Final Project Report
Pacific Islands Climate Adaptation Science Center

Project Title: Impacts of climate change on hydrology and primary production of three Hawaiian fishponds
Graduate Students: Cherie Kauahi, Kamala Anthony
Faculty Advisor: Dr. Steven Colbert, Marine Science Department, UH Hilo
Committee Members (Ms. Kauahi): Jene Michaud, Kehau Springer, Noelani Puniwai
Committee Members (Ms. Anthony): Rebecca Ostertag, Blake McNaughton, Troy Sakihara
Lead Institution: University of Hawai'i at Hilo
Reporting Date: 3/8/18
Total Cost: $58,861

<u>Project Summary (General Audience)</u>
Loko iʻa, traditional Hawaiian fish ponds, are culturally and ecologically important structures that rely on natural nutrient inputs from groundwater as well as surface flow and salt water. Our work investigates the dynamics of groundwater flow, water quality, the interactions between algal growth and salinity in loko iʻa, as well as the socio-ecologic environment in and around three fish ponds in windward Hawaiʻi Island (Fig. 1). Groundwater flow responded to local rainfall events, and the main source of groundwater was rainfall at an elevation of 500 to 900 m. While the total benthic growth increased with salinity, algal growth remained constant, with different communities of algae growing in different salinity regions. Climate change will impact loko i'a, such as sea level rise that will increase the salinity of the loko i'a and increased rainfall that will increase groundwater flow through loko iʻa, both of which may stimulate increased growth on the bottom of the ponds. However, further work is needed to identify if the type of algae that grows at higher salinity is a good food source for target species. Interviews with kia'i found that software that allowed sharing data of different loko i'a was useful for understanding their own loko iʻa, and we provided training in visualization software, which they requested. This project has generated ongoing collaborations between UH Hilo, UH Manoa, kia'i, and Hawai'i Division of Aquatic Resources.

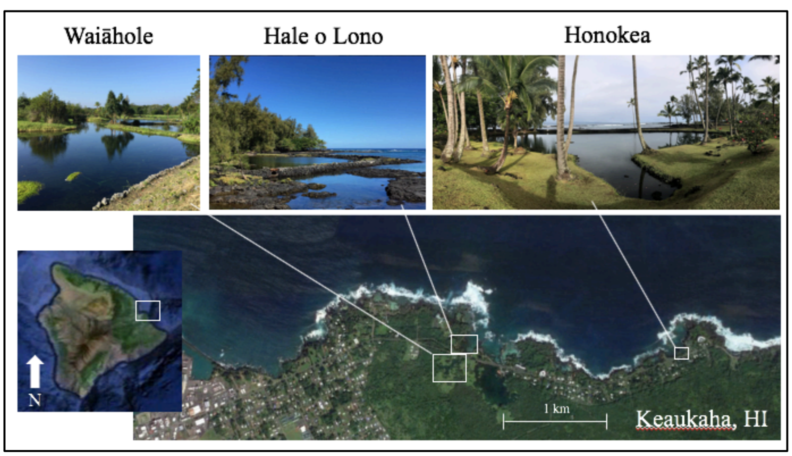

Fig. 1. Map of loko iʻa studied for this project, Keaukaha, Hawaiʻi Island, HI.

<u>Technical Summary</u>
<u>Project Goals</u>: Loko iʻa, traditional Hawaiian fish ponds, are culturally and ecologically important structures that rely on natural nutrient inputs from freshwater for algal growth as a food source for herbivorous fish. Sitting at the boundary between freshwater and seawater, these systems are highly sensitive to climate change, particularly sea level rise and changes in precipitation. The design of this project is to use three loko iʻa with unique characteristics (size, magnitude of freshwater input, connectivity to the ocean) to establish quantifiable relationships

between groundwater inputs and 1) environmental factors (ex - rainfall, tides and moon phases), 2) groundwater fluxes of solutes, and 3) benthic primary production. These relationships will then be used to develop models that examine the response of loko iʻa water quality and primary production to predictions of future rainfall and sea level. Additionally, the project will examine this socioecosystem through the perspectives of those who have a significant experience based relationship with the loko iʻa.

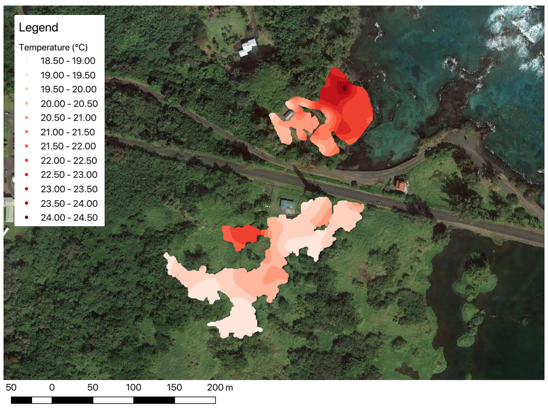

Fig. 2. Contour plot of surface temperature at Hale o Lono (top) and Waiahole (bottom) loko iʻa.

Methods: This study focused on three groundwater-fed loko iʻa in the Ahupuaʻa of Waiākea, near Hilo, Hawaiʻi. These loko iʻa are known as Honokea Loko at Waiuli and Hale o Lono and Waiāhole/Kapalaho at Honohononui (Fig. 1). Field work for this project occurred between December 2016 and December 2017. To determine locations of groundwater flow and groundwater spring chemistry measurements, temperature and salinity surveys (walking and kayak) were completed throughout each loko iʻa within about two hours of the lower low tide of each sampling day (Fig. 2). To assess environmental variability, data loggers that recorded temperature, conductivity (salinity) and pressure (depth) every 6 minutes were deployed for 364 days at 2-3 different locations in the loko i'a. Relative groundwater flow was calculated based on the hydraulic gradient between the loko i'a and the ocean and using a mass balance for water. Water quality measurements included weekly surveys of temperature, salinity and oxygen at 8 stations in each loko i'a and additional bi-weekly sampling of nutrients, turbidity, and chlorophyll *a* at 5 stations. Major ions, nutrients and stable isotopes of water were measured at groundwater springs at each loko and at twelve springs along the shoreline. Benthic productivity was measured on tiles that were deployed 4 times for 6 days at three stations at each loko. Tiles were scraped of all growth (production) and analyzed for ash free dry mass, chlorophyll a, and %C, %N. Project goals and sampling locations were identified through discussions among collaborators to ensure that the project results would best support the kia'i loko (stewards) that make operational decisions about these loko iʻa. In addition, the kia'i were also interviewed to better understand their needs with regards to hydrology, primary production, and climate change.

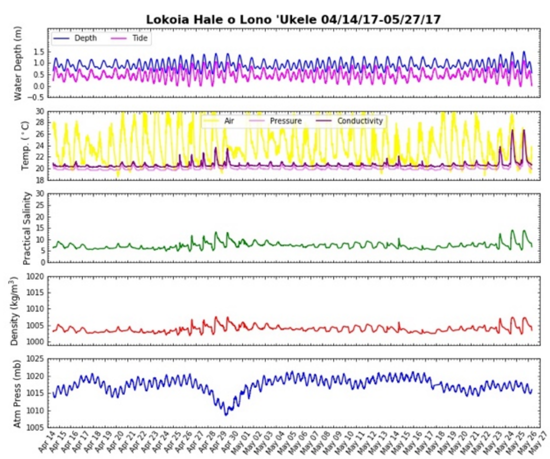

Fig. 3. Time series of water properties at loko iʻa Hale o Lono from data loggers and NOAA Hilo Bay tide gauge data.

Empirical Results

Environmental Variability: Data from loggers allowed the variability of the ecosystems to be assessed (Fig. 3). Water in the loko i'a was always fresher than seawater due to persistent groundwater flow. Spikes in salinity, signifying seawater flowing into the loko iʻa, occurred in all loko iʻa. At Hale o Lono, 92% of the high salinity events could be explained by tides that were greater than 0.95 m and/or waves that were >2.8 m. However, these factors only accounted for 55% and 64% of the high salinity events at Waiāhole and Honokea, demonstrating their sensitivity to either lower thresholds of tides and waves or other processes affecting salinity. This information was used to model how future sea level rise will affect salinity and flow in the loko i'a (see below).

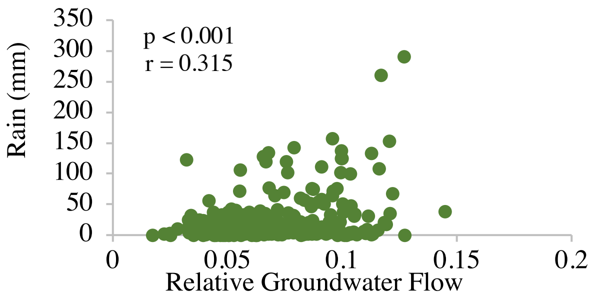

Fig. 4. Relationship between 3-day sums of daily rainfall (average of 4 stations) and relative ground-water flow at Honokea loko iʻa.

Goal 1- Groundwater flow and environmental factors: Relative groundwater flow was significantly correlated with rainfall at all three loko iʻa (Fig. 4). Rainfall generated increases in groundwater flow into the loko i'a in less than 24 hours, and rainfall greater than 75 mm in 48 hours increased groundwater flow 20-50%. No relationships were found between relative flow and tidal height or moon phase, likely because of the variability introduced by frequent rain events.

Goal 2- Groundwater flow and nutrient fluxes: Groundwater recharge for these springs occurred at 500-900 m elevation, based on isotopic ratio of the water (Fig. 5). The elevation of recharge increased toward the east, farther from source of rainfall, which is consistent with models of regional groundwater flow. Makor ions did not differ significantly (Fig. 6), indicating similar aquifer conditions for all flow paths. Nutrients concentrations, however, did vary among springs (Fig. 7), suggesting different additions of nutrients among the flow paths. Nutrients concentrations in groundwater did not change with flow, so changes in nutrient fluxes were proportional to changes in flow. Nutrients in the loko i'a were 20-50x greater than Hawai'i Department of Health standards for estuarine waters (Fig. 7), demonstrating large (excessive?) nutrient sources within the watershed.

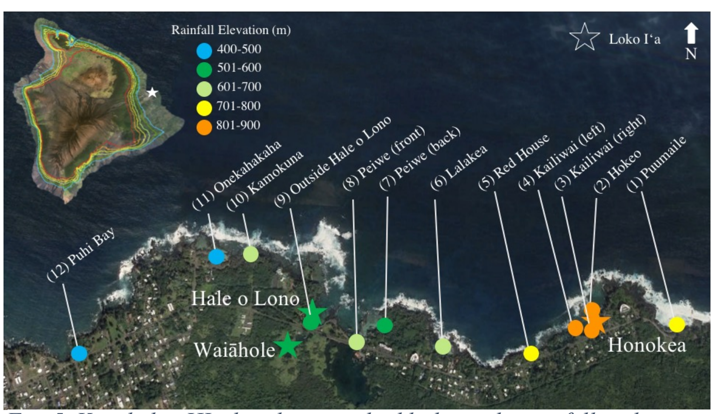

Fig. 5. Keaukaha, HI, shoreline map highlighting the rainfall recharge elevation of spring located along the coast. Rainfall recharge elevation was calculated using the relationship from Scholl et al. (1996) for δ18O in rainfall on trade wind areas of Hawaiʻi.

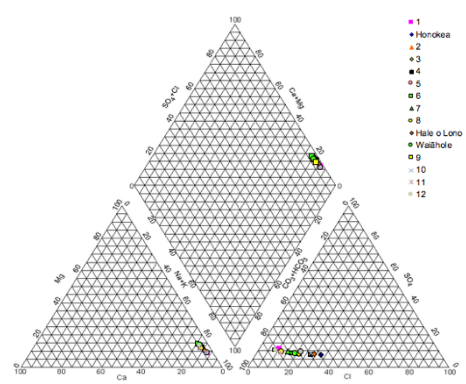

Fig. 6. Piper diagram of major ion distribution in groundwater springs at Keaukaha, HI.

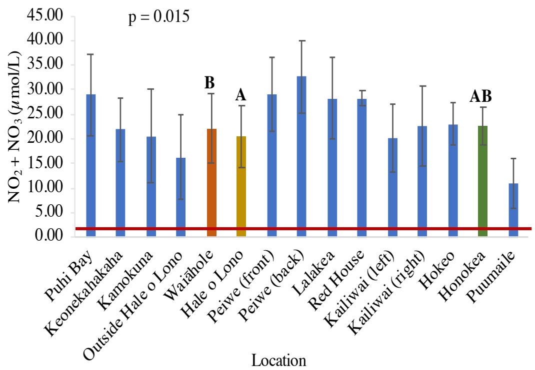

Fig. 7. Average (±SD) of NO_2^-+NO_3^- at groundwater spring locations sampled in Keaukaha, HI. The red line indicates the Hawai'i Department of Health standard of 0.57 µM for estuaries in Hawai'i (DOH 2014).

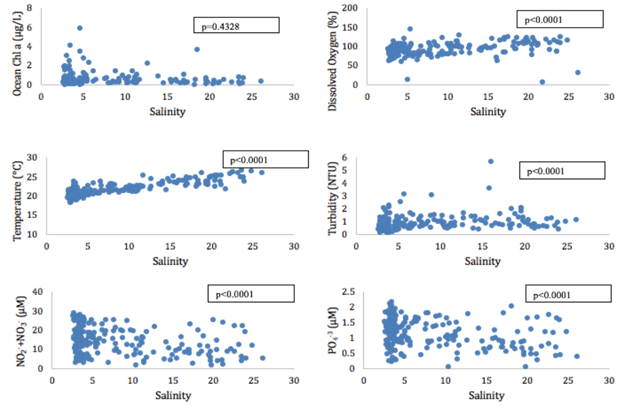

Fig. 8. Correlation of water quality parameters with salinity from biweekly water column measurements from 1/27/17-10/27/17 across all sites.

Goal 3- Groundwater flow and benthic productivity: Tiles were set out for 6 days to monitor the growth of algae in three regions: low and high salinity within each loko i'a, and outside the loko i'a. Mixing between freshwater and seawater was a primary determinant of water quality at different points in the loko i'a, with seawater providing warm, oxygen-rich, nutrient-poor water (Fig. 8). Total growth on the tiles increased with salinity, with the greatest accumulation of organic material at the highest salinities (Fig. 9). However, chlorophyll *a*, an indicator of algal biomass, did not vary with salinity. Differences in algal communities were evident visually and empirically based on differences in the autotrophic index, %C and %N among stations and loko i'a (Fig. 10). Kia'i observed juvenile fish species feeding on the algae on the tiles inside the loko i'a, which led to question about what those varieties are. Further work is needed to identify if the algae that grows at higher salinity (i.e. outside loko) is consumed by the fish raised in the loko i'a. The greatest growth and highest algal biomass occurred in the loko i'a with abundant light, rocky substrate for algae to attach, and swift flowing water. Improving these conditions throughout a loko i'a will likely increase primary production and increase the resilience of these systems to changes in salinity and freshwater flow.

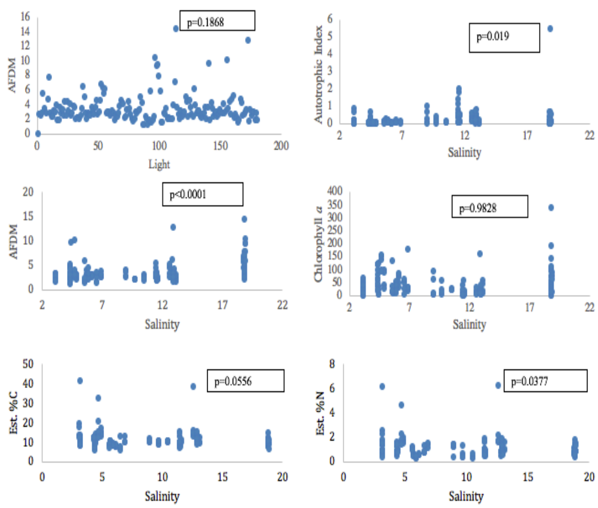

Fig. 9. Correlation of benthic productivity experiments with salinity from August to October 2017 across all sites.

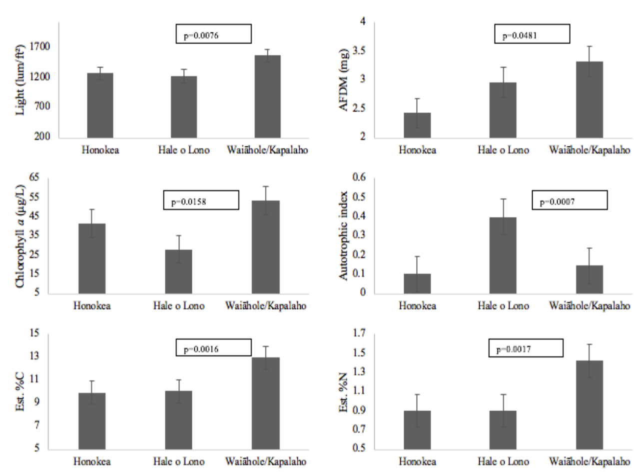

Fig. 10. Total average benthic primary production indicators by site. Sample size of 80 (excludes outer salinity regions) from August to October 2017.

Goal 4- Climate change impact on loko i'a: Climate change will change the flow and distribution of fresh and saltwater within the loko iʻa. Sea level rise (SLR) will, of course, require the kuapā, wall, to be built higher to keep the fish from escaping and predators from entering at high tide. SLR will also change the flow dynamics within the loko iʻa. Currently, there is so much groundwater flow into the loko that as long as the tidal height remains <0.95 m above MLLW, there is a persistent flow of water out of the loko. Only when the tide is >0.95 m above MLLW, which primarily occurs during the bi-weekly spring tides, does the flow reverse and seawater flows steadily into the loko. With SLR, maximum tidal heights > 0.95 m will occur more frequently. At all ponds, the daily maximum salinity will at least double with 0.4 m of sea level rise (Fig. 11). Periods of time when water flows into the loko will increase, and assuming groundwater recharge remains the same, the rate of flow out of the loko i'a will have to increase (i.e. same daily flow of water in a shorter period of time). Productivity increased by 3.8% for each 1 unit increase in salinity. So, an increase in mean salinity from 8 to 16 would lead to an increased production by 33%. However, as noted earlier, whether this is algae that is a good food source for fish raised in the loko i'a needs to be tested.

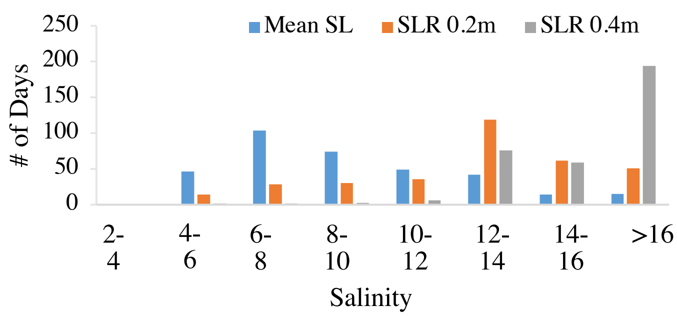

Fig. 11. A comparison between mean sea level for 2017 and projected sea level rise scenarios (0.2 m and 0.4 m) on salinity at Hale o Lono loko iʻa.

For windward Hawai'i, rainfall is highly variable, which inhibited the detection of any long-term trends in rainfall (Frazier & Giambelluca 2017). However, down-sampling of global climate models suggest an intensification of trade winds for windward Hawai'i, which could increase precipitation by 20-40% (Zhang et al. 2016). Assuming a similar 20-40% increase in groundwater recharge, flow through loko i'a would increase to a rate similar to that presently observed after 75 mm of rainfall in 48 hours. Swifter flow of water in the loko i'a is likely beneficial for desired benthic algae and would reduce the occurrence of high salinity events in the loko iʻa.

The results of this study provide insight to support best stewardship practices to optimize the conditions of the pond for the growth of the favored algae in order to attract and maintain the target fish species. Since water quality (salinity, temperature, and dissolved oxygen) are strongly correlated to primary productivity, monitoring of these three parameters on a regular basis is important to monitor the conditions throughout individual ponds. The highest productivity inside a loko i'a was where the water column was clear, there were no limitation on light exposure, and a consistent flow of water. Ways to maintain these features in loko i'a are to clear all terrestrial plants that may limit light exposure; remove sedimentation to access hard substrate for limu to attach; clear all water pathways for flow; and keep the makaha clear of debris. Additional practical efforts that Honokea loko will implement from this study is the identification of the communities of limu growing throughout the pond and to see which of those species are most favored by the targeted 'ama'ama and 'awa species being raised in the loko.

Kiaʻi loko i'a socioecosystem: Collaborating and documentation of data collection at loko iʻa can be successful and beneficial to many efforts involving coastal communities, especially with the expansion of restoration activities of these invaluable resources that are being protected island wide by countless individuals. One of the greatest additions to the methods of this study involved the process of data collection, which could not have been done without the help of the kiaʻi loko of each loko iʻa and the technology introduced by the University of Hawaiʻi at Hilo. The data recording- Makai-Otto software app and the tablet-based application provided a simple and easy-to-navigate user interface. This ʻOtto-softwareʼ platform facilitated multiple functions through a dynamic user interface such as all the weekly water quality including automatic GPS, date, and time coding, collection of photos or drawings, processes data with or without internet. It is also customized to facilitate any desired method of data collection. The ability to use the Otto-software tool on any device will allow for future ʻcrowd-sourcingʼ or large collaborative citizen science projects, as users can log in and provide information using smartphones. This software was adapted for all three loko iʻa in this study and the kiaʻi loko continue to use this platform even after data collection for this study was done. This software has the potential to engage all data collection efforts that are happening in the field and even support expedited data processing and sharing throughout our communities.

Kiaʻi were interviewed during June-July 2017 on the role of hydrology in their loko iʻa and their needs regarding hydrologic information. Three categories were identified from these interviews: data management, educational outreach, and community connection. Kiaʻi identified Kibana visualization software as a powerful tool for presenting the hydrologic data recorded using the Makai-Otto software for funding, presentation of progress, and educational purposes. We wrote a "how-to" install Kibana guide, including extra resources available to assist in the installation and operation of Kibana. Co-PI John Burns submitted a proposal to the Purple Maiaʻa Foundation Aloha ʻĀina Challenge to improve these tools and was a first place winner for additional support of this effort ($12,000).

Collaborative Elements

Collaboration plays a central role in this project, and is necessary for loko iʻa restoration while responding to climate change. The goals of this proposal were developed through an initial collaboration among kiaʻi, Hawaiʼi DAR manager of estuarine fisheries, and researchers from UH Hilo with expertise in hydrology, primary production, data sciences, and socioecology. Graduate students have had at least bi-weekly interactions from Dec 2016-Dec 2017 with kiaʻi in order to complete their bi-weekly water quality sampling. These casual interactions have included regular project updates from students and loko iʻa activities from the kiaʻi (e.g. activities at the loko iʻa, project-relevant updates such as impact of king tide events). Additional meetings were held in March 2018 to discuss preliminary results. DAR manager Troy Sakihara has been instrumental in demonstrating laboratory methods for processing settling tile experiments. Most of the project participants attended the PI-CSC Climate Science Boot Camp (Aug 2017). Formal meetings of all participants to discuss project activities and progress, share preliminary results, and discuss research products were held Oct 2016, Nov 2016, June 2017, and Nov 2017. All but one of these meetings was held at one of the loko iʻa, which has strengthened the connection among participants and the study sites. Additionally, thesis committees met to discuss the project and progress for Ms. Kauahi in May 2017, September 2017, February 2018, and July 2018 and for Ms. Anthony in December 2016, July 2017, October 2017, and July 2018. During Summer 2017, additional talk-story sessions with kiaʻi were held to introduce summer interns to each loko iʻa and to interview each kiaʻi regarding their needs regarding information on hydrology, water quality, primary productivity and climate change. An informative presentation that introduced this study and the data-software app for potential use through all lokoiʻa in Hawaii was made to the larger loko iʻa hui at the annual Hui Malama Lokoiʻa gathering in Hilo (April 2017).

This project has created stronger communication along the Keaukaha coastline through the loko iʻa in this community, and a tighter network that is a consistent source of support throughout the community. During this project, Ms. Anthony and Ms. Kauahi included aspects of this research in project-based learning activities with students from Ka ʻUmeke Ka'eo PCS, Ke Ana Laʻahana PCS, Kua O Ka La PCS, and Lanakila Learning Center during school months. The project has allowed kiaʻi to converse about relationships in the ecosystems that have been discovered through this project. The project has also strengthened the relationship between kiaʻi and the Hawaii Division of Aquatic Resources, allowing a sharing of knowledge on invasive species and gaps in knowledge for the same species of fish in the recreational fisheries managed by DAR and those raised in the loko iʻa. The positive relationship between the University of Hawai'i at Hilo and the kiaʻi is manifest in the development of new projects examining the migration of ʻama'ama (mullet) and continued development of the Makai-Otto software.

Understanding the impact of climate change on a system requires data that can document changes through time. This is one of the take home messages that kia'i felt strongly about, and have maintained their weekly water quality sampling. We also developed several "no regret" management options that would enhance primary productivity. By increasing production now, the loko will be more resilient to the effects of climate change. Kia'i will use this documentation of the benefits of management options, both now and into the future, to attract funding through grants or other means.

Overall Project Conclusions

Research, with emphasis on community needs and collaboration, has the potential to contribute to the renewed growth of the once intimate relationships between native Hawaiians, water, and the land. This study examined the variability and relationships of hydrology, water quality, and primary productivity in loko i'a of Honohononui and Waiuli, Hawaiʻi Island, and developed models that will help in adapting to the conditions accompanying climate change. By investigating and quantifying these relationships, kia'i will be able to develop efficient approaches to raising fish for our local communities as a means of food security for our isolated islands. These results and methods can be applied at other loko i'a throughout Hawai'i, including those at Kaloko-Honokōhau National Historic Park, in the efforts to support local food production. By quantifying an understanding of loko iʻa ecosystems rooted in contemporary scientific approaches, the community efforts in enhancing its coastal resources and habitats are better supported and integrated for all who depend on these ecosystems.

This study also provided training in instruments that support community climate resilience through habitat enhancement, food security, and ecosystem awareness. With consistent communication among scientists, kiaʻi loko, and community members throughout this study, the influence of these impacts was made possible; interactions among these parties was a strong component of this process.

Climate change in its uncertainties and predictions of rainfall, storm events, sea-level rise, and other weather patterns will have direct impacts on loko i'a and is multifaceted. Loko ia, sitting at the shoreline and influenced by a delicate balance of fresh and salt water, are one of the first ecosystems to be impacted by climate change. Hence, the communities that are restoring loko i'a are "first responders" practicing resiliency and progressing in the face of a changing and evolving environment. Resilience will come from practicing the lessons rooted in the ancestral knowledge of Hawaiians and to implement contemporary approaches that serve the communities and coastal ecosystems.

Deliverables

Research Products: From this project, we developed map layers for each loko iʻa with contours of depth, temperature and salinity at the surface and at the bottom, and stratification. These maps will be utilized by managers to plan for future inundation, identify different habitat zones within the fishponds for management considerations, and maximize water sampling strategies. All data was provided to the kia'i of each loko ia, which included one-year time of series measurements of temperature, conductivity, salinity, pressure and depth (>80,000 samples at each station) at 2-3 locations in each loko ia, turbidity, chlorophyll *a*, major ions, and nutrients. Models were developed for each loko to determine: 1) increases in salinity with sea level rise, and 2) primary production as a function of salinity. These models were combined to make predictions of how climate-driven changes in rainfall and sea level will alter the productivity of these fishponds. To help use the Kibana visualization software, we provided each kia'i a manual and example data files.

Education: Two M.S. Theses (Anthony and Kauahi) were completed, which included detailed scientific reports of the project findings. Ms. Kauahi is a native Hawaiian woman, and her advanced degree studying hydrology is important since women comprise only 23% of the geoscience workforce (NSF 2017). Both of graduates are now qualified for advanced work in a science field, where non-white women comprise only 5% of the science workforce (NSF 2017). Five undergraduate students from minority groups were also trained during this project, which included four women and three native Hawaiians.

Presentations: Presentations of this project were made to a large variety of communities, ranging from scientific audiences (Hawaii Conservation Conference, Hawaii Ecosystems Meeting), community meetings (Hilo Sierra Club), to classes at UH Hilo, and to primary and secondary school children as a part of project-based learning at the loko iʻa.

Publications

Anthony K. 2018. Mālama loko iʻa: Salinity and primary productivity relationships at Honokea loko, Hale o Lono, and Waiahole/Kapalaho on Hawaii Island, Hawaii. M.S. Thesis. UH Hilo TCBES graduate program, Hilo, HI.

Kauahi C. 2018. Hydrology of three Loko Iʻa, Hawaiian fishponds, on the eastside of Hawaiʻi Island, HI. M.S. thesis. UH Hilo TCBES graduate program, Hilo, HI.

Presentations (15, listed in chronological order)

K. Anthony, Mālama lokoiʻa: Relationships of Primary Productivity at Honokea loko, Hale o Lono, Waiāhole, and Kapalaho on Hawaii Island. Wiki Presentations, Hawai'i Conservation Conference, Honolulu, HI (July 2018)

C. Kauahi, Hydrology of three loko iʻa, Hawaiian fishponds, on the eastside of Hawaiʻi Island, HI. Wiki Presentations, Hawai'i Conservation Conference, Honolulu, HI (July 2018)

K. Anthony, Mālama loko iʻa: Salinity and primary productivity relationships at Honokea loko, Hale o Lono, and Waiahole/Kapalaho on Hawaii Island, Hawaii. M.S. thesis defense. UH Hilo TCBES graduate program, Hilo, HI (June 2018)

C. Kauahi, Hydrology of three loko iʻa, Hawaiian fishponds, on the eastside of Hawaiʻi Island, HI. M.S. thesis defense. UH Hilo TCBES graduate program, Hilo, HI (June 2018)

S. Colbert, Impact of climate change on hydrology and primary production of three Hawaiian fishponds. Hawaii Ecosystem Meeting, Hilo, HI (June 2018)

C. Kauahi, Hydrology of Loko Iʻa. UH Hilo TCBES Annual Symposium, Hilo, HI (April 2018)

K. Anthony, Understanding relationships of primary productivity among three Hawaiian fishponds at Honohononui and Waiuli, Hawaii. UH Hilo TCBES Annual Symposium, Hilo, HI (April 2018)

S. Colbert, K. Anthony, B. McNaughton, Impact of climate change on hydrology and primary production of three Hawaiian fishponds. PI-CASC 5-Year Review, UH Manoa, Honolulu, HI (January 2018)

K. Steward, Understanding hydrology at Honokea loko iʻa & Comparing pH and alkalinity at 12 springs along the Honohononui and Keaukaha shoreline. PIPES Summer Internship Symposium, Hilo, HI (August 2017)

C. Miner-Ching, Visualization software for kiaʻi loko iʻa. PIPES Summer Internship Symposium, Hilo, HI (August 2017)

S. Colbert, K. Anthony, C. Kauahi, Collaboration across worldviews: utilizing knowledge coproduction on Hawaiʻi Island to thrive through change. Hawai'i Conservation Conference, Honolulu, HI (July 2017)

K. Anthony, C. Kauahi, Climate Change and Loko iʻa. Hilo chapter of the Sierra Club (May 2017)

K. Anthony, C. Kauahi, Understanding Changes in Hydrology and Primary Productivity within three Hawaiian Fishponds in Keaukaha, HI, Island Sustainability Conference, Guam (April 2017)

K. Anthony, C. Kauahi, Effects of climate change on Hawaiʻi Island in relation to loko iʻa. Sociology 408 Island Feminism Course (October 2017)

C. Kauahi, K. Anthony, Ke Alahele Waiwai. Marine Option Program Seminar Class, UH Hilo (March 2017, October 2017)

News Articles (2)

Hawai'i Tribune-Herald. Taking on climate change: Bill would align state strategies with those of Paris accord, create interagency commission. Written by: Ivy Ashe. (May 2017) (http://www.hawaiitribune-herald.com/2017/05/08/hawaii-news/taking-on-climate-change-bill-would-align-state-strategies-with-those-of-paris-accord-create-interagency-commission/)

UH Hilo Stories. Climate change research at UH Hilo: Fishpond management and restoration. Written by: Anne Rivera. (April 2017) (https://hilo.hawaii.edu/news/stories/2017/04/19/fishpond-management-and-restoration/)

Video Presentations (3)

S. Colbert, K. Anthony, C. Kauahi, *Voices of the Sea* episode: *Adapting Culture to Climate Change*, video by UH SeaGrant. (https://vimeo.com/277677963) (July 2018)

K. Anthony, C. Kauahi, *E lauhoe mai: Redefining "classroom" in Keaukaha,* video by Kamehameha Schools (https://youtu.be/42LRvwzDBDo) (May 2018)

S. Colbert, K. Anthony, C. Kauahi, *Building Climate Resiliency at Honokea Loko Iʻa*, climate adaptation video from the US Fish and Wildlife Service (https://vimeo.com/238703932/40a6d8b84b) (February 2017)

Photos

Cherie Kauahi investigates groundwater sources in a loko iʻa, or traditional Hawaiian fishpond

Investment from many community members (laulima) is vital to the adaptive management that has sustained loko iʻa over centuries.

Through water quality monitoring, the effects of climate change on loko iʻa will be documented.

Loko iʻa management must adapt to changing climate, salinity, and nutrient loads.

Final List of Collaborators
Steven Colbert, Associate Professor, UH Hilo Marine Science, TCBES Advisor
Jason Adolf, Endowed Associate Professor, Monmouth University
Kamala Anthony, Manager, Honokea Fishpond & TCBES student
Cherie Kauahi, TCBES student
Noelani Puniwai, Assistant Professor, School of Hawaiian Knowledge, UH Manoa
Kēhau Springer, Conservation International Hawaiʻi
Luka Mossman, Manager, Hale o Lono Fishpond, Edith Kanakaʻole Foundation
Blake McNaughton, Manager, Waiāhole and Kapalaho Fishponds, Kamehameha Schools Kumuola Science Education Center
Troy Sakihara, Department of Land and Natural Resources, Division of Aquatic Resources
John Burns, Assistant Professor, UH Hilo Marine Science

Our list of collaborators is the same as at the beginning, with the addition of two faculty from UH Hilo that participated on the thesis committees for Ms. Anthony and Ms. Kauahi. Dr. Jene Michaud (Geology) provided expertise in hydrology, and Dr. Rebecca Ostertag (Biology, TCBES) provided expertise in biological systems and climate change. Both joined the project in August 2017. In May 2018, the primary advisor for Ms. Anthony shifted from Dr. Adolf to Dr. Colbert.

Undergraduate Students: Without the help and input of many hands, this project is not made possible. During the Summer 2017, two PIPES undergraduate interns, Kainalu Steward and Candice Miner-Ching, assisted with the project. Fall 2017, two Keaholoa STEM program students, Joelle Guerreiro and Mary Metchnek, made flow measurements at the makaha, and two Ike Wai (EPSCoR) interns, Kainalu Steward and Uakoko Chong, assisted in biweekly water quality collections, tile experiment deployments, chlorophyll *a* processing, and data organization. During their internships, undergraduate students were financially supported by external programs.

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