and seasonal variability

[1] Intergovernmental Panel on Climate Change.

(Ibid). The many specific impacts of global climate change on small islands include, "increased coastal erosion; changes in aquifer volume and water quality with increased saline intrusion; coral reef deterioration resulting from sea-level rise and thermal stress; outmigration caused by permanent inundation; social instability related to inter-island migration; loss of income resulting from negative effects on tourist industry; increased vulnerability of human settlement due to decrease in land area; and loss of agriculture and vegetation" (Ibid). Therefore, as an Island chain in the Pacific Ocean, Hawaii is highly susceptible to these impacts.

6. Sea-level Rise and the Keaukaha Coastline

Studies show that the potential impacts of climate change on Hawaii can be critical. Hawaii seems to be most vulnerable to the changes in sea-level resulting in two main activities. For one, as extreme temperatures increase, the ocean water warms and expands, taking up more space [11, p. 145]. Second, the warming also leads to the melting of glaciers and ice sheet, which in turn gives way to sea level rise by adding water to the oceans (Ibid). It is estimated that the average rate of sea level rise over the last 100 years has been 1.0-2.0 mm/year [12]. More particularly, a report of negative impacts of sea-level rise, especially on low-lying coastal plains such as Hawaii are susceptible to a range of threats to the natural and human assets (SOEST. Hawaii.edu). Hawaii Island as the youngest island in the Hawaiian chain has a heavy load of geological young volcanic rock and is "flexing the underlying lithosphere causing the island to subside" (USGS, 2011). This could be the reason sea level is rising in relation to the island land mass faster in the Hilo region than any other areas in Hawaii. Records show rise of approximately 1.5 mm/year over the past century (USGS, 2011). The Keaukaha (Hilo, HI) coastline is known to consist of numerous small pocket beaches that are separated from the sea by natural lava flows. In addition, there is a considerably low coastal slope along the entire coastline. As a consequence, the effects of climate change on the Keaukaha coastline is its tendency to be inundated more often, if not permanently, due to the rising sea [2]. This means any ecosystem that occurs within this coastline can be potentially threatened by sea-level rise.

7. Sea-level Rise and Brackish Water Ecosystem

The many effects of sea-level rise on islands nations include flooding more frequently from higher storm tides, and a lost in coastal land as the sea inundates low-lying shorelines [11]. Shoreline flooding in regards to sea-level rise can occur as an intrusion of salt water into these brackish water ecosystems and in result throw off the natural equilibrium. In other words, at the near shore, fresh groundwater could be reduced due to the free rise of the sea [13]. The major consequences of this lead us to the next concern of habitat disturbance within these brackish water ecosystems. I am interested in the impacts of sea-level rise on the brackish water habitat because as a critical transition zone, the brackish water ecosystem is a natural occurrence that requires a consistent environment. Therefore, this coastal ecosystem and its biodiversity can be greatly affected by changes in the processes that create and sustain them [2]. These sensitive ecosystems are influenced by many different factors that can have a very negative impact if there is even a slight change in its quality. Water temperature in particular, affects the health of fish in many ways. Since fish are cold blooded organisms, they assume an approximate same temperature as their surroundings. Temperature also affects fish activity, behavior, feeding, growth, and reproduction. More importantly, temperature can determine the amount of dissolved gasses in water such as oxygen which is the most important parameter in water quality [14]. Fluctuations of water temperature are highly dependent

on the flow of the tide in the brackish water ecosystems. With only these few examples of many factors that determine the health of a habitat, we can imagine that the force of sea-level rise will have a negative impact on the brackish water ecosystems. In this case, how can we adapt to these changes on a local level?

8. Restoration

There are many routes we can examine to figure out how to adapt to our ever-changing environment, but there is just one strategy that seems most beneficial out for this particular topic of brackish water ecosystems of Keaukaha, Hawaii. I come back to the *lokoi'a* of Hawaii that are primary contributors to the health of the brackish water ecosystems. Not only do *lokoi'a* significantly support the coastlines, we as humans have an opportunity to keep this resource in place.

Today, *lokoi'a kuapa* still remain along the shorelines of Hawaii, with three active ones in Keaukaha alone and many others abandoned. The fishponds of today are not as extensive and productive as before due to the neglect over the past centuries and lack of dependency on them. Many efforts for fishponds include restoration for the revitalization of these unique systems. All of the practices that originated from Hawaiian fishponds still continue today for many practitioners. In addition, modern material, techniques, and modifications have been implemented into the practices of fishponds that remain to be beneficial to the habitat. Considering the health state that the *lokoi'a* are presented with today, restoration efforts can act as the most significant activities for the protection of these fishponds because they are directly related to supporting the brackish water ecosystem along with the coastal sea water immediately connected to them.

Restoration of fishponds in Hawaii remains to create a series of activities that help Kanaka Maoli better understand the changes in the environment. A lot of these activities are done through education and outreach in the communities that consist of coastal monitoring, water quality, and labor intensive cleaning and rebuilding of the *lokoi'a*. Coastal monitoring at Hale O Lono fishpond in Keaukaha has students from KaUmekeKa'eo Hawaiian Immersion Public Charter in making daily observations on the coastal environment for that particular place to understand the different trends in that area. Water quality is also an efficient modern technique used in *lokoi'a* restoration throughout Hawaii to analyze the changes in the quality of the water by monitoring parameters such as dissolved oxygen, temperature, salinity, etc. Most importantly, all fishpond restoration efforts include the labor intensive activities that take the community to support it.

For *lokoi'a* Honokea in Keaukaha, the community partakes in rebuilding rock walls as shown in figure, opening up springs, removing sediment and weeds, reconstructing *makaha*, and keeping the *lokoi'a* free of debris. By participating in restoring the *lokoi'a*, the community is able to build a stronger and healthier habitat within the brackish water habitat, raise food for their families, and strengthen the coastline directly connected to it.

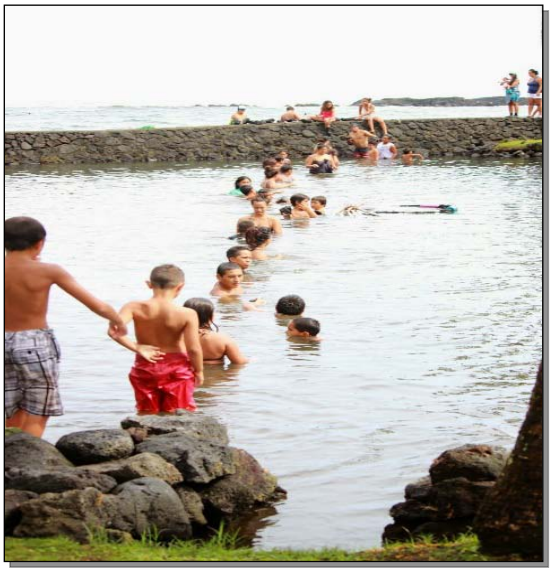

Fig. 6 Kids of the community restoring rock walls. IS: O kaaina.

Fig. 7 Learning how to reconstruct a traditional makaha. IS: O kaaina.

9. Conclusion

Without the perpetuation of *lokoi'a* methods and traditions, I would not be able to share the importance of this ecosystem and how it has supported me and all my relatives in some way or another. Story-telling and the engagement with practices of fishpond maintenance in this case play the largest role in sustaining the ecosystem.

Studies suggest that climate change will alter the shoreline in Hilo, Hawaii due to its low-lying coastal landscape. As the sea level increases, the Keaukaha coastline is vulnerable to a disturbance in water quality with a potential excess of salinity into the brackish water ecosystems. With an alteration of the water quality within the brackish water ecosystems of Keaukaha, the ecological habitat that lives within are where most of the concerns lie. Species that are found nowhere else in the world are threatened by the changes in a habitat that they cannot survive without. There are many factors on islands that interact with the greatest rates of extinction on earth such as, habitat destruction, violent storms, salinization of ground water, over exploitation, invasive species, and climate change [4].

It is obvious that the loss of a healthy habitat within the brackish water ecosystems of Keaukaha, could devastate the people of the community who depend on it. The brackish water ecosystem has facilitated generations of *kanaka maoli* cultural ecological knowledge that has provided the people with a sustainable food source and a valueble and practical learning environment. The creation and existence of *lokoi'a* maintenance in this sense is one of the most significant features along the coastline that has given the man the opportunity to be the apex predator of the pyramid within a *lokoi'a* and at the same time managing to sustain an equal and balanced communication with that environment [14]. While scientist examine climate change as anthropogenic and greenhouse gas emissions, local indigenous people interpretations are based on the changes in their lifestyle in the environment [4]. The interpretation of climate change in this perspective is viewed by the impacts it has on agricultural activities, hunting, fishing, and resource gathering [Iblid]. If a fisherman is noticing a decline of fish stock in a familiar fishing ground, the approach is that his/her environment is changing. Instead of seeking for another abundant area to fish, a wise fisherman will urge to better understand that changing environment and adapt to the needs of that particular place. This is because, from a local perspective, the term global climate change seems to be unknown and is rather a very personal understanding that is recognized as an alteration of a resource that is highly depended on. It is an approach to the things that have been an intimate part of one's life that is changing and evolving especially for Tom Anthony who was born in Fiji but has lived most of his life in Hawaii where he raised his own family [15].

Considering all of the threats that sea-level rise has on these brackish water ecosystems of Keaukaha, understanding the ecosystem better through fishpond restoration can ease our efforts in adapting to the challenges of this particular environment. As a fishpond restoration practitioner, I see many strategies that can apply to the threats at hand. For instance if the sea-level is rising, building rock walls higher can continue to protect the species within the fishponds from larger predators. Also, knowing that sea-level rise

means a greater salt water influence for these ecosystems, locating and opening up clogged springs within these areas should be a top priority in fishpond restoration efforts. Overall, a deeper understanding of the ecological processes of *lokoi'a* within the brackish water ecosystems of Keaukaha, by physically practicing fishpond restoration, will open up the greatest opportunity to adapting to the everlasting changes in our environment. Furthermore, this practice will hold the key for future generations to maintain a symbiotic relationship with the environment for the sake of a balanced Hawaii.

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