Title: Quality assured sampling by engaged citizen scientists supports state agency coastal water quality monitoring programs for improved watershed management

Short title: Coastal water quality monitoring supports watershed management

Authors: Kim Falinski[1*], Tova Callender[2], Emily Fielding[1], Robin Newbold[3], Dana Reed[4], James Strickland[3], Alana Yurkanin[1], Hudson Slay[5], Myron Honda[6]

Affiliations:

1 The Nature Conservancy, Hawaii Marine Program, Honolulu HI

2 West Maui Ridge to Reef Initiative, c/o DLNR DAR, Wailuku, HI

3 Maui Nui Marine Resource Council, Kihei, HI

4 Hui o ka Wai Ola, Napili, HI

5 United States Environmental Protection Agency Region 9, Pacific Islands Contact Office, Honolulu, HI

6 Hawaii Department of Health, Clean Water Branch, Pearl City, HI

* Corresponding author

kim.falinski@tnc.org

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.27548v1 | CC BY 4.0 Open Access | rec: 22 Feb 2019, publ: 22 Feb 2019

Abstract

Pacific island coral reef ecosystems are particularly threatened by anthropogenic stresses we can manage in the context of global threats we cannot control. State agencies are challenged to sample coastal waters at the spatial and temporal resolution needed to make decisions about improving watershed management. The acquisition of environmental data by committed non-profit organizations and trained community members represents a major opportunity to support agency monitoring programs and to complement field campaigns in the study of watershed dynamics. When data collection protocols match state agency protocols and these are supported by sufficient documentation there is an opportunity to create regulatory-quality data that can inform management. We describe the formation of the first volunteer group in Hawaii to establish a quality assured water quality sampling program to match the Hawaii Department of Health's protocols. Hui O Ka Wai Ola, a partnership between three non-profit organizations on Maui, Hawaii, has trained 40 volunteers to use methods that directly match the state program. The group has taken over 900 discrete samples at 48 sites, providing the most comprehensive picture of water quality in Maui to date, motivating community activism and catalyzing large-scale restoration efforts in the adjoining watersheds. Results highlight coastal areas that have poor water quality, delineate a baseline from which to compare future restoration projects, and emphasize parts of the sampling protocol that might be improved for more reliable data.

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.27548v1 | CC BY 4.0 Open Access | rec: 22 Feb 2019, publ: 22 Feb 2019

1. Introduction

Watershed managers need long term measurements of physical and chemical water-quality data to assess current conditions in the coastal waters, to detect and quantify spatial and temporal trends in water quality, and to support water-quality management decisions [1]. However, the historic lack of resources at the state level for comprehensive monitoring efforts creates challenges to acquiring the data needed by decision makers [2]. Federal, state and county agencies often do not collaborate on data collection methods or sharing policies, limiting the potential for the data to impact policy. At the same time, communities support enacting policies that reduce brown-water events, ensure healthy water for swimming and improve coral reef health.

Pacific island ecosystems are particularly threatened by sea level rise, coral bleaching due to higher temperatures and increased development, and are in need of long term continuous data sets to support watershed management efforts that mitigate these threats [3]. These sensitive ecosystems are the backbone of thriving economies, providing recreation opportunities for tourists and locals, healthy reefs to protect coastlines from storms and flooding [4,5], and habitat for food fish [6,7].

Citizen science can provide quality data. Recent literature on citizen science has focused on the quality and relevance of citizen-led science, and the benefits and challenges of citizen science [8-10]. Hyder et al. [11] ask, "Can citizen science contribute to the evidence-base that underpins marine policy?", concluding that high quality citizen science can play an important role in the policy landscape. Some have acknowledged that citizen-science data collection is a solution to building large temporal or spatial datasets.[12-14].

Few studies consider specifics on how to establish quality in citizen science, which can limit application of data collected in policy, resource management and scientific research. In the last twenty years, data quality from citizen science has come under fire [8,15,16]. Countering skepticism about citizen science credibility, Pfeffer and Wagenet (2007) cite numerous studies demonstrating the relative accuracy of biological sampling by trained volunteers when compared to control groups of professional scientists [17]. However, because there are generally more people involved in citizen science sampling efforts, there are also varying skill levels and competencies within the samplers. Significant progress has been made by stream monitoring

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.27548v1 | CC BY 4.0 Open Access | rec: 22 Feb 2019, publ: 22 Feb 2019

groups in creating standardized, document protocols, but to date coastal water quality groups have varying levels of quality assurance / quality control (QA/QC) to ensure standardized monitoring (Alabama Water Watch).

Citizen science can motivate community action. Collecting data as a source of inspiration for conservation is another acknowledged benefit of citizen science program [9]. Across the United States, volunteers are engaging in programs to improve water quality by monitoring streams, lakes, oceans and estuaries [18]. Civil society networks have drastically increased the capacity for monitoring for water quality and ecosystem health [19]. Acknowledging the framework described by Jalbert et al (2014), volunteer networks can focus on either education or advocacy in their efforts. Through monitoring groups focused on education and outreach, volunteers observe how the quality of surface and ground water is affected by our actions on the land and how we can protect our water resources. In turn, monitors help to educate the local community on water quality issues, thereby protecting drinking water quality and human health. Volunteers become advocates for conservation commissions, county and state planning boards, and condo associations.

Most projects obtain or manage scientific information at scales or resolutions unattainable by individual researchers or research teams, whether enrolling thousands of individuals collecting data across several continents, enlisting small armies of volunteers or engaging with committed citizens to translate consistent place-based knowledge into reliable data [20]. In resource-poor jurisdictions (of any spatial scale) where there is substantial community interest and social capital surrounding clean coastal water but a lack of government resources, water quality data acquired by citizens can help fill information gaps. Monitoring is costly, but citizen- led programs are a solution to obtain baseline monitoring, thereby solving tricky problems where insufficient resolution data exists to diagnose problems.

The objective of this paper is to document the program structure and QA/QC protocols used to build and maintain a coastal water quality monitoring programs on the island of Maui in Hawai'i, and to report on the successes and challenges of implementing this program. In addition, the results from the first two years of the programs' operation demonstrate the usability of these data in establishing high resolution spatial and temporal trends in water quality. Lastly, we consider the successes and challenges of this type of program, and its scalability across similar communities.

2. Site Selection: Empowering the Maui community

In May 2014, a group of concerned citizens and representatives of federal, state and county agencies were convened on Maui by the Maui Nui Marine Resource Council (MNMRC) and The Nature Conservancy for a day long planning session to determine how we could help collect water quality data that would be useful to HI State Department of Health (HDOH), the state water quality agency. The impetus for the meeting was another HDOH report, issued every 2 years as required by the federal Clean Water Act, listing coastal water quality on Maui as more impaired than elsewhere in the main Hawaiian Islands.

Coral reefs at threat from land-based pollution. The 20-mile coast of West Maui has long suffered from documented water quality concerns that threaten the health of an extensive coral reef ecosystem [21-24]. Although a number of researchers had conducted monitoring and modeling water quality studies in south and west Maui [25,26], a consistent dataset of water quality data that assessed turbidity and nutrient concentrations over time was needed to prioritize action. The HDOH targets the busiest recreational beaches statewide for sampling as part of their BEACH Act bacteria monitoring program (http://health.hawaii.gov/cwb/clean-water-branch-home-page/water-quality-standards/). Statewide, Tier 1 beaches are monitored weekly. On Maui, Tier 2 beaches are monitored approximately once every other week. The HDOH began collecting chemistry (nutrients) samples statewide from Tier 1 and Tier 2 beaches in June 2018. In the beginning of October, 2018, CWB moved the Maui chemistry sampling sites to focus on the West Maui sites. The HDOH currently has 18 Tier 1 and 47 Tier 2 beaches on Maui (see Figure 1). From 2014 to 2016, HDOH collected 3,107 beach samples from 65 sites on Maui, of which 754 sample from 15 sites were from West Maui.

Figure 1: Hui o ka Wai Ola study sites and historical/current Department of Health sampling sites.

The coral reef in North Ka‘anapali, west Maui is one of two Priority Coral Reefs in Hawaii named by the State of Hawai‘i , and the Kahekili Herbivore Fisheries Management Area is one

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.27548v1 | CC BY 4.0 Open Access | rec: 22 Feb 2019, publ: 22 Feb 2019

of only four marine conservation zones on the island of Maui. The nearshore areas of west Maui include highly diverse and valued coral reef ecosystems [27]. Honokōwai Beach Park and the nearshore waters from Honokōwai Point to Kāʻanapali are impaired (do not meet state water quality standards) by total nitrogen, total phosphorous, ammonium nitrogen, algal growth (chlorophyll-a), and turbidity, and are given a total maximum daily load (TMDL) priority of medium (2018 State of Hawaii Water Quality and Assessment Report). Ecologically, the coral reef along the Kāʻanapali coast has suffered degradation and the area remains sensitive to bleaching events, such as those seen in 2014-2015 driven by a strong El Nino [28]. In the most recent 2017 survey, Vargas-Angel et al. [29] suggests that left unattended, land-based source pollutants (LBSP) will continue to negatively affect the coral reef communities of West Maui. Given the current nutrient, turbidity and terrestrial sediment loading conditions, Wahikuli and Honokōwai watersheds in west Maui are identified as having the highest risk for deterioration due to impaired water quality because they harbor prominent and well-developed reefs.

Hawaii Department of Health monitoring capacity. The assessment methodology used by HDOH Clean Water Branch (CWB) for its Integrated Reports submitted to EPA requires long-term monitoring data, generally collected over a two-year period. A minimum of 30 samples collected over the two-year period are required to determine waterbody impairment. The CWB has not been able to collect a significant amount of external monitoring data for use in the Integrated Report, despite the call for data published in the newspapers and on our website. The CWB relies mostly on its internal monitoring data for the assessments.

3. Hui o ka Wai Ola Program Development

The mission of Hui o ka Wai Ola is to generate quality-assured coastal water-quality data, and to provide this data to HI-DOH, other resource agencies, non-governmental organizations, researchers, and the public to improve coastal water quality and reduce the anthropogenic stress on coral reefs.

The specific goals of Hui o ka Wai Ola ("Hui") proposed at the Hui's inauguration were to 1) increase community capacity for long-term monitoring water quality in Maui coastal waters; 2) generate quality-assured reliable data that can be used to assess coastal water quality conditions that can augment HI-DOH CWB Water Quality Monitoring and Assessment Reports to EPA, also known as the Integrated Reports; and 3) empower community and government managers to take action to improve coastal water quality, benefiting the coral reef ecosystem and people alike. During a strategic planning session in 2018, the group agreed on a vision of "Clean coastal waters for reefs and people" and a revised mission to "Deepen understanding of Maui's coastal water quality through science and advocacy to accelerate positive change." The Hui's guiding values derived from native Hawaiian cultural practice, are as follows:

1. **Ahonui** – Patience with perseverance. We focus on supplying high quality data to improve our nearshore water quality.
2. **Hana Maika'i** - Good work. With integrity, competency and attention to detail, we produce quality assured information for our community.
3. **'Ike -** Understanding, recognition, comprehension and thus learning. We recognize that conservation is best advanced through a culture of learning, change, creativity, growth and mutual understanding and high quality work.
4. **Laulima** – Many hands working together cooperatively. Our strength and vitality lie in our collaborative spirit, team work, open communication, welcoming and nurturing attitude.
5. **Ho'oka'ana** – To divide equally, share. We freely share our work, from protocols and processes to data and analysis, so that we may learn from one another and expand the scale of our collective efforts for clean oceans.

These practices are executed by a Steering Committee chosen from the partner organizations. Those involved in the Hui are organized as shown in Figure 2.

Figure 2: Organizational structure of the steering committee of Hui o ka Wai Ola, a partnership of multiple non-profit and community groups

In May 2014, The Nature Conservancy and Maui Nui Marine Resource Council convened a group of government officials (including the State Department of Health and the County Department of Public Works), researchers working across Maui, watershed managers and community leaders to discuss coastal water quality concerns, commonalities among sites experiencing poor water quality, and how to regularly acquire more coastal water quality data. The group provided the guidance to write the quality-assurance project plan, and to begin organizing a partnership. With support from the National Fish and Wildlife Foundation, the County of Maui, and private donors, The Nature Conservancy and Maui Nui Marine Resources Council acquired funding for lab startup and equipment costs and a coordinator for five original sites in west Maui, which expanded to 24 sites within a year. The first step of organizing the partnership included convening a community meeting specific to water quality to describe the vision of the Hui and training process to interested community members. A sample of that

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.27548v1 | CC BY 4.0 Open Access | rec: 22 Feb 2019, publ: 22 Feb 2019

agenda is presented in Figure 3. Follow-up meetings were focused on training new volunteers and describing the results collected to date.

Figure 3: Water quality working group process

4. Program Methods

4.1. Quality assurance process

The outcome of the May 2014 meeting was to follow up on creating a Quality Assurance Project Plan that would be approved by the HDOH. The QAPP was developed jointly with the HDOH, and adopted by the Hui. Instrumental in its success was the selection of a point person to act as a Quality Assurance officer, who was independent of all sampling activities and who had the technical knowledge and ability to oversee the field operations, lab analyses, training, and data management. Equally important was the development of standard operating procedures (SOPs) to ensure all aspects of the project were implemented consistently, including the creation of standardized chain of custody forms and a standard data entry process. The QA process provides for sufficient oversight to ensure that quality controls and all quality assurance activities were properly implemented, including assurances that the data was correctly transcribed, the instruments were calibrated and in working order and the holding times and other lab protocols were met. The Hui o ka Wai Ola QAPP was approved by the HDOH on February 28, 2017.

Prior to the Hui's application, the HDOH CWB received several inquiries regarding volunteer groups wanting to collect data but they lacked staff with relevant experience or expertise to ensure data quality. CWB indicated that it would welcome more volunteer groups, but unfortunately, CWB lacks the resources to adequately train and mentor these groups, especially those who lack members with prior experience. Having a dedicated, named team as shown in Figure 2 was a key part of building trust between the HDOH and the new partnership.

4.2. Site selection

The project pre-selected sites according a prioritization process. High priority sites were sites where funding was available and that met the following criteria:

a) Is there safe access to collect samples?
b) Is the sample site reasonably representative of the WQ in the area?
c) Has a baseline been established?
d) Does the impairment negatively impact coral reefs or human health?

e) Are there current or pending changes on land that may increase or reduce pollution?
f) Can another organization collect and process the samples and meet our QAPP standards?
g) Is someone addressing the source of pollution? Is there a watershed management plan?
h) Does the level or intensity of impairment warrant sampling?

The first 24 sites selected by the group are shown in Figure 1, alongside the HDOH sites described above for west Maui.

4.3. Equipment and parameters

Data collection included measurements of physical parameters of coastal waters including temperature, salinity, dissolved oxygen (DO), turbidity and pH. Measurements were made using a Hach HQ40D multiprobe unit with DO, pH, temperature and salinity probes, and a Hach 2100Q turbidimeter for turbidity analysis. Instruments were chosen to match HDOH equipment. Chemical and physical parameters collected included dissolved nutrient analysis of water samples and total suspended solids. Samples were filtered in field using 0.2 µm GF/F filters, frozen and shipped to O'ahu for analysis with one week. Samples were pre-filtered to remove the sand fraction, filtered at 0.7 µm, oven dried at 65°C, and weighed. Additional details regarding sample collection, processing and analysis are available in the Hui o ka Wai Ola QAPP (huiokawaiola.com/volunteers).

Sampling was completed early in the morning at a standard time (0700 to 1000) in the near shore at knee depth water. Water quality monitoring took place every two weeks beginning on June 13, 2016 at the 24 sites, which met the criteria described in section 4.2 above.

4.4. Laboratory facilities

For the quality assurance project plan to be approved by the HDOH, the Hui also had to identify different laboratories qualified to potentially support this project. For nutrients, analyses were performed at University of Hawaii at Mānoa's SOEST Laboratory for Analytical Biogeochemistry (S-LABs) . The lab underwent an external process to evaluate data quality in collaboration with the Hui, and uses an SEAL Analytical AA3 autoanalyzer. A separate set of quality control guidelines and documentation protocols were needed to account for the lab's processes. This QA/QC was reported on the datasheets and included with the results.

Table 1: Analytical methods for each parameter used in water quality analysis.

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.27548v1 | CC BY 4.0 Open Access | rec: 22 Feb 2019, publ: 22 Feb 2019

4.5. Training

Each volunteer received a minimum of 12 hours of training prior to sampling, in addition to First Aid and CPR training. Trainings were conducted at first by the quality assurance officer, and then by the most experienced volunteer team leads. Material included background on water quality science, hands-on modules to learn protocols, and exercises for data entry, conducted over two days. New cohorts of volunteers were trained as needed, and after the first public recruitment event, were drawn from the community through word of mouth. The purpose of the training was to establish both a theoretical understanding of the science behind the data and hands-on experience with sampling protocols.

4.6. Quality control

In order to verify our data, initially ten sites were co-located with HDOH sites in west Maui. Sampling at these sites had discontinued as of October 2016.). Sampling at the HDOH sites was conducted from January 2008 to October 2016, but not on a regular schedule (n=556). We used a paired t-test to compare the geomeans of the parameters at collocated sites using the stats package in R, acknowledging that while the site was the same, the time frame was different, and the results would reflect changes in time (including differences in hydrologic conditions) as well as potential differences in method.

4.1. Data management

Because of the group's interest in making the data public, a communications platform in the form of a website was developed early-on to provide a place to store the quality-controlled, outward facing dataset (www.huiokawaiola.com). To date, the website receives over 400 unique visitors per week on average. Records show that community members, teachers, academic researchers and visitors have downloaded the data set and looked at the prepared visuals. Additionally, the data is regularly shared with university databases and included online in the PacIOOS system (https://www.pacioos.hawaii.edu/voyager-news/hui-water-quality/). Results were posted to the national EPA Water Quality Exchange (WQX) database.

5. Results

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.27548v1 | CC BY 4.0 Open Access | rec: 22 Feb 2019, publ: 22 Feb 2019

The Hui o ka Wai Ola coastal water quality program has successfully collected over 900 samples to date and maintains a regular and consistent program with trained volunteers. Hui o ka Wai Ola developed capacity to monitor 24 sites that were not continuously sampled by HDOH. The results from this ongoing investigation show that all 24 west Maui sites are impaired for at least one parameter according to the HDOH State Water Quality Standards.

5.1. *Data quality*

In order to verify our data at the start of the program, nine sites were co-located with HDOH sites, and one site was approximately one mile away from a Hui site (n=321). Results demonstrated that the two datasets were not statistically different for all variables except for temperature and dissolved oxygen (Table 2). We believe these differences are methodological, because the HDOH does not sample at a set time of day, but rather when they are able to get to the site during the day. For ammonia, early analysis of the Hui data noted that there were differences at collocated sites, possibly due to different hold times between the groups. Lastly, for turbidity (p-value 0.12), we might expect that variation between years to be more significant, and look forward to being able to compare data taken at the same site at the same time to complete this analysis.

Table 2: Comparison of the geomeans of Hui data (n=321) with the geomeans of State Department of Health data (n=556) for two parameters. Data were not taken at the same time, but at the same sites.

5.2. *Water quality results for west Maui, 2016 to 2018* **.**

Water quality monitoring took place every two weeks beginning on June 13, 2016 at the 24 sites shown in Figures 4 and 5, Table 3. After the first six months of the program it was decided to sample every three weeks to vary the tidal cycle during sampling sessions. Results are presented below for nutrient, silicate, turbidity, pH and dissolved oxygen. Table 2 shows the geometric mean by site for each of the nutrient water quality samples, and for the turbidity measurements. Geometric means were compared to Hawaii Department of Health standards for “dry” season to be conservative, and are presented in both Table 3 and Figure 4. The HDOH “dry” season is defined as locations that have less than 3 MGD of surface flow. Sites in west Maui are generally below this and considered “dry” [30]. Eighteen of the 24 sites all in the northern, former agriculture watersheds, were above the standard for dissolved inorganic nitrogen (nitrate +

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.27548v1 | CC BY 4.0 Open Access | rec: 22 Feb 2019, publ: 22 Feb 2019

nitrate, NNN), (Figure 5). All sites exceeded the state standard for turbidity, and 11 sites exceeded the standard for ammonia (NH_4). Pohaku Beach Park consistently had the highest concentrations of silicates, indicating that it had the most groundwater inputs of any of the sites.

Of note was the effect of tidal state on the data. When the tide was low, and corresponding silicate concentrations were high, nutrient concentrations were higher (Figure 6). This effect was previously demonstrated by Swarzenski et al. [31] and Amato et al. [26] for Maui coastal systems. Practically, the time of day and tide state become critical to either constrain by keeping constant (to eliminate the variability) or include by sampling across the tidal cycle to see the full spectrum. The Hui chose to sample every two weeks to first eliminate the effect of groundwater by sampling on the same tide, and then switched to measure the full cycle. We continue to consider the effect of this decision, because although we are collecting a more accurate picture of the nutrient concentrations, it might take us much longer to understand what the baseline is, and respond if there are changes such as restoration activities or a new subdivision.

Table 3: Geometric means for selected water quality parameters. Values highlighted in red exceed the geometric mean standard of the Department of Health for dry weather. All values are in ug/L, with the exception of turbidity [Data as of October 2018]

Figure 4: Map of study area showing nitrate concentrations in west Maui (ug/L).

Figure 5: Concentrations of nutrients and turbidity measurements from the 24 sites observed to date by Hui o Ka Wai Ola. The dotted red line represents the State of Hawaii coastal water quality standard for each parameter (Dry season).

Figure 6: Nitrate concentrations for all data points by site, colored by silicate. The highest nitrate concentrations correspond with high silicate values. The data highlight the need to consider the effects of tidal state when choosing when to sample.

The data revealed temporal patterns that are valuable to watershed managers and scientists interested in understanding how coral reefs respond. Turbidity, especially, provided an opportunity to observe how long sediment stays around at specific sites once it is introduced. Honolua Bay, the northernmost site in this study, is an enclosed bay with a formerly thriving coral reef ecosystem. At Honolua, turbidity continued to remain elevated for months after a

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.27548v1 | CC BY 4.0 Open Access | rec: 22 Feb 2019, publ: 22 Feb 2019

storm event on October 24, 2017 (rainfall at Pu'u Kukui rain gauge was 5.3 in), while at other sites that are more exposed, the same event did not stay around for many weeks at all (Figure 7). The storm event did not affect the Canoe Beach site to the south nearly as badly, and conditions were able to return to a lower baseline more quickly. On November 15, 2017, just 3 weeks after the October event, another 5 in of rain was delivered at Pu'u Kukui, but the rainfall rate was not high, and the streams did not respond in the same way. A smaller storm on January 6th had 1.6 in of rainfall at Pu'u Kukui, and the turbidity rose to 65 NTU at Honolua.

Figure 7: Changes in turbidity after storm events on October 24 and November 15, 2017, and January 6, 2018 (dashed black lines) at Hui- and HDOH- site Honolua compared with Canoe Beach. Fine temporal scale data contribute to better understanding coastal water quality trends.

6. Discussion

6.1. Programmatic successes and challenges

Developing a quality-assured citizen water quality monitoring program is a dynamic, interactive process that ideally involves quality assurance experts, potential data users, and members of the volunteer monitoring project team (EPA, 1996). Hui o Ka Wai Ola was not the first group in Hawaii to regularly sample water quality to support community and regulatory action, but to our knowledge it was the first to adopt state QA/QC standards for sampling. To be successful, the group needed to balance pragmatism with available financial and social capital.

6.1.1. Quality assurance process

The QA process to ensure that the data standards were being met went through many iterations in the first six months of the program, as trainers and volunteers learned what did and did not work, and the methods for recording and processing samples evolved. The data was valid when the QAPP was approved. One of the biggest initial challenges was data management. The program struggled to keep up with data entry, and the system for checking the data evolved as well. We learned that the volunteers and team leads are well equipped to conduct initial data review and enter data online. We also learned that having multiple checks and balances is more effective than having a single QA volunteer enter and check the data. Concerns that the data entered into a cloud system like Google Sheets would be susceptible to multiple changes from multiple

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.27548v1 | CC BY 4.0 Open Access | rec: 22 Feb 2019, publ: 22 Feb 2019

volunteers proved unfounded, and the use of comments on values that were suspect was an effective means for tracking possible errors.

A major HDOH concern is the oversight of organizations that piggy-back onto the Hui's QAPP if the QA Officer will not be providing oversight. Although the QAPP is a guiding document to maintain standards, it is only as good as the training and oversight that the program supports for those collecting, calibrating, entering data, shipping samples and managing the data. It is imperative that a new organization designate a qualified person to oversee QA activities.

It is also possible to have QAPP or SOP drift, where seemingly minor procedural changes end up leading to major deviations from the QAPP or SOP over time. If left unchecked this may lead to data that are unusable. QA oversight helps to minimize such occurrences. This is one of the reasons that QAPPs must be reviewed and/or revised by the organization and resubmitted for CWB approval every five years. If there are any changes in protocol, including changes in the sampling locations, it must be reflected in the updated QAPP.

Collaboration with the HDOH. Small changes to the protocols were discussed with the HDOH. For example, Hui samples were filtered, frozen and shipped, while HDOH samples were shipped the same day. HDOH insisted that all samples be taken in knee-deep water. While this protocol can be frustrating for those who want to understand water quality as it affects coral reefs, keeping this piece of the program identical between organizations was essential for the HDOH because it is a simple, reproducible instruction. Sampling at depth, or offshore, would be more difficult to reproduce consistently, from week to week and year to year.

6.1.2. Parameters

Although the initial intent of the Hui effort was to include *Enterococcus* as a parameter, startup efforts did not provide either the human or financial capacity to begin sampling for bacteria alongside the chemical and physical parameters collected. Lab analysis protocol for *Enterococcus*, the primary indicator bacteria currently used in Hawaii to identify human sewage, requires samples be processed within 8 hours of sampling, and checked after another 24 hours. The Hui did not immediately have the lab resources to dedicate to this type of program. Furthermore, additional parameters that were not included in the pilot phase of the project included total suspended solids (TSS) and chlorophyll A. With additional resources, future monitoring may include all of these additional parameters.

6.1.3. Program costs

It is often assumed that citizen science-provided data is free. Indeed, the program was conceived by community groups who wanted to contribute to solving the problem using non-salaried labor, in partnership with government and non-profits who did not have the labor resources to collect data at the frequency needed for management decisions. However, our experience in this program is that hybrid solution utilizing both volunteers and paid labor is needed to maintain data quality, consistency and precision. Initially, a part-time coordinator was hired, followed by team leads who managed groups of 3-5 volunteers and were responsible for data entry and calibrations. The coordinator was responsible for ordering lab supplies, maintaining equipment and managing volunteers. The added capacity of coordinators was deemed essential for keeping the group reliably sampling. In addition, the members of the Steering Committee, representing three non-profit organizations, were supported by their respective organizations to outline a strategic plan and establish, manage, grow, and continue to apply for the grants and private donations needed to keep the Hui program fiscally viable. These functions could all be accomplished by volunteers, but the added resources increased the speed and organization of the group.

The average cost to maintain a single sampling site for a year is calculated at $4500, including overhead and sample analysis. In comparison, consultants might charge a similar amount for the same service, $4065 calculated at $75 per hour, with 3 days of labor time for 24 sites, plus overhead. However, a consultant would not be able to sample 24 sites at the same time of day, thereby changing the data which is affected by time of day and tide state.

6.1.4. Volunteer retainment

Of the first cohort of volunteers, 11 out of 13 trainees stayed with the program for at least one year. The caliber of the volunteers and founding members greatly contributed to the success of Hui o ka Wai Ola. Thirty-five percent of volunteers were formerly involved in STEM (science, technology, engineering and mathematics) fields and were able to bring their expertise to the

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.27548v1 | CC BY 4.0 Open Access | rec: 22 Feb 2019, publ: 22 Feb 2019

program. Additionally, 78% of the volunteers were retired and had ample time to give to the program. Volunteers were nearly evenly male/female, with 56% women on the teams, and all volunteers reported that working with other volunteers and becoming advocates for clean water is the most rewarding part of the experience.

6.1.5. Data management

Citizen-provided water quality data may not only meet expectations of academic researchers, but may also exceed researcher quality. Because of the rigor of the quality control process, the increased temporal frequency that is possible when engaging with volunteers, and the team effort in analyzing the data, the Hui program has created a robust dataset. There were multiple iterations needed to learn how to manage this growing dataset, and in the end, having a dedicated data manager as a final step of quality assurance was necessary for the group to ensure that the correct data, in the correct version, was shared publicly at quarterly intervals. Most of the initial errors in the data were identified at the data processing stage as it was entered into the database. Using cloud-services like Google Docs helped to organize the data and share it amongst multiple people. The group decided not to use off the shelf products that were available to save money, but that meant that the Hui had a longer start-up to creating a working solution to managing data with quality assurance as a priority.

6.1.6. Collaboration with the Hawaii Department of Health

Collaboration with the HDOH was integral in this process. Long term monitoring programs provided for by the federally mandated Beaches Environmental Assessment and Coastal Health (BEACH) Act of 2000 (33 U.S. Code §1251) were designed to create quality data for use in determining coastal recreational water quality. Administered by individual states, these programs have been successful and are the cornerstone available data with which to make decisions in Hawaii. Although academic researchers do collect data, few datasets that span more than three years are available because datasets are often tied to time-limited grant deliverables on specific projects rather than long term monitoring programs. Release of the data is tied to manuscripts, and is often not easily discoverable. The Hui program motivated additional support from the HDOH, including re-prioritizing sites that had not been monitored for some years due to funding shortages.

The Hui o ka Wai Ola program expanded to 48 sites by November 11, 2018, including an additional 24 sites in south Maui. Working closely with the HDOH, the state agency recommitted to sampling for nutrients at some of the Hui sites, as well, reducing the sampling demand for volunteers and allowing the program to extend its resources. Similar programs are being planned for other communities across Hawaii, and materials such as the standard protocols, quality assurance guidelines and data entry sheets are being shared as best practices with these groups.

6.2. Management recommendations

The data are clear in demonstrating that human-impacted sites have average nitrate and total phosphorus concentrations that are 3-5 times higher than sites which historically have not had intensive agriculture or tourism upland. Results from the first 24 months of regular sampling in west Maui indicate that nitrate remains elevated to over 10 times the Hawaii Department of Health state standard for nitrate at Pohaku, Kapalua Bay, and Canoe Beach [32]. The Kahana, Napili, Ka'opala and Wahikuli watersheds are particularly high in nutrients, indicating there are still serious coastal water quality issues, despite cesspool removal above most of these sites (Barnes et al., in press). Moreover, testing revealed that 100% of the sites had average turbidity over the state standard of 0.2 NTU.

Data collected in West Maui revealed hot spots with high nutrients which had not been previously identified due to no or infrequent sampling at many sites due to limited HDOH capacity, and not identified as priorities in watershed management plans. This underscores the importance of pursuing water quality data alongside planning efforts if LBSP inputs are to be accurately identified and addressed.

In the almost three years the program has been running, data analysts have also noted the variability in the system with large storms correlating with elevated turbidity that may last for weeks or months (for instance, in Honolua Bay (Figure 7)) . Understanding the sediment dynamics that increase coastal turbidity can help to prioritize management actions that are dependent on rainfall rate.

In addition, the regular, frequent sampling has made identification of these longer-term trends possible. It also allows us to track progress of restoration activities and changes in land use

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.27548v1 | CC BY 4.0 Open Access | rec: 22 Feb 2019, publ: 22 Feb 2019

upstream that may impact water quality positively or negatively – with the understanding that some of these remediation measures may take years or longer to show improvement in coastal waters. We also acknowledge that for nutrients or areas that are more exposed, sampling every three weeks does not allow us to capture water quality events that are less than 10 days. Finer scale sampling, including perhaps storm sampling, would be needed to understand these processes.

The water quality data have been incorporated into academic work to validate models, including a state planning process to manage 30% of coastal waters by 2030 [33]. Recent modeling studies have corroborated these findings [34], and attributed the high concentrations of nutrient to groundwater contamination from legacy agriculture, and sources from wastewater.

7. Conclusion

The Hui o ka Wai Ola program has contributed over two years of coastal water quality data for decision makers and watershed managers to use for future decisions about where and how to manage watersheds for improved water quality. The program has paralleled state-collected data protocols, and developed standards for future groups in Hawaii and U.S Coral Reef Jurisdictions in the Pacific and the Caribbean to adopt in creating similar programs. Major challenges included establishing systems for quality assurance of data, managing data and recruiting volunteers, and establishing novel funding mechanisms to support the program. These challenges were overcome through the dedicated efforts of a partnership of organizations committed to improving Maui's coastal water quality.

This process on Maui demonstrates that the lack of existing data is not an insurmountable challenge as local non-profits and community groups can not only create high quality data, but also motivate policy changes in a relatively short time frame when given the correct support and resources. It also demonstrates citizen collected water quality data can be used beyond education or advocacy, but can also support state-level decisions regarding natural resources.

8. Acknowledgements

We would like to thank all of the volunteers for their time and passion in keeping this program running. In addition, we thank our funders, including National Fish and Wildlife Foundation (Awards 0104.15.046650), County of Maui Office of Economic Development, Napili Bay and

Beach Foundation, and the North Beach-West Maui Benefit Fund. Our thanks extends to Lahainaluna High School and the Hawaiian Islands Humpback Whale National Marine Sanctuary for hosting our West and South Maui labs. The views expressed in this article are those of the authors and do not necessarily represent the views or policies of the US EPA. This manuscript was greatly improved through the contributions of an anonymous reviewer.

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.27548v1 | CC BY 4.0 Open Access | rec: 22 Feb 2019, publ: 22 Feb 2019

9. References

1. Lovett GM, Burns DA, Driscoll CT, Jenkins JC, Mitchell MJ, et al. (2007) Who needs environmental monitoring? Frontiers in Ecology and the Environment 5: 253-260.
2. Tan P-L, Bowmer KH, Mackenzie J (2012) Deliberative tools for meeting the challenges of water planning in Australia. Journal of Hydrology 474: 2-10.
3. Hoegh-Guldberg O, Mumby PJ, Hooten AJ, Steneck RS, Greenfield P, et al. (2007) Coral reefs under rapid climate change and ocean acidification. science 318: 1737-1742.
4. Storlazzi CD, Elias E, Field ME, Presto MK (2011) Numerical modeling of the impact of sea-level rise on fringing coral reef hydrodynamics and sediment transport. Coral Reefs 30: 83-96.
5. Kittinger JN, Ayers AL (2010) Shoreline Armoring, Risk Management, and Coastal Resilience Under Rising Seas. Coastal Management 38: 634-653.
6. Beck MW, Heck KL, Able KW, Childers DL, Eggleston DB, et al. (2001) The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. Bioscience 51: 633-641.
7. Kittinger JN, Finkbeiner EM, Ban NC, Broad K, Carr MH, et al. (2013) Emerging frontiers in social-ecological systems research for sustainability of small-scale fisheries. Current Opinion in Environmental Sustainability 5: 352-357.
8. Cohn JP (2008) Citizen science: Can volunteers do real research? Bioscience 58: 192-197.
9. Kim S, Robson C, Zimmerman T, Pierce J, Haber EM. Creek watch: pairing usefulness and usability for successful citizen science; 2011. ACM. pp. 2125-2134.
10. Dickinson JL, Shirk J, Bonter D, Bonney R, Crain RL, et al. (2012) The current state of citizen science as a tool for ecological research and public engagement. Frontiers in Ecology and the Environment 10: 291-297.
11. Hyder K, Townhill B, Anderson LG, Delany J, Pinnegar JK (2015) Can citizen science contribute to the evidence-base that underpins marine policy? Marine policy 59: 112-120.
12. Newman G, Graham J, Crall A, Laituri M (2011) The art and science of multi-scale citizen science support. Ecological Informatics 6: 217-227.
13. Bradsworth N, White JG, Isaac B, Cooke R (2017) Species distribution models derived from citizen science data predict the fine scale movements of owls in an urbanizing landscape. Biological conservation 213: 27-35.
14. Kawrykow A, Roumanis G, Kam A, Kwak D, Leung C, et al. (2012) Phylo: a citizen science approach for improving multiple sequence alignment. PloS one 7: e31362.
15. Fore LS, Paulsen K, O'Laughlin K (2001) Assessing the performance of volunteers in monitoring streams. Freshwater Biology 46: 109-123.
16. Bonter DN, Cooper CB (2012) Data validation in citizen science: a case study from Project FeederWatch. Frontiers in Ecology and the Environment 10: 305-307.
17. Jalbert K, Kinchy AJ, Perry SL (2014) Civil society research and Marcellus Shale natural gas development: results of a survey of volunteer water monitoring organizations. Journal of Environmental Studies and Sciences 4: 78-86.
18. Latimore JA, Steen PJ (2014) Integrating freshwater science and local management through volunteer monitoring partnerships: the Michigan Clean Water Corps. Freshwater Science 33: 686-692.

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.27548v1 | CC BY 4.0 Open Access | rec: 22 Feb 2019, publ: 22 Feb 2019

19. Bonney R, Cooper CB, Dickinson J, Kelling S, Phillips T, et al. (2009) Citizen Science: A Developing Tool for Expanding Science Knowledge and Scientific Literacy. Bioscience 59: 977-984.

20. Bonney R, Shirk JL, Phillips TB, Wiggins A, Ballard HL, et al. (2014) Next Steps for Citizen Science. Science 343: 1436-1437.

21. Laws E, Brown D, Peace C (2004) Coastal water quality in the Kihei and Lahaina districts of the island of Maui, Hawaiian Islands. Impacts from physical habitat and groundwater seepage: implications for water quality standards. International Journal of Environment and Pollution 22: 531-546.

22. Sustainable Resources Group International (2012) Wahikuli-Honokowai watershed management plan: Volume 1, Watershed characterization. Silver Spring, MD: West Maui Ridge 2 Reef Initiative and NOAA Coral Reef Conservation Program. 277 p.

23. West Maui Watershed Management Advisory Committee (1997) West Maui Watershed Owner's Manual. In: Hawaii Department of Health, U.S. Environmental Protection Agency, editors.

24. Soicher AJ, Peterson FL (1997) Terrestrial nutrient and sediment fluxes to the coastal waters of West Maui, Hawai'i. Pacific Science 51: 221-232.

25. Oleson KLL, Falinski KA, Lecky J, Rowe C, Kappel CV, et al. (2017) Upstream solutions to coral reef conservation: The payoffs of smart and cooperative decision-making. Journal of Environmental Management 191: 8-18.

26. Amato DW, Bishop JM, Glenn CR, Dulai H, Smith CM (2016) Impact of Submarine Groundwater Discharge on Marine Water Quality and Reef Biota of Maui. Plos One 11.

27. Williams ID, White DJ, Sparks RT, Lino KC, Zamzow JP, et al. (2016) Responses of herbivorous fishes and benthos to 6 years of protection at the Kahekili Herbivore Fisheries Management Area, Maui. PloS one 11: e0159100.

28. Friedlander A, Aeby G, Brown E, Clark A, Coles S, et al. (2008) The state of coral reef ecosystems of the main Hawaiian Islands. In: NOAA Technical Memorandum, editor. The state of coral reef ecosystems of the United States and Pacific freely associated states. pp. 222-269.

29. Vargas-Angel B, White D, Callender T, Maurin P (2017) Baseline assessments for coral reef community structure and demographics in west Maui. NOAA Fisheries Pacific Science Center 44 p.

30. Cheng CL (2014) Low-flow characteristics of streams in the Lahaina District, West Maui, Hawai‘i. In: U.S. Geological Survey, editor. Scientific Investigations Report 2014–5087. pp. 58.

31. Swarzenski P, Dulaiova H, Dailer M, Glenn C, Smith C, et al. (2013) A geochemical and geophysical assessment of coastal groundwater discharge at select sites in Maui and O'ahu, Hawai'i. Groundwater in the Coastal Zones of Asia-Pacific: Springer. pp. 27-46.

32. Hawaii Department of Health, Clean Water Branch (2014) Water Quality Standards. HAR 11-54. pp. 110.

33. Ige DV (2016) Governor David Ige's remarks at the IUCN World Conservation Congress.

34. Barnes MD, Goodell W, Whittier R, Falinski KA, Callender T, et al. (2019) Decision analysis to support wastewater management in coral reef priority area. PeerJ Preprints 7: e27470v27471.

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.27548v1 | CC BY 4.0 Open Access | rec: 22 Feb 2019, publ: 22 Feb 2019

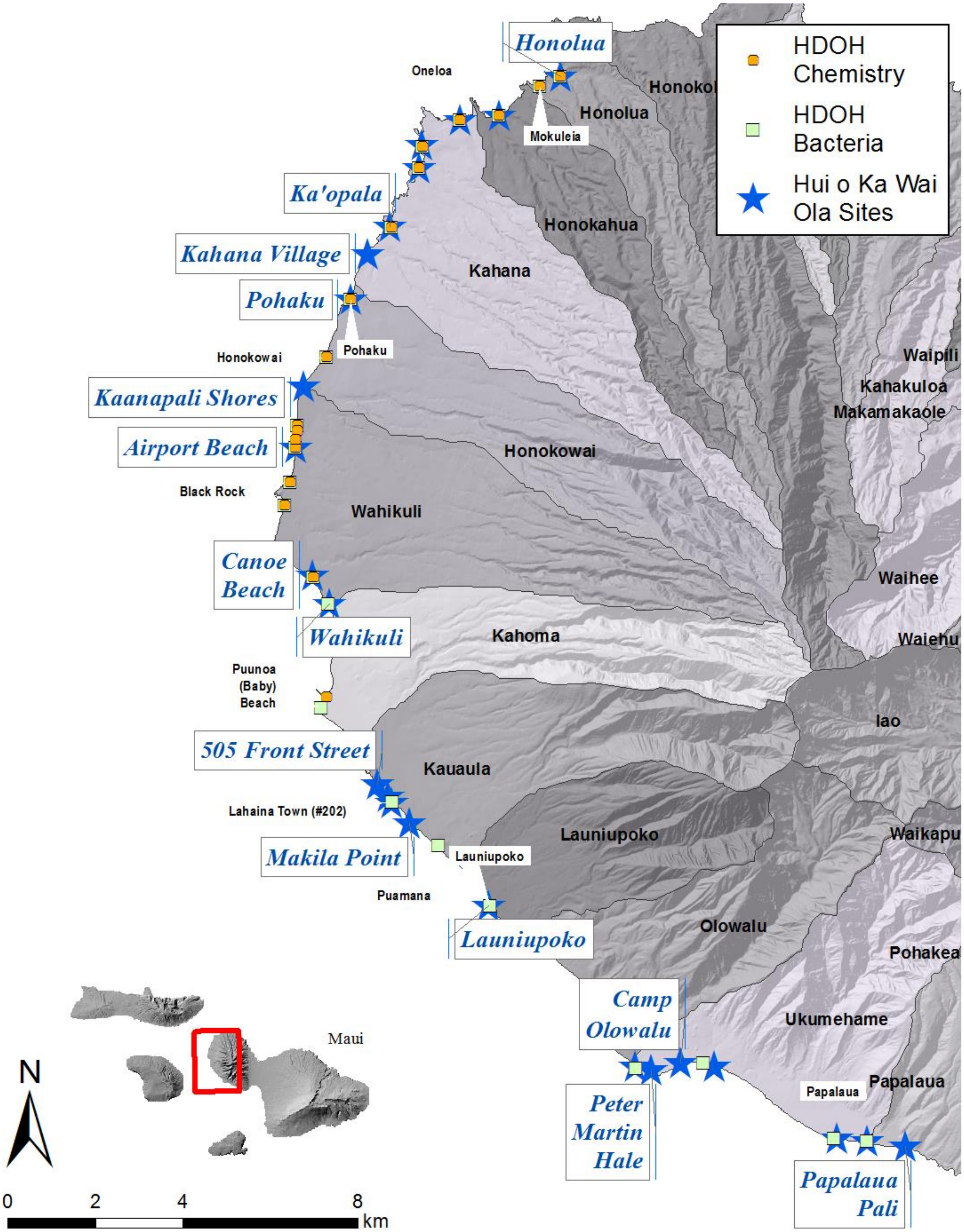


Figure 1

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.27548v1 | CC BY 4.0 Open Access | rec: 22 Feb 2019, publ: 22 Feb 2019

Figure 2

May 15-16, 2014 Water Quality Technical Working Group
DRAFT AGENDA

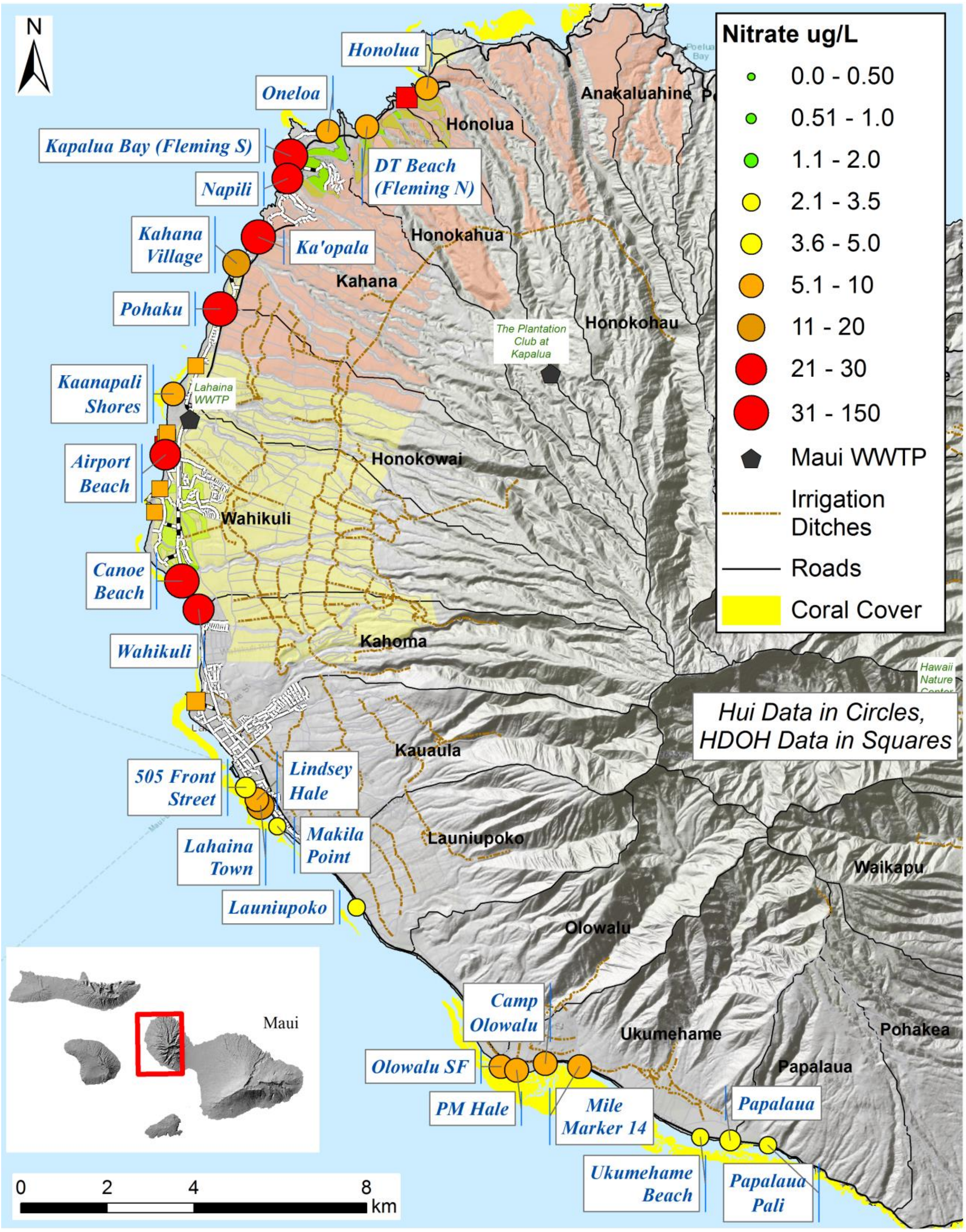
Purpose and need:
MNMRC and TNC seek to ensure that the Maui Nui Network sites, Coral Reef Recovery sites, and other MNMRC members have the tools and support they need to document and address the sources of sediment stress on coral reefs and people.

Meeting Objectives:

1. Learn about the issues each site is experiencing.
2. Explore the commonalities and differences among the sites.
3. Identify which sites have enough similarities to merit a common, standardized testing for sediment.
4. Identify what those methods would be, and what mix of professional and community involvement would be optimal for use by regulatory agencies.
5. Determine next steps for this group

Figure 3

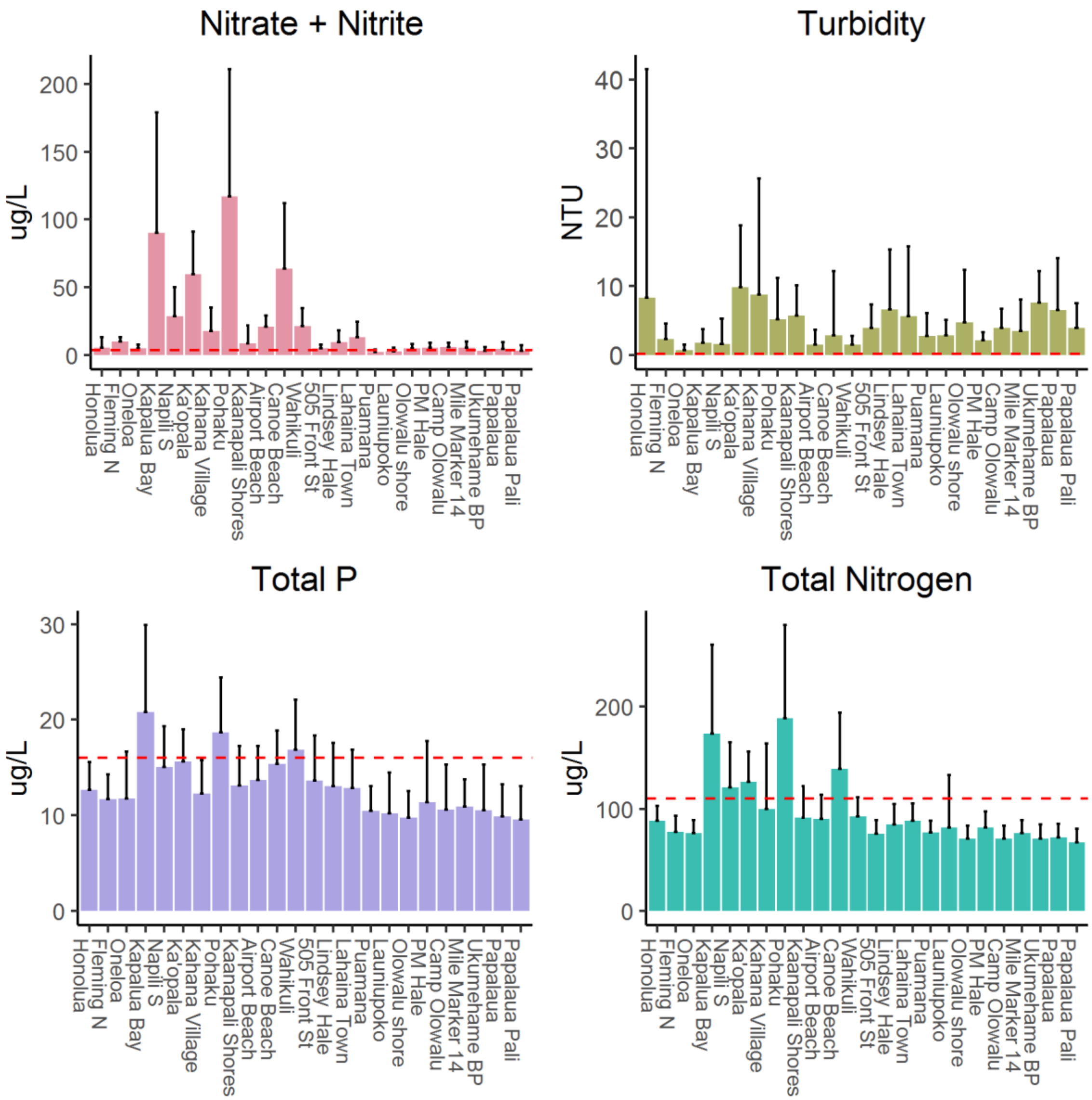
PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.27548v1 | CC BY 4.0 Open Access | rec: 22 Feb 2019, publ: 22 Feb 2019



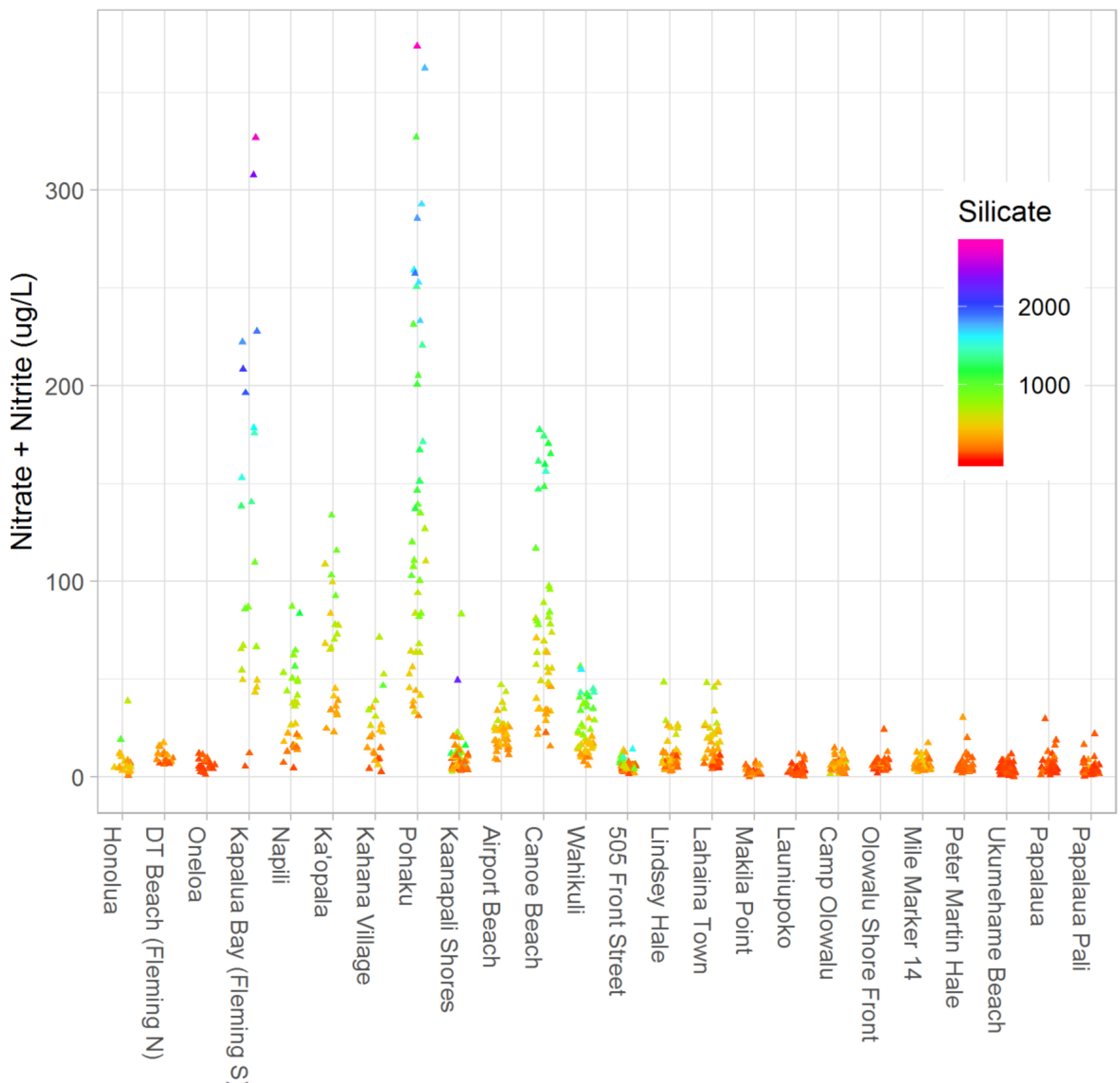
613

614 Figure 4

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.27548v1 | CC BY 4.0 Open Access | rec: 22 Feb 2019, publ: 22 Feb 2019

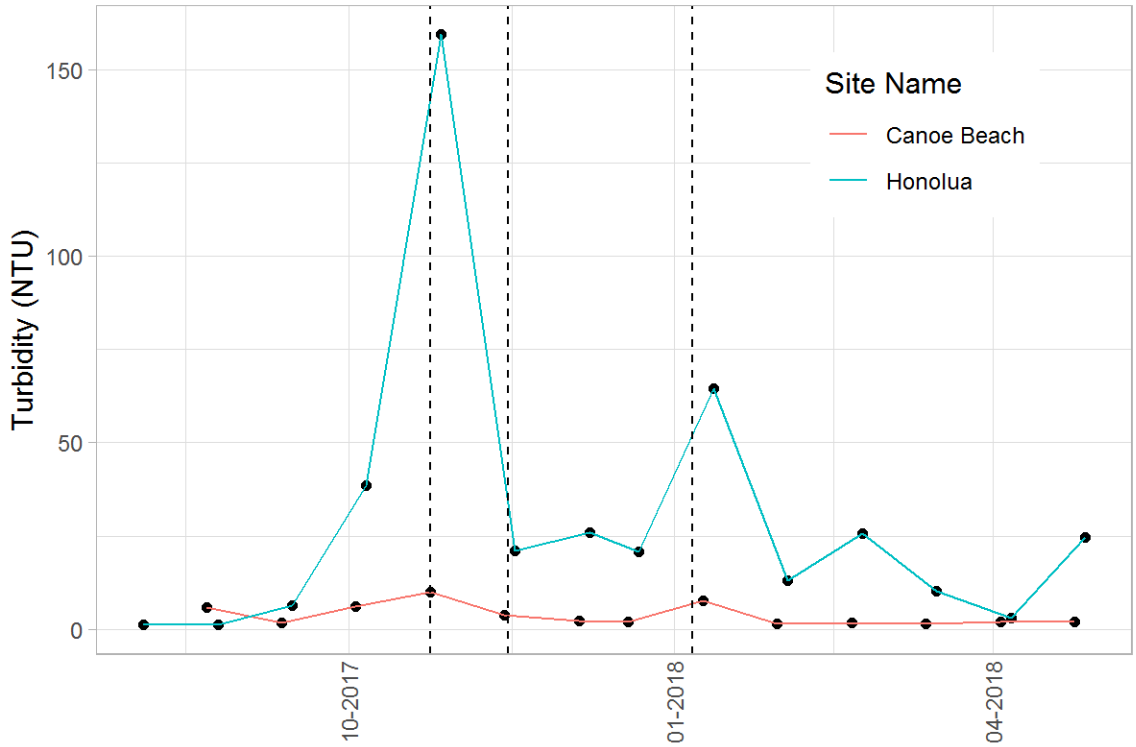


615
616 Figure 5



617
618 Figure 6

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.27548v1 | CC BY 4.0 Open Access | rec: 22 Feb 2019, publ: 22 Feb 2019



619
620 Figure 7
621
622 Table 1:

Parameter	Method number or description	Parameter	Method number or description
NH_4	EPA Method 350.1	TDN	UV-Digestion, EPA 353.2, Rev.2
NNN	EPA Methods 353.2	TDP	EPA Method 365.1
DRP	EPA 365.1	Silicate	EPA Method 366.0

623
624

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.27548v1 | CC BY 4.0 Open Access | rec: 22 Feb 2019, publ: 22 Feb 2019

625 Table 2:

Parameter	p-value
Total N	0.6352
Turbidity	0.1225
pH	0.8573
Nitrate	0.885
Total P	0.3695
Ammonia	0.1153
Salinity	0.8348
Temperature	0.00568
Dissolved Oxygen	<0.001

626

627 Table 3:

	TP	NH4	Nitrate	TN	Turb
Honolua	12.7	5.4	5.5	88.0	8.3
DT Beach (Fleming N)	11.7	2.2	9.9	77.4	2.3
Oneloa	11.7	2.0	5.1	76.2	0.7
Kapalua Bay (Fleming S)	20.8	4.3	90.0	173.4	1.8
Napili	15.0	5.7	28.5	120.8	1.6
Ka'opala	15.6	3.6	59.5	126.1	9.9
Kahana Village	12.3	3.7	17.9	99.4	8.8
Pohaku	18.7	4.1	117.0	188.9	5.2
Kaanapali Shores	13.1	4.4	8.6	91.0	5.8
Airport Beach	13.7	3.0	20.9	90.3	1.5
Canoe Beach	15.4	4.7	63.7	138.9	2.8
Wahikuli	16.9	2.3	21.3	92.2	1.5

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.27548v1 | CC BY 4.0 Open Access | rec: 22 Feb 2019, publ: 22 Feb 2019

505 Front Street	13.7	2.7	5.0	75.3	4.0
Lindsey Hale	13.1	4.3	9.4	84.5	6.6
Lahaina Town	12.9	4.9	13.1	88.2	5.7
Makila Point	10.5	2.7	2.2	76.9	2.8
Launiupoko	10.2	3.4	2.7	81.4	2.8
Olowalu Shore Front	9.8	2.8	5.2	70.6	4.8
Peter Martin Hale	11.4	4.5	5.7	81.6	2.1
Camp Olowalu	10.6	3.6	6.1	70.7	3.9
Mile Marker 14	10.9	2.5	5.2	76.4	3.5
Ukumehame Beach	10.5	2.2	3.1	70.8	7.6
Papalaua	9.9	2.6	4.5	71.9	6.5
Papalaua Pali	9.6	2.2	3.3	66.8	3.9
DOH State Coastal Water Quality Standards (HRS 11-54, Dry Standards)	16	2	3.5	110	0.2

628

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.27548v1 | CC BY 4.0 Open Access | rec: 22 Feb 2019, publ: 22 Feb 2019