Hanauma Bay Biological Carrying Capacity Survey
1st Annual Report: May 2018 - May 2019

For:
City and County of Honolulu
Parks and Recreation Department
Hanauma Bay Nature Preserve
Honolulu, Hawai‘i

Location:
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Prepared for:
City and County of Honolulu: Parks and Recreation
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Table of Contents

List of Tables

List of Figures

List of Figures cont.

EXECUTIVE SUMMARY

The biological carrying capacity study was designed to determine acceptable limits of disturbance to the marine resources of the Hanauma Bay Nature Preserve (HBNP). Year One of this study focuses on the carrying capacity as it relates to corals. Consecutive years will center on biological fish community factors as they relate to visitor population. Successive components of the overall carrying capacity will include the physical, facility, and social carrying capacities. Recommendations referenced in this Year One annual report are associated solely with the sustainability of coral communities. In addition, historical literature and data sets collected at Hanauma Bay have been compiled into a single file, and an annotated bibliography has been written summarizing all published and unpublished public documents to assist managers and future research.

To assess stress on corals from human pressure, two sets of 30-day experiments were performed throughout the months of June and October quantifying the number of people swimming and wading in each sector of the HBNP, trampling of experimental coral skeletons, and visual water quality. To assess the influence of seasonal variability on coral breakage, visibility, and sediment accumulation, the June 30-day study was repeated in October of 2018. Visual clarity was better on closed days as compared to days open to visitors. Water visibility was approximately 30% clearer on closed days than on days open to the public in both summer and winter months. However, this varied by sector. During the winter, all sectors with the exception of Witches Brew had clearer water. This was most strongly related to wind direction and speed and tidal fluctuations. Visitor use, as measured by snorkelers and waders, was also correlated with decreased visibility. The highest water visibility was measured offshore where little human disturbance was recorded.

The breakage rate per day in each sector correlated strongly with the percent total swimmers and waders in each sector. The sectors with the highest human use showed the highest coral breakage and the lowest coral cover with the exception of the Channel where large vertical colonies exist that are protected from trampling. Keyhole sector, the most frequently snorkeled sector, saw the highest rate of partial breakage and whole colony loss in trampling experiments, lowest coral cover and highest sediment accumulation of all inshore transects. Offshore and Witches Brew sectors had the lowest rate of coral breakage with the least amount of snorkeling traffic.

Colony coral cover within each transect was surveyed in December, 2018 and was compared between inshore sites. In addition, Coral Reef Assessment and Monitoring (CRAMP) long-term monitoring stations were resurveyed in October 2018. Coral cover at the 33’ (10 m) station in 2017 (16%) dropped by nearly half when compared to the previous 2012 survey (30%) due to the widespread bleaching event in 2014. The most recent 2018 survey (20%) shows some recovery. The 10’ (3 m) station at Witches Brew, in waters with little human impact, remains primarily unchanged from 2017 (14%) to 2018 (15%).

Coral breakage, coral coverage, and human use surveys show a clear pattern of increased breakage and lower coral cover in the sectors with highest human use. These findings justify the recommendations to lessen impact to corals. However, no recommendation is included to reduce the level of visitors based on prior research showing larger reductions would be needed than is realistic (see Introduction). There are also currently existing healthy corals in areas inaccessible to trampling but accessible to snorkelers. An integrated set of management strategies to address the specific problem of further coral damage by visitors includes: user dispersal among other activities, snorkeling pathways, educational signage on snorkeling etiquette, additional website information, guided snorkeling lessons from vendor, weather station installation, a climate change response strategy, and an increased user fee to support State Division of Aquatic Resources presence and research. These recommendations are specific to present coral reef sustainability. They do not address the sustainability of fishes or control other anthropogenic impacts.

INTRODUCTION

Concerns relating to recreational impacts on reefs in Hawaiʻi have increased. Interest in coral reefs as a recreational resource have also increased, yet inadequate data results in inadequate decisions. The first component is understanding the impact of visitors on the coral community. Even no-take regions can be of concern, due to resource damage and environmental degradation. Marine protected areas that have become areas of concern for management including the marine life conservation district of the Hanauma Bay Nature Preserve (HBNP).

Tourism is Oʻahu's number one industry with total tourist expenditures of $6.12 billion from January to September of 2018. Of the 4.5 million visitors to the island of Oʻahu last year, it is estimated that 80% participated in ocean recreational activities (DBEDT 2018, DBEDT 2013). A large percent of Hawaiʻi's reefs are located within close proximity to major urban centers and are easily accessible. Over 1,000 ocean recreation companies exist that use our marine resources. Use by residential and visitor populations have increased on both spatial and temporal scales, with documented damage to the reefs (Gulko 1998, Rodgers 2001). There are increasing concerns about sustainability and carrying capacities that have generated research within the industry (DBEDT 2000).

The HBNP is the most popular visitor snorkeling experience in the Hawaiian Islands. In 2017, 842,439 tourists and residents visited this Marine Life Conservation District (MLCD) established in 1967 (City and County Fiscal Records in Data Compilation Folder). Even no-take MLCDs can be of concern, due to resource damage and environmental degradation. These marine protected areas have become areas of concern for management including the HBNP. Funded studies on carrying capacities have indicted a growing concern for the resources in these areas (Brock 2000, Wanger 2001). All facets of the tourism industry have successfully marketed these regions. Marine protected areas have become an open invitation to the tourist industry. There has been much effort and expense applied to promoting the industry, but sparse resources have been allotted to investigating the impact of the industry on the resources even though these businesses are dependent on the health of the reefs.

Direct and indirect impacts result from increased tourist use of marine resources. Changes in diversity and abundance of fish populations can result from reef damage. Habitat destruction from trampling can affect fish nurseries, habitat for flora and fauna, recruitment sites and coral populations.

The amount of human use a reef community can withstand to assure sustainability of the resource is often defined as the carrying capacity of the region. It can serve as a benchmark to assess implemented management strategies. Due to the complexity of coastal marine ecosystems and spatial and temporal variation, it is extremely difficult to isolate specific impacts.

Trampling effects in Hawaiʻi were first quantified by Rodgers in 2001. Direct cause and effect, manipulative field experiments coupled with calibrated observations of human use showed a strong relationship between coral growth and mortality and human trampling. Results showed coral mortality can be low if the trampling impact is removed with a sufficient recovery period. However, most accessible near-shore environments throughout the state receive continuous chronic impacts with little or no time for undisturbed recovery. It was determined that even brief periods of intense trampling can significantly affect the growth of corals (Rodgers et al. 2003a).

The response of corals to breakage is size and species dependent. Smaller fragments have lower survivorship. Initial trampling produces the most damage. At the HBNP the existing corals are found in cracks and crevices, at depths greater than human height, on vertical substrate, and comprised of species that have strong skeletal strengths and morphologies not conducive to breakage. The level of breakage for a species is consistent with the habitat they inhabit. Species colonizing protected, low energy regions typically exhibit significantly higher breakage rates than species inhabiting high wave energy environments (Rodgers et al. 2003b). Due to chronic heavy human use, corals at Hanauma Bay are more consistent with areas of high wave energy consisting of lobate or encrusting corals.

HBNP corals are among the species with the highest skeletal strength and most resistant morphologies. However, mechanical stress tests show coral skeleton is a weak biological material. The average weight of a human or kick of a fin can cause compressive or tensile coral breakage (Rodgers 2001).

A transplantation study similar to the current one was conducted in 2001 along a gradient of human use, using live corals (Rodgers 2001). The highest impact site which received 200,000 visitors a year (Kahaluʻu Bay, Hawaiʻi) had no remaining corals after eight months. This is strong supporting evidence, along with the level of breakage found in this study at the HBNP, that a reduction in the level of visitors will not relate to an increase in coral cover at any level above 200,000 visitors annually. Coral growth was affected but mortality was low at levels up to 50,000 visitors a year. Sites with a long history of high use such as at the HBNP have low coral cover of only a few percent in high use areas. The statewide average is 22% (Rodgers et al. 2015).

In 1977, the Hanauma Bay Beach Park Site Development Plan estimated the recommended carrying capacity at 1,350 visitors a day, nearly half a million visitors annually. This was based on the Bureau of Outdoor Recreation and U.S. Army Corps of Engineers' standards for beach capacity (Vieth and Cox, 2001). However, by 1999, this recommendation had been exceeded by five times. Today, management efforts have greatly reduced the number of visitors and possibly visitor damage by enforcing an educational program, parking limitations and a weekly beach closure. These efforts have decreased the visitor counts to an average of 3,000 visitors a day (2,700/day in 2017). Despite these management efforts the direct and indirect impacts resulting from visitor use have not been quantified. There has yet to be a long-term study documenting the sustainability of marine resources within Hanauma Bay in relation to the average 3,000 daily visitors. This study was designed to determine the acceptable limits of human disturbance to the marine resources of Hanauma Bay Marine Life Conservation District by performing an investigation of physical, social, environmental, and biological variables relating to the current usage of marine resources. This integrated, multi-year, comprehensive carrying capacity study will identify gaps and provide data and recommendations to managers to move towards sustainability of the resources at the HBNP.

Projected Scope of Work Details from Project Work plan

Quarter	Task/Activity	Anticipated Results /Deliverables

1^{st}:
May – July
	Task 1: Find sources and reference of historical data.
	• Compile annotated bibliography of all available historical published and unpublished literature on Hanauma Bay.
	Task 2: Summer Human Counts
	• Monitor spatial and activity patterns of human use within Hanauma Bay.
	• Identify high vs. low use areas of snorkeling on reefs.
	Task 3: Summer Direct Human Impact Monitoring
	• Perform Coral Skeleton Experiment
	• Perform Sediment Experiment
	    o Sediment Traps
	    o Secchi Disk Measurements
	• Perform Visual Adult Coral Surveys
		Raw data from first set of experiments.

2^{nd}: Aug. – Oct.	**Task 1:** Find sources and reference of historical data. **Task 2:** Human Counts • Analyze data collected 1^{st} Quarter. • Winter Human Counts o Monitor spatial and activity patterns of human use within Hanauma Bay. **Task 3:** Direct Human Impact Monitoring • Analyze coral skeleton, suspended sediment and adult coral cover data collected 1^{st} Quarter. • Winter Direct Human Impact Monitoring **Task 4:** Perform yearly monitoring of CRAMP sites.	Results of 1^{st} quarter experiments.
3^{rd}: Nov. – Jan.	**Task 1:** Find sources and reference of historical data. **Task 2:** Human Counts • Analyze data collected 2^{rd} Quarter and compare to 1^{st} Quarter. **Task 3:** Direct Human Impact Monitoring • Analyze coral skeleton, suspended sediment and adult coral cover data collected 2^{rd} Quarter and compare to 1^{st} Quarter.	Results of 2^{nd} quarter experiments.
4^{th}: Feb. - May	**Task 1:** Find sources and reference of historical data. **Task 2:** Human Counts • Analyze data collected 2^{rd} Quarter and compare to 1^{st} Quarter. **Task 3:** Direct Human Impact Monitoring • Analyze coral skeleton, suspended sediment and adult coral cover data collected 2^{rd} Quarter and compare to 1^{st} Quarter. **Task 4:** Analysis yearly monitoring of CRAMP sites. **Task 5:** Analysis temperature data from inner reef flat.	Annotated Bibliography Final Report

Detailed Descriptions and Outcomes of Research Activities:
Quarter 4-Task 1: Find sources and references of historical data.
During the first year of the 2018/2019 biological carrying capacity study, 45 published and unpublished sources of literature were obtained from several sources including Sea Grant, Library and web searches, private records, and City & County lifeguard records. An annotated bibliography (Appendix A) summarizing all published and unpublished literature pertaining to Hanauma Bay has been compiled as a working annotated bibliography in which additional literature will continue to be added as it is located or published. This includes a timeline of management and research (Appendix A), as well as a database of historical statistics of visitor counts, fish biomass, and benthic coverage. All summarized references in one location will allow managers, educators, and researchers to easily access and determine the temporal and spatial nature of all prior projects to identify gaps in research and make sound management decisions based on scientific data.

Summary of historical studies performed within Hanauma Bay related to concurrent levels of human use.
The majority of biological historical studies performed within Hanauma Bay focus on fish abundance and biomass and how these parameters may relate to the benthic and coral environment. Other studies narrowed their efforts to provide detailed assessments on larval fish populations (Whittle, 2003), coral bleaching events (Neilson, 2014; Rodgers et al., 2017) and coral disease (Walton, 2013).

Historical Fish Biomass
The first literature accounting for fish biomass on the inner reef flat was recorded by Stender and Russel (1991) only a few years after the peak attendance at HBNP reached 3.6 million visitors per year (timeline received from Sea Grant) and almost 10 years prior to the fish feeding ban (Stender & Russel, 1991). In their surveys, they observed 139 fishes, representing 28 species from 10 families with an average biomass of 43 g/m^2. At this time, the six dominant spp. by abundance were the Convict Tang (*Acanthurus triostegus*), Saddle Wrasse (*Thalassoma duperrey*), Yellowfin Surgeonfish (*Acanthurus xanthopterus*), Grey Chub (*Kyphosus bigibbus* or *Kyphosus sandwicensis*), Blackspot Sergeant (*Abudefduf sordidus*), and Manybar Goatfish (*Parupeneus multifasciatus*) (left side of Fig. 1). The 5 dominant species by abundance accounted for 68% of the standing crop. The five dominant fish species in biomass were the Yellowfin Surgeonfish, Grey Chub, Sharpnose Mullet (*Chaenomugil leuciscus or Neomyxus leuciscus*), Blackspot Sergeant, and Striped Mullet (*Mugil cephalus*)(right side of Fig. 1).

In 1999 the first carrying capacity study of Hanauma Bay was conducted. At this time, the volume of visitors had decreased from 3.6 to 1.1 million per year, the Bay had just begun a Tuesday closure to the public, and fish feeding was banned as of July 15, 1999. Brock and Kam (2000) found the most abundant reef flat fish species to be the sergeant major (*Abedefduf abdominalis*), grey chub (*Kyphosus bigibbus*), convict tang (*Acanthurus triostegus*), ringtail surgeonfish (*Acanthurus blochii*), blackspot sergeant (*Abudefduf sordidus*), brown surgeonfish (*Acanthurus nigrofuscus*), saddle back wrasse

(*Thalassoma duperrey*), and bluelined surgeonfish (*Lutjanus kasmiral*) (Brock & Kam, 2000). Fish abundance and biomass were surveyed along 25 m by 5 m belt transects. For each inner reef flat transect, Brock and Kam (2000) found a mean of 19 fish species with a mean number abundance of 153 individuals. They performed the carrying capacity study during the year that fish feeding was banned and surveyed the standing crop of fishes on both days when the Bay was open to the public and days when it was closed to the public (starting in 1998). They found the standing crop of fishes to be significantly greater ($p<0.0002$) on Wednesdays (mean = 655 g/m^2) than the preceding closed Tuesdays (mean biomass = 382 g/m^2)(Brock & Kam, 2000). They attributed these changes in fish biomass to fish behavior acclimating fishes to humans during the feeding of the past 30 years. The most significant contributors to biomass at this time were the grey chub, ringtail surgeonfish, convict tang, eyestripe surgeofish (*Acanthurus dussumieri*), orangespine surgeofish (*Naso lituratus*), blueline snapper (*Lutjanus kasmira*), sergeant major (*Abudefduf abdominalis*), stareye parrotfish (*Calotomus carolinus*), redlip parrotfish (*Scarus rubroviolaceus*), spectacle parrotfish (*Scarus perspicillatus*) and blue trevally (*Caranx melampygus*)(Brock and Kam 2000).

Figure 1. The six most common in abundance and five most contributing to biomass fish species found on the inner reef flat surveys of Hanauma Bay in 1991 (Stender and Russel, 1991).

Of the six most abundant inner reef flat fish species observed by Stender and Russel in 1991, the convict tang, grey chub, black spot sergeant and saddle wrasse remained some of the most abundant fish species in Brock and Kam's surveys performed in 2000. Brock and Kam did not find the yellowfin surgeonfish or manybar goatfish in abundance, like Stender and Russel, but instead observed a higher abundance of ringtail, brown, and bluelined surgeonfishes (2000). Although the grey chub contributed greatly to biomass in both the 1991 and 2000 surveys, all other species contributing to biomass in these studies were dissimilar. Stender and Russel (1991) found two species of mullet (sharpnose and striped) to greatly influence the biomass of the reef flat environment, while Brock and Kam found species of surgeonfish, parrotfish and trevally to be most influential in biomass totals. A later metadata analysis of 25 fish survey data sets performed on the outer and inner reef of Hanauma Bay found that upon establishment as an MPA (1967), goatfishes and parrotfishes dominated fish abundance (Friedlander et al. 2018). Chubs became more abundant in the late 1970s when visitor counts and fish feeding was highest. After fish feeding was banned, they began seeing more goatfish and parrotfish, like observed in the 1960's. It was noted that following the fish feeding ban, two invasive fish species increased in abundance within Hanauma Bay: the blue spotted grouper (*Cephalophus argus*) and the blue lined snapper (*Lutjanus kasmira*) (Friedlander et al. 2018). Species such as jacks, flagtail, and surgeon fishes were found consistently throughout the years (Friedlander et al. 2018). When biomass of resource fish was analyzed from the year Hanauma Bay became an MLCD in 1967 until the present, there was a significant linear increase (green line on Fig. 2). A piecewise trend line analyzing how the direction of resource fish changed over time shows a large increase for the first 15 years after establishing Hanauma Bay as a no-take area, with a change in slope to a slight decrease after 1982 (grey line on Fig. 2) (Friedlander et al. 2018). The underlying cause of the change in slope from a steady increase in resource fishes to a slowly decreasing density of resource fishes is unknown, but the change in slope occurs simultaneously with the increase of the visitor population to 3 million.

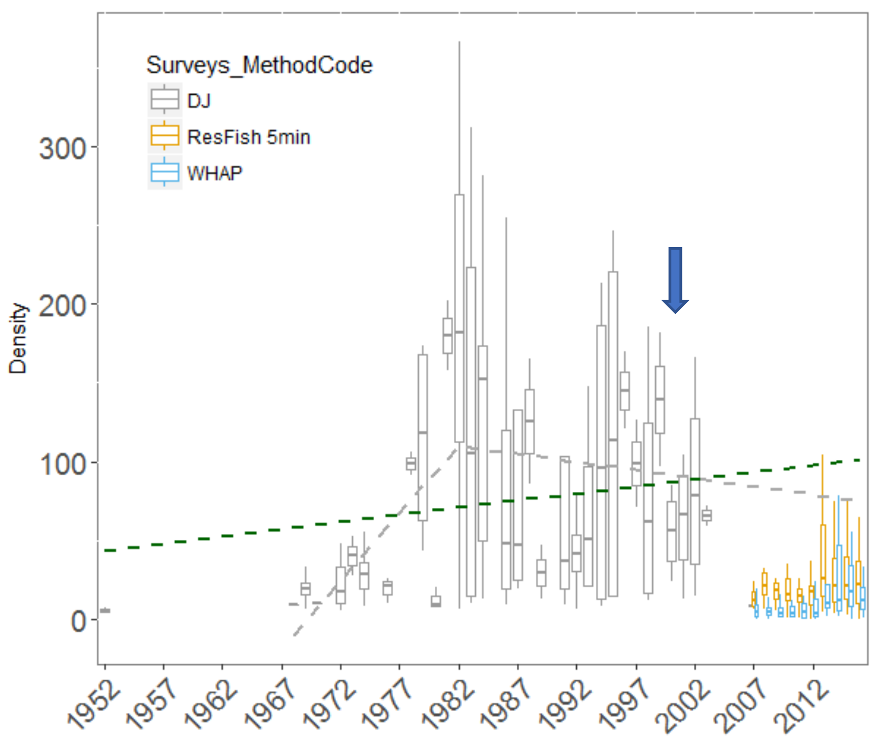


Figure 2. Resource fish density from a metadata analysis performed by Friedlander et al. (2018). Survey methods changed at the year 2007 (different color bars). A linear trend line shows a significant increase in resource fishes over time (green dotted line). A piecewise trend line shows an increase if resource fishes for 15 years after HBNP became an MLCD, with a slight decreasing slope after 1982 (grey dotted line). Fish feeding was banned in 1999 (blue arrow).

Historical Coral Cover

Prior to the first quantitative surveys, Maragos (unpublished) qualitatively recorded coral species and relative locations. In the early 1990's, Dr. Cindy Hunter established stations throughout the Bay and continued quantitative surveys for a decade (unpublished). In 1998, Grigg found coral cover on the inner reef flat to be less 1%, with coral diversity (H') less than 0.01. The reef pavement was dominated by 90% coralline algae cover and 10% bare limestone (Grigg, 1998). Several years prior to the establishment of the Coral Reef Assessment and Monitoring Program (CRAMP) in 1999, Jokiel recorded 11 coral species on the inshore reef flat and 22 species on the outer reef. The octocoral *Sarchothelia edmonsonii* and *Montipora verrili* were not found as in the earlier Maragos survey. A year later, Brock and Kam (2000) reported that corals were most often seen growing in depressions and vertical surfaces of the reefs. The overall coral coverage was very low, 0.8%, with the most common coral species at this time being lobe coral (*Porites lobata*), variegated coral (*Montipora verrucosa* now rice coral, *M. capitata*), ocellated coral (*Cyphastrea ocellina*), cauliflower coral *(Pocillopora meandrina*) and lace coral (*Pocillopora damicornis*). These species still dominate the coral cover on the reef flat of Hanauma Bay (this study). In 2007, a study observing spatial variability of coral growth in the Bay found coral cover to be highest in the SW region (21%), followed by NE region (18%) and center region (17%) (Jackson, 2007). The carrying capacity study to follow found the highest coral cover observed in the SW and Central regions with the lowest coral cover in the NE region, with coral coverage much less than observed by Jackson (2007).

The CRAMP long-term monitoring site at Hanauma Bay used one of the Hunter locations at 3 m depth. The total coral cover found (24%) was higher than the statewide average of 22%. The second long-term monitoring station located at 10 m depth had coral cover of 27% (Brown et al. 2004). Several years later Jayewardene et al. (2009) found even greater coral coverage on the inner reef (38 ± 6%) and similar coverage on the outer reef (25 ± 2%). The dominate species at this time was *Porites lobata* (19 ± 2 % shallow, 20 ± 2% deep). This study also documented the amount of fish predation on corals by placing fragments of corals at the monitoring sites and documenting their size over time, as well as, bite marks located on neighboring coral colonies. They found that fish bite frequency decreased exponentially with increased abundance of coral prey and suggested that corallivory at HBNP may limit the recovery or growth potential of coral populations (Jayewardene et al. 2009). In 2013, a study was performed documenting coral disease and cover within the deeper outer reef of HBNP and compared coral cover and disease prevalence to the adjacent area outside the reserve. Hanauma was found to have significantly higher coral cover (~32%) within the preserve than adjacent areas (~10%). Both within the reserve and outside the reserve were dominated by *P. lobata*, with some *Montipora patula, Montipora capitata,* and *Pocillopora meandrina* (Walton, 2013). HBNP showed significantly higher disease prevalence when compared to the adjacent control site with increases in *Porites lobata* growth anomaly and *Porites lobata* tissue loss. Hanauma was also found to have greater disease prevalence than both Pūpūkea and Waikīkī MLCD's (Walton, 2013). Walton proposed that Hanauma Bay contains larger and older coral colonies, and therefore, the accumulation of stress throughout the years may contribute to the higher observed disease prevalence.

Historical Environmental Studies

Other aspects of geological, physical, and chemical oceanography have been examined in Hanauma Bay throughout recent history. Geological aspects of oceanography have been addressed through studies of Hanauma Bay's coastal bench formation and weathering (Bryan & Stephens, 1993) and estimates of reef accretion through radiocarbon dating of reef substrate cores (Easton & Olson, 1976). Easton and Olson (1976) provide evidence through radiocarbon dating of reef cores, that vertical growth on the inner reef flat of Hanauma Bay has been "stunted" by the lowering of sea-level. The highest growth rates found on the inner reef flat during this study were of lateral or downward growth into channels or pockets in the reef. A follow up study used reef accretion data gathered from Easton and Olson's (1976) coral cores coupled with the physical properties of wave action to determine that coral communities at the shallow sites of Hanauma Bay are thought to be constrained by aerial exposure during low tide events (Grigg, 1998). Other studies have focused on mapping currents and tidal waves (Smith, Rocheleau, Merrifield, Jaramillo, & Pawlak, 2016; Whittle, 2003) within Hanauma to provide insight into patterns of coral mortality and bleaching (Rodgers et al., 2017). Rodgers et al. (2017) found the highest prevalence of coral bleaching in areas that were not directly exposed to a source of open ocean water. When circulation patterns cause parcels of water to remain on the shallow reef flat they accumulate heat quickly. In addition to water circulation, water quality can be influential to the health of a reef. Brock and Kam (2000) performed the first and only prior Biological Carrying Capacity study at Hanauma Bay, and stated that monitoring water quality was of extreme importance. They studied the water quality as it related to human use within the Bay, and found that excess water from the showers was running-off into the Bay. The shower water has since been diverted. Another study examined concentrations of fecal coliform, *E. coli* and enterococci found in the soils and sands of the lower beach park (Oshiro & Fujioka, 1995). Oshiro and Fujioka (1995) found that the major sources contributing to periodic high levels of bacteria in the waters of Hanauma Bay are contaminants of the beach sand, such as pigeon feces. The Department of Heath currently samples the water at the Bay on a weekly basis for these indicator bacteria, however, they do not sample the sand, which is where Oshiro and Fujioka (1995) found the greatest quantity of contaminants. In more recent years, the Bay was surveyed for oxybenzone pollution (Downs, 2018). This survey was performed once on November 17th, 2017 around 4 pm during an incoming tide. Concentrations of oxybenzone ranged from 30 ng/L to 27,880 ng/L. More investigation must be performed into this topic and repetitive sampling must be performed before conclusions can be drawn.

Detailed Descriptions and Outcomes of Research Activities:
Quarter 4-Task 2: Human Counts: Monitor spatial and temporal activity patterns of human use within the Hanauma Bay Nature Preserve (HBNP). Identify high vs. low use areas of snorkeling on reefs.

During the months of June and October, 2018, a total of 18 randomly selected days were chosen (including one of each weekend day and one holiday) to monitor spatial and temporal patterns and activity of human use within the HBNP. To avoid observer and spatial variability, visual counts were performed by the same observer from the same vantage point at approximately 8 am, 11 am, and 2 pm on June 1st, 4th, 6th, 7th, 8th, 10th, 16th, 17th, and 20th and October 5th, 8th, 10th, 11th, 12th, 14th, 20th, 21st, and 24th. In June, these counts were separated by sector (Backdoors, Keyhole, Channel, Witches Brew, and Offshore) and by human activity (swimming, wading or sunbathing on the beach) (for raw data from June and October see Appendix A). Observations in June revealed a dissimilarity of use within sectors, therefore, in October visual counts were separated into further defined areas (Backdoors East, Backdoors West, Keyhole East, Keyhole West, Channel Null, Channel East, Channel West, Witches Brew East, Witches Brew West, Offshore East, and Offshore West) (Fig. 3).

Counts in June were replicated in October, 2018, to compare peak summer and winter visitor counts and wave energy. October counts showed a reduction in visitor counts by 5.1%, but the ratio of visitors in each sector was approximately the same (Table 1). Both June (51.1%) and October (49.7%) visual counts found the majority of snorkeling and wading at the HBNP to occur within Keyhole sector (Figure 4). The next most popular sector for snorkeling and wading was Channel (39.1% in June, 41.2% in Oct.), followed by Backdoors (June: 5.41%, Oct: 3.35%), Witches Brew (June: 2.78%, Oct: 2.63%) and Offshore (June: 1.54%, Oct: 3.09%). The two greatest changes in distribution of swimmers and waders were seen in Backdoors, which decreased by 2.06%, and Offshore, which increased by 1.55%. This is likely due to the calmer ocean conditions prompting visitors to expand their snorkeling area.

Table 1. Summary of data collected in visual count surveys and coral trampling experiment.

		Backdoors	Keyhole	Channel	Witches Brew	Offshore
% of Swimmers and Waders within Sector	June	5.40%	51.1%	39.1%	2.80%	1.50%
	Oct.	3.40%	49.7%	41.2%	2.60%	3.10%
Coral Skeleton Total at Start of Experiment	June	14	14	13	14	5
	Oct.	14	14	14	14	14
Coral Skeleton Total at End of Experiment	June	10	7	10	14	5
	Oct.	12	7	12	14	14
Percent Whole Colony Loss	June	29%	50%	23%	0%	0%
	Oct.	14%	50%	14%	0%	0%
Average Percent Skeletal Loss per Day (Partial Breakage)	June	2.18%	2.33%	1.75%	0.557%	0.519%
	Oct.	1.42%	2.44%	1.32%	0.906%	0.630%

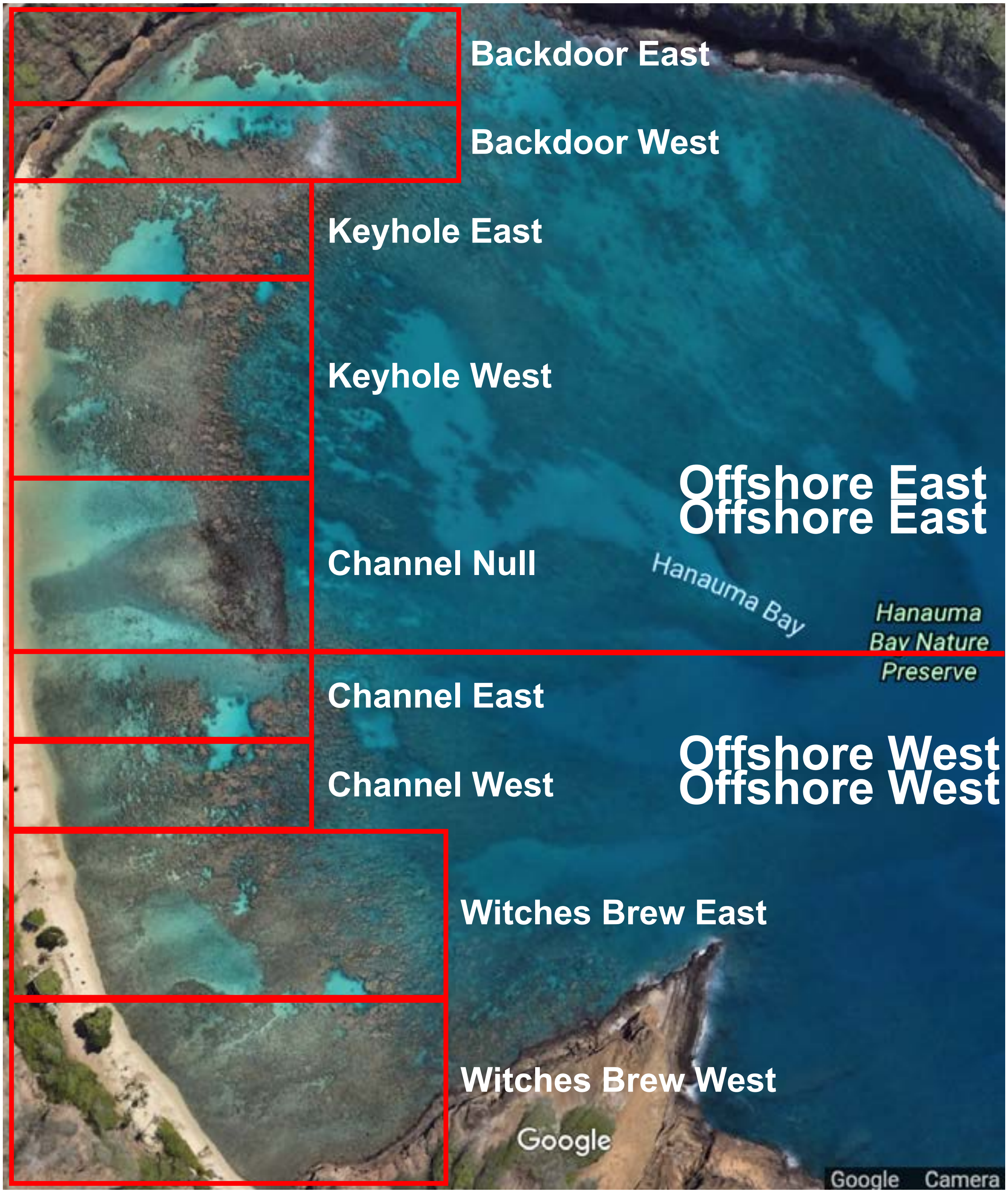


Figure 3. Eleven Sectors of Hanauma Bay used to separate visual human counts and activity: Backdoor East and West, Keyhole East and West, Channel Null, East and West, Witches Brew East and West, and Offshore East and West.

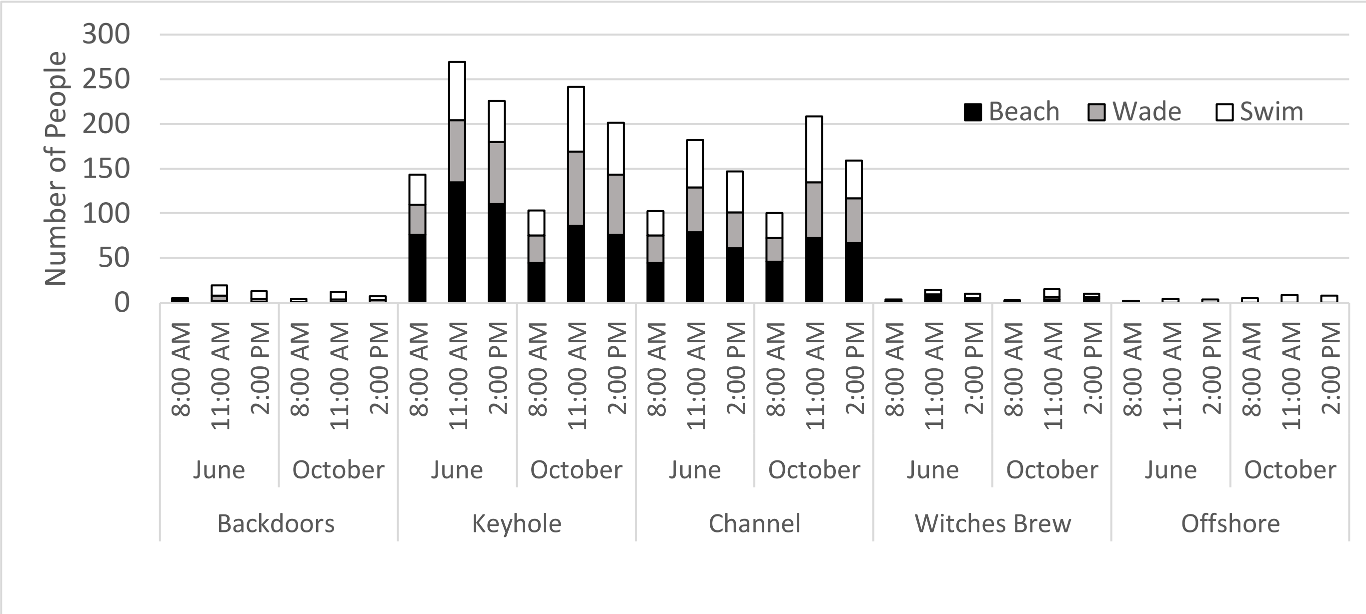


Figure 4. Comparison between visual human counts and human counts derived from photographs. Counts are averaged over a 9-day observation period (June 1st, 4th, 6th, 7th, 8th, 10th, 16th, 17th, 20th and 28th and October 5th, 8th, 10th, 11th, 12th, 14th, 20th, 21st, and 24th) and separated by time of day (8:00 am, 11:00 am, and 2:00 pm) and human activity (beach, wade, swim).

Detailed Descriptions and Outcomes of Research Activities:
Quarter 4-Task 3: Direct Human Impact Monitoring: Analyze Coral Skeletons, Analyze Suspended Sediment, Sediment Traps, Secchi Disk Measurements, Analyze Data from Visual Adult Coral Surveys, and Coral Recruitment Surveys.

Coral Skeleton Experiment: Direct human impact monitoring was conducted along two permanent transects within each inshore sector and two permanent transects offshore (Figs. 3 & 5). Each transect encompassed an area of 15 m in length by 5 m in width (75 m^2) running perpendicular to the shoreline.

On 29 May, 2018, coral skeletons were placed along each of the 10 transects for a 30-day trampling study and recovered 26 June, 2018. Each transect contained five Rice coral (*Montipora capitata*) and two Finger coral (*Porites compressa*) skeletons for a total of 60 colonies (with the exception of the Channel B transect which contained four *M. capitata* and two *P. compressa* and the offshore reference station transect that contained four *M. capitata* and one *P. compressa* (Figs. 3 and 4). Daily swims were conducted to record the presence/absence of the coral skeletons (for raw data on presence/absence of coral skeletons see Appendix B) and weekly top-down photographs were taken to record percent loss of skeleton (Fig. 7). The offshore transect in deeper water, controlled for coral skeletal breakage resulting from stressors other than direct human trampling.

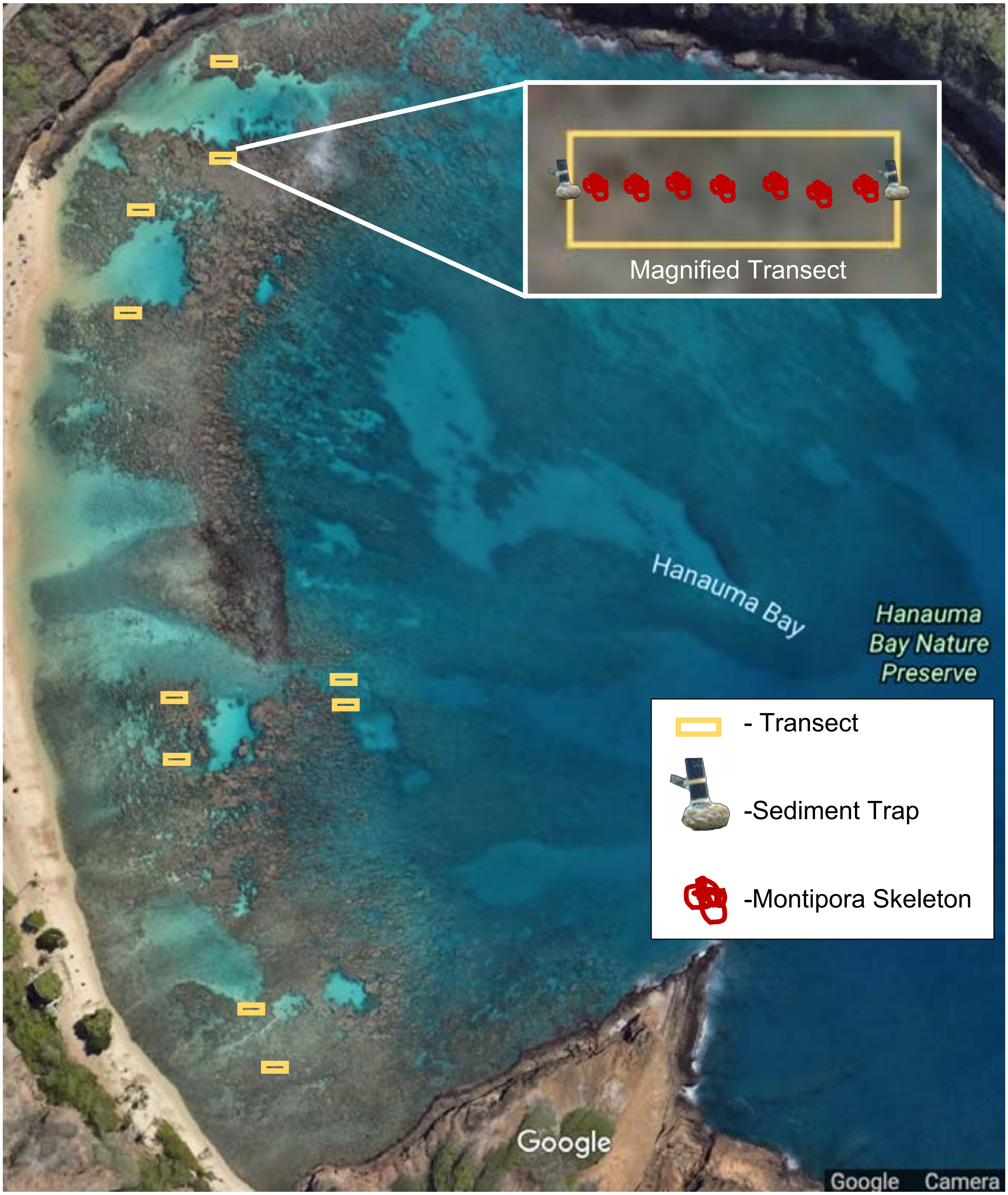


Figure 5. Experimental sectors of Hanauma Bay. Each sector contains two 15 m x 5 m transects. In June, transects contained five *Montipora capitata* and two *Porites compressa* coral skeleton colonies, and two sediment traps. In addition to coral trampling and sediment traps, visual coral colony surveys and water clarity surveys were performed within the transect boundaries.

In October, coral skeletons were placed along the identical transects as in June for a replicate 30-day trampling study beginning on 2 October, 2018 and recovered 30 October, 2018. Each transect contained 7 Rice coral (*M. capitata*) skeletons placed along each of 10 transects, for a 70 total of coral colonies (Fig. 6). Swims were conducted to record the presence/absence of coral skeletons approximately every-other day, and weekly top-down photographs were taken to record percent loss of skeletons (Fig. 7, for raw data see Appendix B). Two changes were made from the June to the October study; in October, (1) only Rice coral (*M. capitata*) skeletons were used for the trampling study and (2) a second transect was added to the offshore sector. Rice coral is the species most sensitive to trampling, has the lowest tensile and compressive strength, and exhibits the highest levels of breakage (Rodgers, 2003). A second transect was added offshore to increase the sample size of skeletons that were too deep to be trampled by humans.

Partial breakage of coral skeletons was measured using top-down photographs (Table 1). Analysis of photographs produced a value of percent loss of skeleton, which was then divided by the number of days it was present on the reef flat (hereafter referred to as 'percent loss') (for raw data see Appendix B). Data on percent loss could not be normalized, and therefore, non-parametric statistics were used to analyze patterns of loss between transects and sectors.

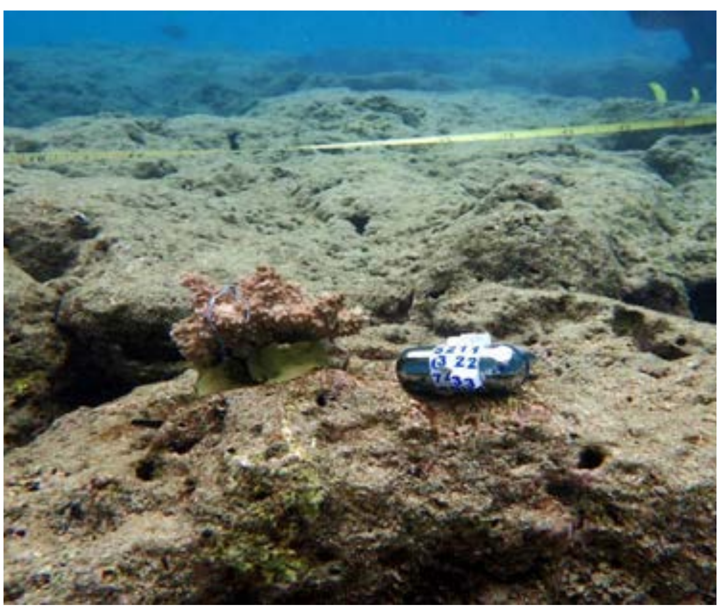


Figure 6. Coral skeletons were secured to reef with epoxy and cable ties for 30 days to assess percent loss of skeleton due to human trampling. Example photo is of a Rice coral, *Montipora capitata,* skeleton placed in the Backdoor West transect. Each transect contained five Rice, *Montipora capitata,* and two Finger, *Porites compressa* skeletons during the June coral trampling study. Lock placed in image for identification and scale.

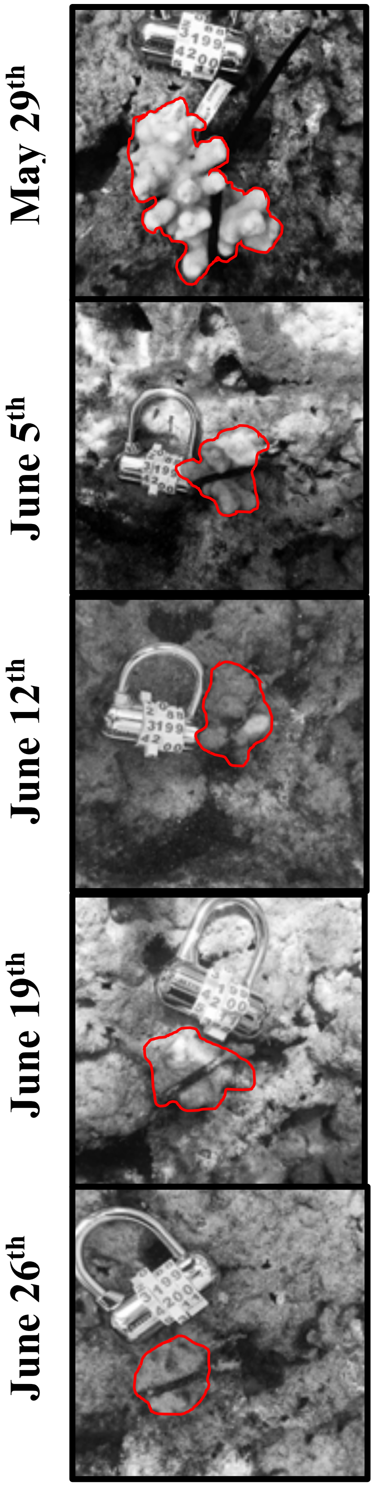


Figure 7. Coral skeletons were placed in the field for 30 days to assess percent loss of skeleton (outlined in red) due to human trampling. Example photo of a *Porites compressa* colony placed in Keyhole East transect. June, each transect contained five *Montipora capitata* and two *Porites compressa* coral skeletons. Top-down photographs were taken weekly to calculate percent loss. These values were regressed with weekly human usage counts for each sector. Temporary lock placement identifies colony and provides scale.

Overall results show as percent total swimmers and waders in each sector increases, the average percent breakage rate per day increases (Kendall's tau_b = 0.571, $p<0.048$) and the average total coral cover in each sector decreases (nonsignificant). The sectors with the highest human use showed the highest coral breakage and the lowest coral cover. The exception was in the Channel where the 2nd highest use was reported, although it had the highest coral cover of the inshore stations. This is conducive with the large vertical colonies that can be found in this area. Vertical corals growing on natural wall formations and crevices are not subject to impact from human use due to their inaccessibility to trampling. Channel has the highest rugosity of all inshore sectors, thus more available vertical substrate for undisturbed growth of corals (Table 2). Rugosity was measured by laying a chain over the substrate of each transect with an additional 10 meters shoreward of the transect, then dividing the chain length by the total of 25 meters of transect length. The data for June and October were pooled and averaged to determine a mean for the daily breakage rate (%) and the percent of the total for each sector of swimmers and waders (Table 2). The breakage rates were adjusted by subtracting the average offshore breakage from the average of each inshore station. This was conducted to derive a more accurate rate that excludes any natural breakage that may have occurred. The offshore station was beyond depths that can be easily accessed by swimmers or waders nearly eliminating the possibility of breakage from human use. Total coral cover means were derived from transect surveys conducted at each station during the coral breakage field experiments. The results from the offshore means are from the Coral Reef Assessment and Monitoring Program (CRAMP) long-term monitoring site at the 10 m station last conducted in 2018. (Table 2).

Table 2. Coral breakage, coral cover,rugosity, and human use (swimmers and waders) at the HBNP.

Station	**Breakage/Day (%)**	**Total Coral Cover (%)**	**Rugosity**	**Human Use (%)**
Keyhole	1.8	0.500	1.35	50.4
Backdoors	1.2	0.700	1.45	8.80
Channel	1.0	11.6	1.65	40.2
Witches Brew	0.20	4.70	1.25	2.70
Offshore (Control)	0.60	20.1	2.55	2.30

June:

A non-parametric independent-samples Kruskal-Wallis test found a significant difference in percent loss for each sector (15.200, n = 60, degrees of freedom = 4, p<0.004) with transects pooled. Backdoors had the largest range (0% - 4.8%) of percent skeletal loss (Fig. 8). This sector does not receive many snorkelers (5.41%), and fish bites were documented on some of the coral skeletons, therefore, it is hypothesized that the skeletons that suffered high percent loss did so because of fish bites and wave action. This will be positively determined in 2019 using exclusion cages that exclude fishes from corals and closer approximations of wave energy. Despite having some skeletons experience high percent loss, the mean percent loss of skeleton was less in Backdoors (2.18%) than in Keyhole (2.33%) sector. Keyhole sector is known to have the highest traffic of snorkeling and wading (51.1%) of all sectors and was observed to have the highest mean (2.33%) and median (2.8%) skeletal loss of all sectors. Pairwise comparisons of the independent-samples Kruskal-Wallis test found the percent loss of coral skeleton per day in Keyhole sector to be statistically higher than the loss experienced in Witches Brew sector (20.393, p < 0.02). Channel sector was found to have less skeletal loss per day on average (1.75%) when compared to Backdoors and Keyhole sectors, despite Channel sector being the second highest snorkeled (39.1%). Witches Brew sector had the lowest mean percent loss of skeleton per day (0.56%) of all inshore sectors with only 2.78% of all snorkelers and waders visiting this area during the month of June, 2018. Despite the low overall loss of skeleton, the range of loss in Witches Brew sector is between 0% and 2%.

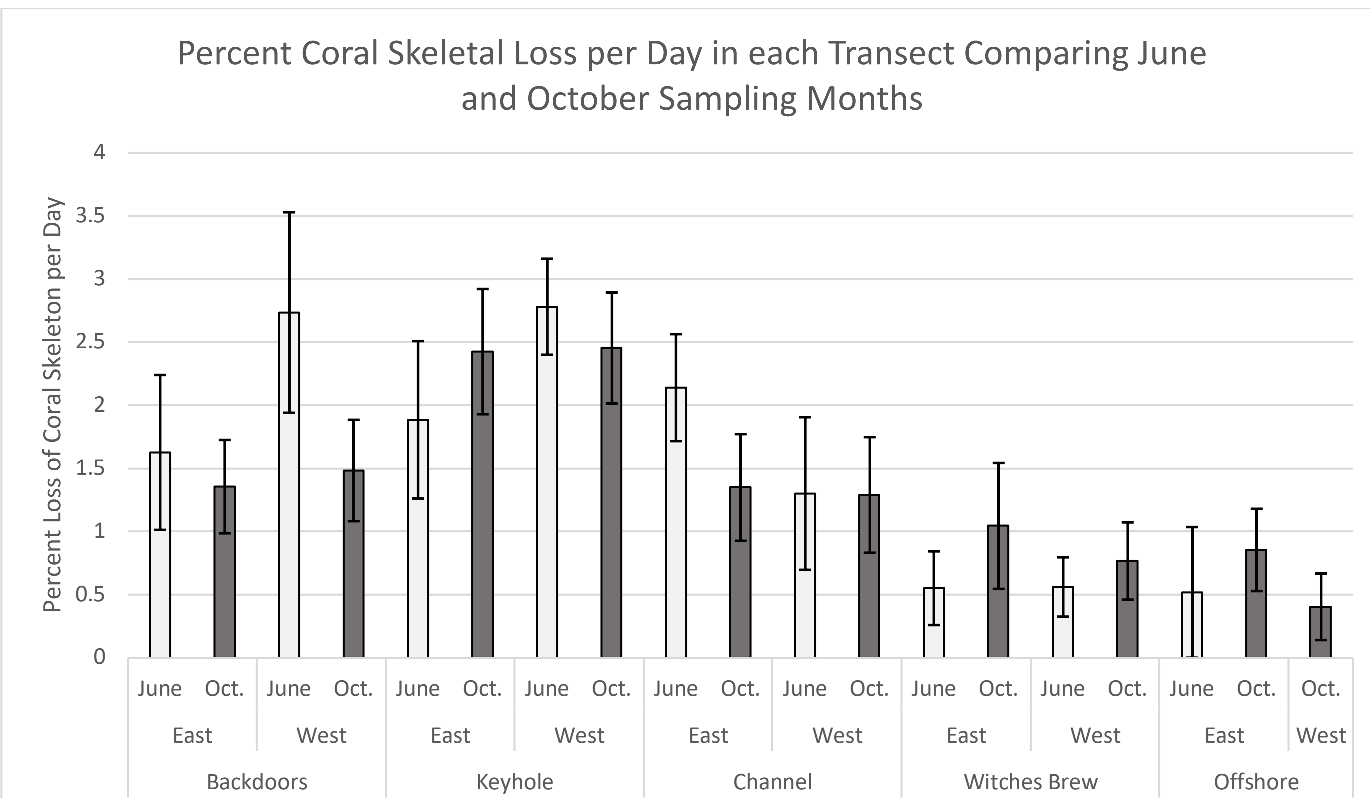


Figure 8. Comparison of percent skeletal loss per day in each transect of the Hanauma Bay Nature Preserve. Error bars represent $\pm$1 standard error.

Witches Brew does not receive many visitors, therefore, this amount of breakage might be the result of fish grazing. Offshore corals were left intact (mean loss per day of 0.52%), with the exception of one coral out of the five, which experienced 2.5% skeletal loss per day. Because snorkelers are very infrequent (1.54%) and this site is too deep (~9 ft., ~3 m) for visitors to trample, it is hypothesized that this loss was due to fish grazing, wave action, or human error. It is unlikely that only one skeleton would be affected if this loss was due to fish grazing or wave action, therefore, the most likely explanation for this large percent loss observed in only one skeleton is human installation error. If the coral skeleton was not securely tightened to the reef substrate, it would allow for seemingly negligible wave action to destabilize it, causing the breakage observed in only one coral. Contact with skeletons was avoided during the duration of the study, thus, the stability of the coral was not noticed.

When mean percent loss per day per sector was regressed against the number of visitors during the month of June, a weak positive correlation was produced (Pearson Correlation coefficient = 0.306, $r^2 = 0.094$, $p < 0.01$) (Fig. 9). This relationship shows as the proportion of visitors increased, the percent loss of coral skeleton also increased ($Y = 1.117 + 0.022(x)$, $p < 0.02$). A regression analysis was performed due to the normal distribution of residuals.

There was no significant difference in percent loss of skeleton between the two different coral skeleton species used in this study, Rice coral (*Montipora capitata)* and Finger coral (*Porites compressa)* (Independent -Samples Mann-Whitney U Test, 0.493, n = 60, degrees of freedom = 1, p = 0.480). Rice and finger corals were subject to the same levels of breakage through the June study despite their differing skeletal strengths. This is likely indicative of high enough tensile and compressive force to cause breakage. There was also no significant difference in percent loss of skeleton between locations of the skeleton placement along the transect (Independent-Samples Kruskal-Wallis Test, 2.624, n = 60, degrees of freedom = 6, p = 0.854). Breakage of coral skeletons was no different depending on where it was placed within the transect. The first skeleton along a transect received a similar amount of breakage as the second and third, etc. This may indicate enough use in all areas to cause breakage.

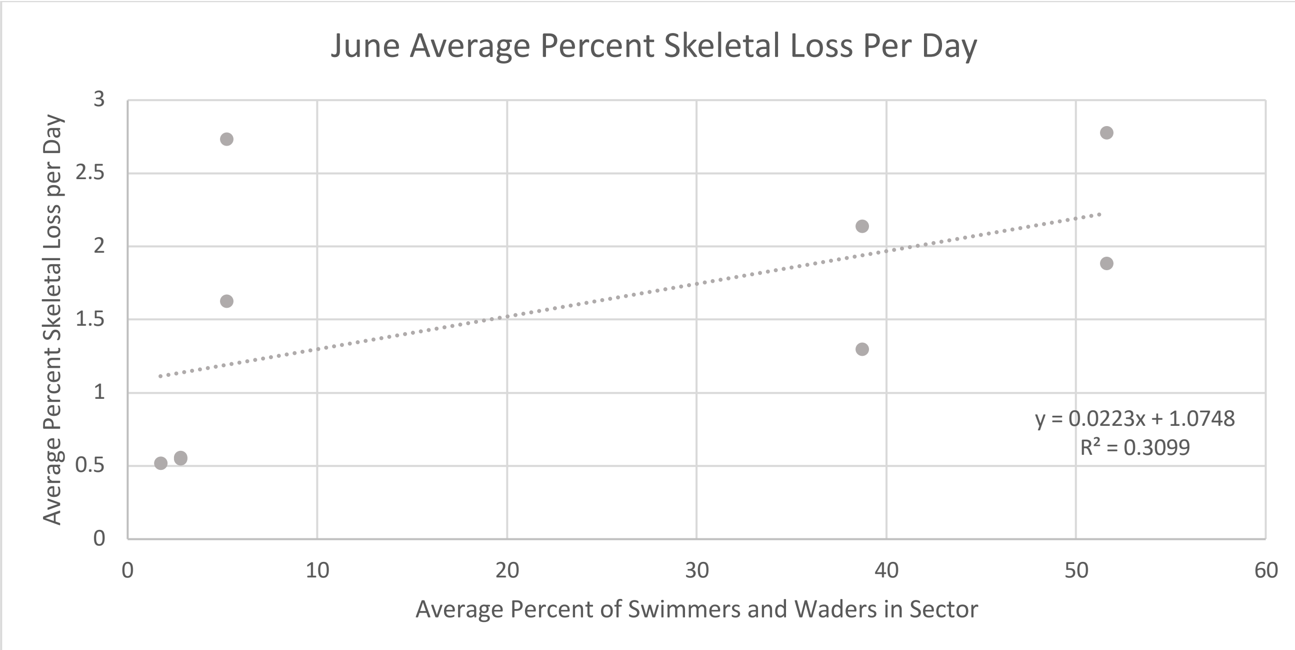


Figure 9. Average percent skeletal loss per day regressed against the average percent of swimmers and waders of each transect within the HBNP over the June coral trampling study.

October:

A non-parametric independent-samples Kruskal-Wallis test found a significant difference in percent loss for each sector (18.17, n = 70, degrees of freedom = 4, p<0.002) with transects pooled. Keyhole sector had the highest traffic of snorkeling and wading (49.7%) of all sectors and was observed to have the highest mean (2.44%) and median (3.14%) skeletal loss. Pairwise comparisons of the independent-samples Kruskal-Wallis test found the percent loss of coral skeleton per day in Keyhole sector to be statistically higher than the loss experienced in Witches Brew (24.964, p < 0.02) and Offshore sector (29.714, p < 0.002). Channel sector was found to have less skeletal loss per day on average (1.32%) when compared to Backdoors (1.42%) and Keyhole (2.44%) sectors, despite Channel sector being the second highest trafficked (41.2%) (Fig. 8). Witches Brew had the lowest mean percent loss of skeleton per day (0.91%) of all inshore sectors with only 2.63% of all snorkelers and waders visiting this area during the month of October, 2018. All corals in offshore transects were left intact (mean loss per day of 0.63%). Because snorkelers are infrequent (3.09%) and these sites are too deep (~9 ft., ~3 m) for visitors to trample, it is hypothesized that this loss was due to fish grazing or wave energy. To avoid human error in the 30-day October study, two transects (14 total coral skeletons) were placed in the offshore environment, more than doubling our offshore sample size. A second offshore transect and more replicates of coral skeletons within transects provided a clearer picture of the factors determining skeletal loss in the offshore sector. In addition to increasing the sample size in the offshore sector, the coral skeletons were attached with the use of SCUBA to ensure proper fastening to the substrate (skeletons in June study were attached while free diving).

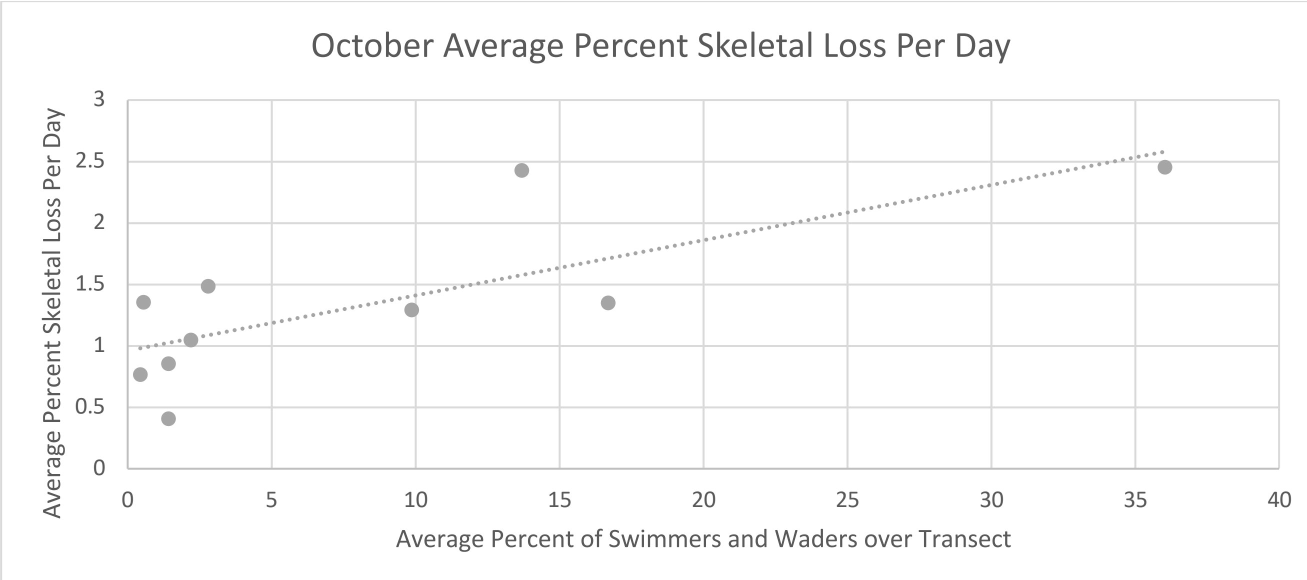


Figure 10. Average percent skeletal loss per day regressed against the average percent of swimmers and waders of each transect within the HBNP over the October coral trampling study.

To better understand the relationship between human counts and coral breakage within each transect, during the month of October, counts were recorded over each transect instead of each sector (counts were taken grouping both transects within each sector for the June study). When mean percent loss of coral skeleton per day per transect was regressed against the number of visitors during the month of October a positive correlation was determined (Pearson Correlation coefficient = 0.411, $r^2 = 0.169$, $p < 0.001$). This positive relationship shows that as the proportion of visitors increased, the percent loss of coral skeleton also increased ($Y = 0.961 + 0.045(x)$, $p < 0.001$) (Fig. 10) similar to the results from June. A regression analysis was conducted due to a normal distribution of residuals.

Comparison of June and October:
In both June and October, coral skeletons within Keyhole sector received the highest rate of partial breakage per day and rate of whole colony loss (Table 1). Keyhole sector also contained the highest proportion of swimmers and waders of any other sector. When mean loss of coral skeleton per day per sector was regressed against the number of visitors during the months of June and October, regression analyses showed a positive relationship. As the proportion of visitors in each sector increased, the percent loss of coral skeleton for that sector increased in response (Figs. 9, 10, 11, & 12). The findings of the June trampling study were supported further in the results from October. Although overall patterns of partial mortality and human use in each sector were similar, Channel sector saw a decrease in partial breakage of coral skeletons in October as compared to June. This decrease in percent coral skeletal loss within Channel sector between June and October was found to be non-significant (Kolomogorov-Smirnov Z = 0.827, $p > 0.5$). No statistical differences were seen in Witches Brew sector, which experienced an increased level of partial coral skeletal breakage in October as compared to June (Kolomogorov-Smirnov Z = 0.567, $p > 0.905$). These non-significant results do not allow detection of seasonal differences.

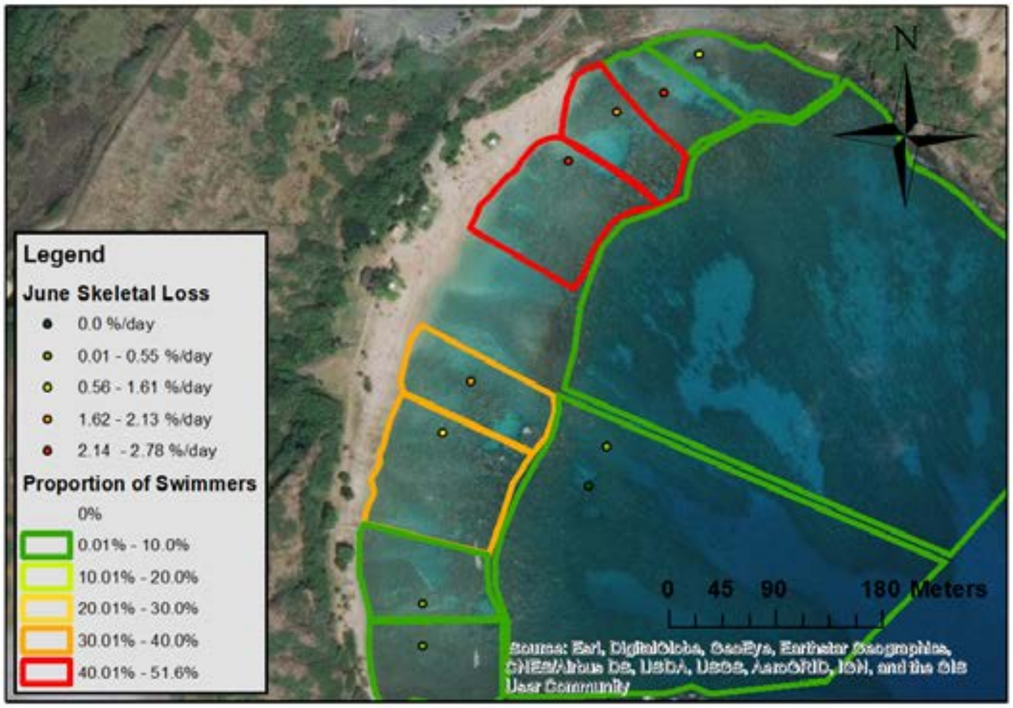


Figure 11. Average percent skeletal loss per day during the June 2019 study of coral skeletons place along a transect in each sector paired with the proportion of swimmers and waders present in that sector.

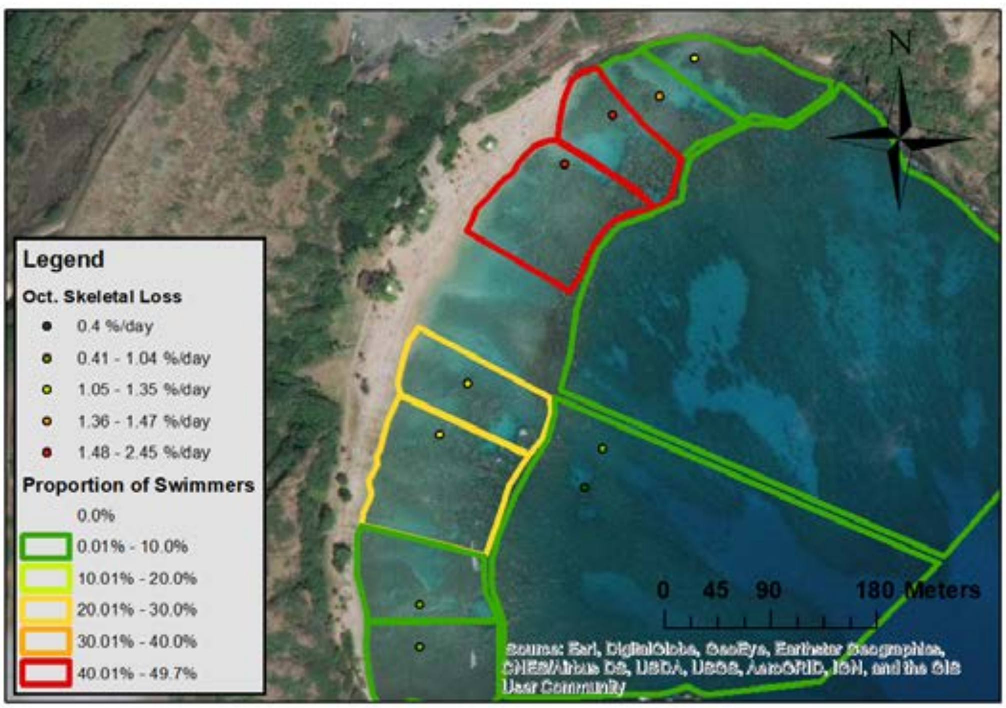


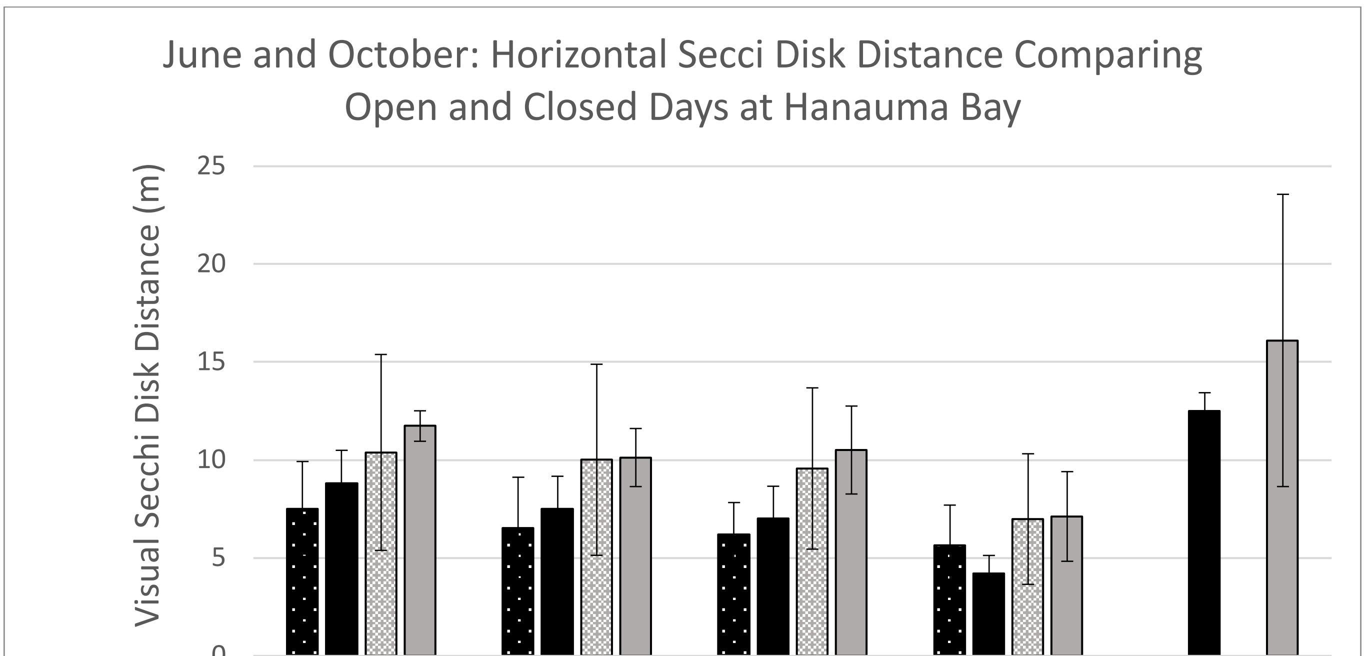
Figure 12. Average percent skeletal loss per day during the October 2019 study of coral skeletons place along a transect in each sector paired with the proportion of swimmers and waders present in that sector.

Secchi Disk Measurements: To determine water visibility between days and conditions, Secchi disk water clarity tests were performed on nine randomly selected non-closure days and 3 closure days in June (June 1^{st} ,5^{th}, 6^{th}, 7^{th}, 8^{th}, 10^{th},12^{th}, 16^{th}, 17^{th}, 19^{th}, 20^{th} and 28^{th}) and October (October 5^{th}, 8^{th}, 9^{th}, 10^{th}, 11^{th}, 12^{th}, 14^{th}, 16^{th}, 20^{th}, 21th, 23^{rd}, and 24^{th}). Four replicate measurements were performed using two observers along each permanent transect within each inshore sector (Fig. 6) (see Appendix C for raw data).

Methods for secchi disk measurements are as follows (Fig. 13): Surveyor one holds the secchi disk while surveyor two swims away with the connected transect tape until the secchi disk is no longer visible. Surveyor two records the distance at which they lose sight of the disk. The surveyor swims away from the disk, and waits for 30 seconds before swimming toward the disk and stopping to record the distance at which the secchi disk is again visible. This results in determination of distances from each surveyor. See appendix C for raw secchi disk water clarity data.

Figure 13. Secchi disk measurement conducted along a transect.

June:
Visual horizontal secchi disk distance was significantly greater (longer horizontal visual distance) in all sectors on days when the HBNP was closed as compared to open access days (Independent-Samples Kruskal-Wallis Test = 13.244, $n = 384$, degrees of freedom = 1, $p < 0.001$) (Fig. 14). In the Keyhole sector, the average visibility was 3.5 m greater on days closed to the public. Similarly, visibility in the Channel (3.4 m), Backdoors (2.9 m), and Witches Brew (1.4 m) sectors were greater on days when the HBNP was closed to the public (Fig. 14). With transects pooled, Independent-Samples Jonckheere-Terpstra Test for Ordered Alternatives found a significant difference (standardized test statistic = -4.652, $p < 0.001$) between the secchi disk lengths observed in each sector. On average, secchi distances in Witches Brew sector were found to be significantly shorter than those observed in Channel (-2.596, $p < 0.05$), Keyhole (-2.739, $p <0.04$), and Backdoors (-4.853, $p < 0.001$) sectors. Witches Brew sector is known to have poor circulation. Considering the circulation patterns within each sector is important for understanding their average visibility. Differences in water circulation within each sector cause average water clarity values to differ naturally, and therefore, comparisons between open and closed days are a more reliable result of differences in visibility. It is important to note that human activity (sediment resuspension) is only one factor contributing to visibility for each sector.



	Backdoors	Keyhole	Channel	Witches Brew	Offshore
June Open	7.5	6.5	6.2	5.6	
October Open	8.8	7.5	7.0	4.2	12.5
June Closed	10.4	10.0	9.6	7.0	
October Closed	11.7	10.1	10.5	7.1	16.1

Figure 14. A comparison of visual horizontal secchi disk measurements (m). Error bars represent ± 1 standard deviation.

Human use was not the major factor in determining secchi distance, and therefore, a non-parametric Kendall's Tau correlation was performed to determine how secchi distance is correlated with several different variables: human counts, tidal coefficient, wind direction, wind speed, wave height, and cloud cover (Table 3). Tidal coefficient is the amplitude of the tide forecast and was acquired from tides4fishing.com (the difference in height between the consecutive high tides and low tides). Wind direction, wind speed, and wave height were acquired from NOAA weather Buoy 51202 and weather station OOUH1 (https://www.ncdc.noaa.gov/cdo-web/datatools/marine). The variable with the highest correlation to secchi distance was wind direction (coef = 0.378). As wind direction increases it begins to shift from the northeast to the southeast. Although this is a weak relationship, as south easterly winds increase, secchi distance length also increases, with greater visibility on these days.

Table 3. Results of a non-parametric Kendall's tau correlation test between the June & October Secchi Distance and Human Counts, Tidal Coefficient, Wind Direction, Wind Speed, Wave Height, and Cloud Cover. Negative correlation coefficient numbers signify a negative relationship between water clarity and the above factor. The higher the number in either direction, the stronger the correlation. (* indicates a significant correlation).

		Human Counts	**Tidal Coefficient**	**Wind Direction**	**Wind Speed**	**Wave Height**	**Cloud Cover**
June 2018	**Correlation Coefficient**	-0.099*	-0.192*	0.378*	-0.261*	-0.153*	-0.250*
	Sig. (2-tailed)	0.005	0.0001	0.0001	0.0001	0.0001	0.0001
Oct. 2018	**Correlation Coefficient**	-0.123*	-0.029	-0.136*	0.094*	0.012	-0.067
	Sig. (2-tailed)	0.001	0.423	0.001	0.01	0.730	0.068

The second strongest relationship was found between secchi distance and wind speed (coef = -0.261). As wind speed increases the water may become more turbulent causing the distance of visibility to decrease in the water column. There was also a strong relationship between cloud cover and secchi distance (coef = -0.250). With lower light levels in the water column, visibility is often decreased. Tidal coefficient was found to have a negative relationship with secchi distance (coef = -0.192). As the speed and severity of tidal changes increase, and more water is displaced at a faster rate, the amount of sediments resuspending increases, resulting in decreased visual clarity. As wave height increased, secchi distance was found to decrease (coef = -0.153). Although this is a weak relationship, it shows that as the water becomes stirred up due to wave action, it may suspend sediment resulting in visual distance decrease. The least correlated was human counts of waders and swimmers (coef = -0.099). As visitor counts increase, the suspended sediments within the water column have been found to increase. This could be the result of fin kicks and human movement stirring up sediment and causing the visual distance to decrease. Wind direction, wind speed, and cloud cover may be the contributing factors of visual water clarity within the inner reef of the HBNP.

A regression analysis between human counts of swimmers and waders against secchi distance was performed based on normality. The Pearson correlation found a weak negative relationship (coef = -0.177, $p < 0.001$). As the number of people in each sector increases, the secchi distance (visual water clarity) decreases ($Y = 7.625 + x(-0.004)$).

October:
Visual horizontal secchi disk distance was significantly greater (longer horizontal visual distance) in all sectors on days when the HBNP was closed as compared to open access days (Independent-Samples Kruskal-Wallis Test = 96.359, n = 416, degrees of freedom = 1, $p < 0.001$) (Fig. 14). The greatest inshore visual water clarity difference between open and closed days was observed in Channel sector, which was 3.5 m (11.6') greater on closed days when compared to open days. The second largest visual water clarity difference between open and closed days was observed in Witches Brew and Backdoors sectors (2.9 m/9.6'). Keyhole had the smallest difference in visual water clarity between open and closed days (2.6/8.6' m). Witches Brew sector had the lowest visual water clarity of all sectors, followed by Channel and Keyhole with better visibility, and Backdoors with the greatest visibility of all inshore sectors (Fig.14).

A non-parametric Kendall's Tau correlation was performed to determine how inshore secchi distance is influenced by the following environmental variables: human counts, tidal coefficient, wind direction, wind speed, wave height, and cloud cover (Table 3). In October, secchi distance had the strongest significant relationship with wind direction (coef = -0.136), showing that as wind direction increased from easterlies to westerlies the visual water clarity decreased. The next strongest relationship was a weak negative relationship to the proportion of snorkelers and waders present in each sector (coef = -0.123). This weak negative relationship indicates that as human use increases within an area, visual water clarity decreases. The only other significant correlation was wind speed (coef = 0.094). This very weak relationship shows as wind speed increases, water clarity increases. This relationship is counterintuitive for the inner reef flat and may be confounded by the combination of wind speed and direction. When stronger winds were associated with a wind direction that is blocked by the surrounding Hanauma Bay mountains, this correlation would seem more plausible. Wind measurements attained from NOAA weather stations from Honolulu offshore buoy 51202 and Honolulu ground observation site OOUH1 do not read wind speeds and directions directly at the HBNP, but are representations of the nearby surrounding area. Tidal coefficient, wave height and cloud cover were correlated with secchi distance in June, but not in October.

A regression analysis based on data normality was performed between human counts of swimmers and waders against secchi distance. The Pearson correlation found a weak negative relationship (coef = -0.134, $p < 0.004$). As the number of people in each sector increase the secchi distance, or visual water clarity, decreased ($Y=8.702+x(0.01)$).

Comparison of June and October:
Overall, water clarity in October appears greater than the water clarity observed in June. June's water clarity was highly influenced by environmental variables such as tidal fluctuations, wind direction and speed, wave height, and cloud cover, whereas, October water clarity was most influenced by human counts, wind direction and wind speed. This may be that during October, with the lack of strong winds and waves, the negative influence of human activity on water clarity is easier to detect.

The same or greater visual water clarity within each sector was observed in October, as compared to June (Fig. 14). The visual distance through the water column was only slightly farther in October. The only exception was seen in Witches Brew sector, where there was a decrease in water clarity during October on days where the HBNP was open to the public. June observations were more variable than in October, with higher water clarity fluctuation from day to day (Fig. 14). This is likely the result of higher wave action or wind swell generation in June when south shores have higher wave regimes.

In both October (coef = -0.123) and June (coef = -0.099), human counts were found to weakly correlate with secchi distance measurements. As the numbers of swimmers and waders in an area increases, the water clarity decreases. This correlation was found to be slightly stronger in October than in June. Wind direction was much more influential in water clarity measurements in June (coef = 0.378) than in October (coef = -0.136). Also, in June, as the wind direction shifted to a more westerly direction, the water clarity increased. Whereas, in October, a more westerly wind direction decreased water clarity. Wind speed was also found to have conflicting results with water clarity in June when compared to October. However, the June correlation with increased wind and associated decreased water clarity was a much stronger relationship (coef = -0.261) and provides a stronger explanation of wind driven increases in turbidity. Wave height and cloud cover were not found to have significant correlations with visual water clarity in October.

Data from both June and October produced weak negative regressions between the number of swimmers and waders in each area and the water clarity. October found overall greater water clarity, and therefore, the constant value in the regression was approximately 1 m greater than in June. However, October water clarity was influenced by human activity more often than in June, which appears to be driven by stronger winds and other environmental variables. Therefore, the slope of the regression curve was greater in October ($Y = 8.702 + x(-0.01)$) as compared to June ($Y = 7.625 + x(-0.004)$).

Sediment Trap Accumulation

June:

During the month of June, Keyhole West transect received the most sediment accumulation of all transects (~4 grams/day) (Fig. 15). However, this observation was not significant (independent-samples Kruskal-Wallis test = 9.255; $p < 0.321$), and therefore, sediment accumulation between all transects are statistically similar. The position of the sediment trap along the transect (front or back) was also found to have no significant difference on sediment accumulation (independent-samples Kruskal-Wallis Test = 0.593; $p < 0.441$). A regression analysis showed a correlation of marginal significance between sediment accumulation per day at each transect and the proportion of visitors within the sector ($y = 1.348 + x\ (0.025)$; $p < 0.054$). The linear regression shows that for each swimmer or wader in a sector, sediment accumulation increases by 0.025 grams (Fig. 16). Regression analysis was performed following determination of normality of residuals.

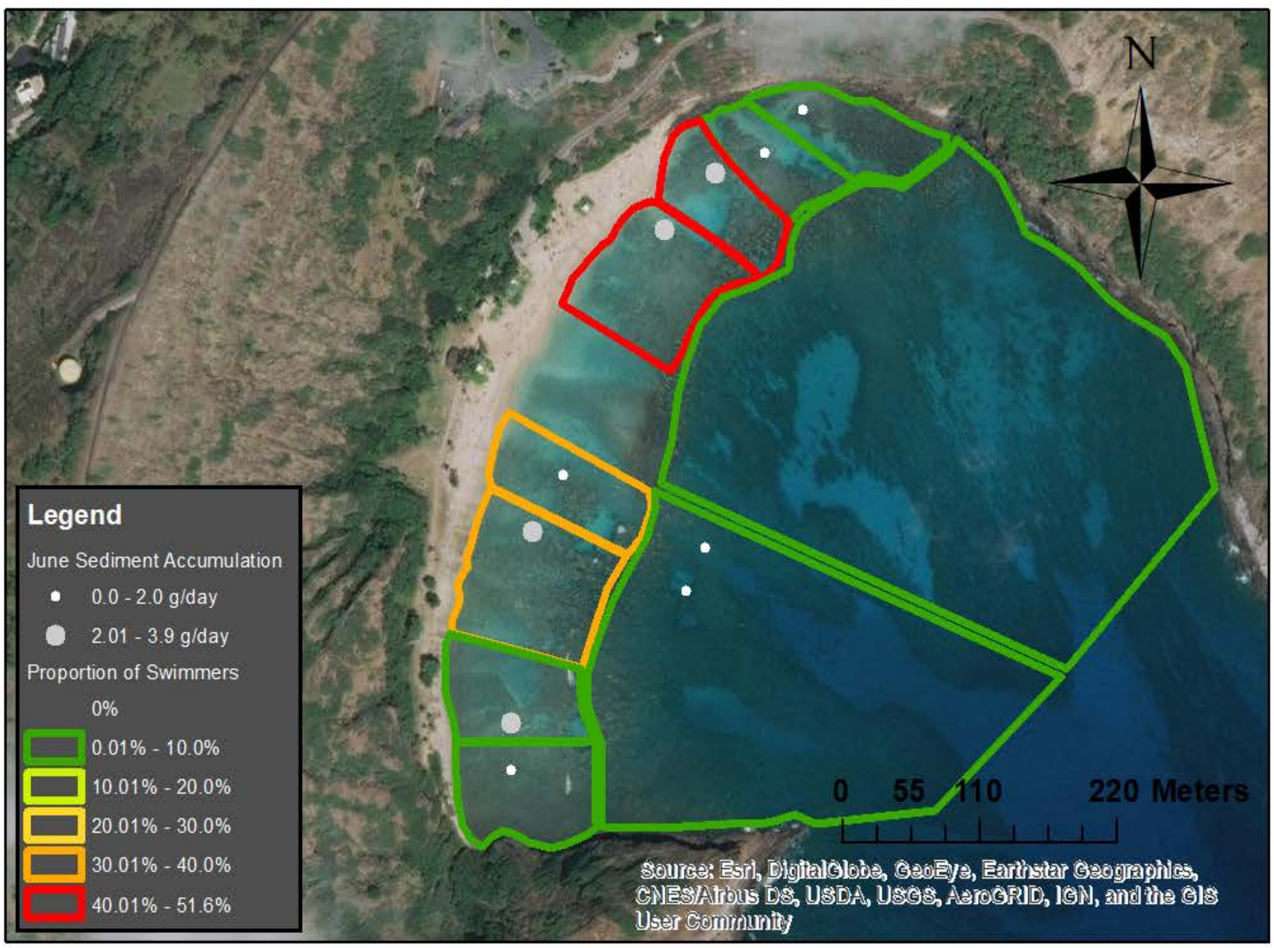


Figure 15. Sediment accumulation (g/day) during the month of June as it relates to the proportion of swimmers and waders present in each sector.

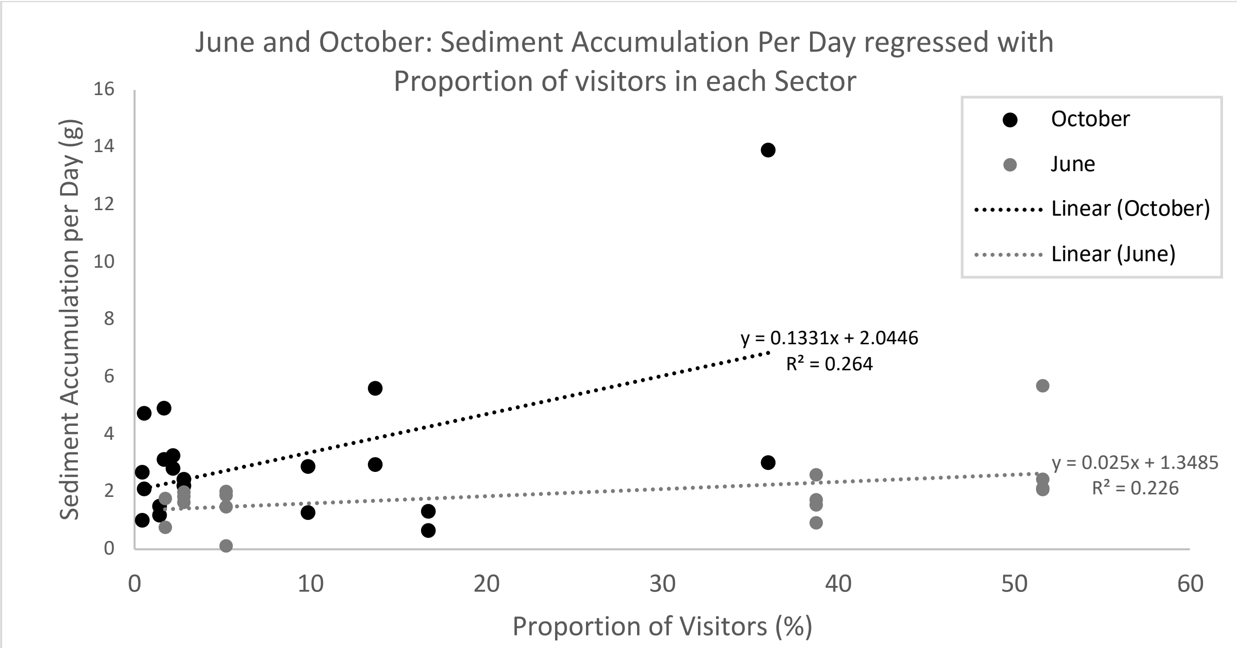


Figure 16. June (grey) and October (black) sediment accumulation (g) per day regressed with proportion of visitors in present in each sector of the HBNP.

October:
Keyhole West had the highest accumulation rate of all transects (~7.5 grams/day), all other transects accumulated between 1 and 4 grams of sediment per day on average (Fig. 17). Despite Keyhole West accumulating greater than double the amount of sediment than other transects, these differences were not significant (independent-samples Kruskal-Wallis test = 13.857; $p < 0.127$) due to high variability. Therefore, statistically, the amount of sediment in all traps was similar. Placement of the sediment trap along the transect (west or east) had no effect on the sediment accumulation per day (independent-samples Kruskal-Wallis test = 0.206; $p < 0.65$). A regression analysis was performed after analysis of residuals showed normality. A strong significant correlation between the proportion of visitors swimming and wading in each transect and the sediment accumulation within the transect was found ($y = 2.045 + x (0.133)$; $p<0.02$) (Fig. 16). Although a strong correlation between these two variables exist, the r^2 value (0.264) shows that visitor counts can only explain some, of the variability in sediment accumulation. Fluctuations in sediment accumulation can result from human activity, wave action, biomass of bioeroders or other factors.

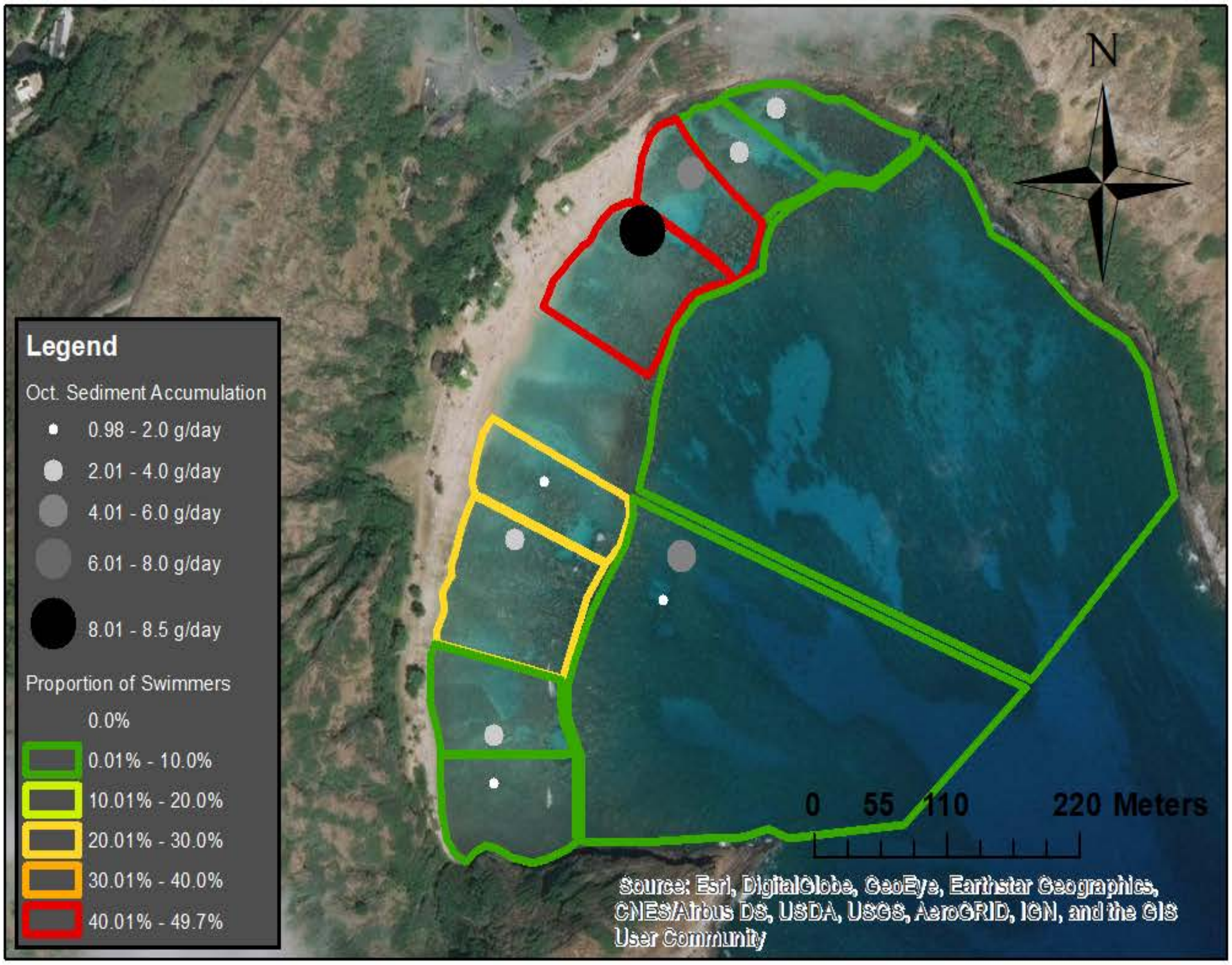


Figure 17. Sediment accumulation (g/day) during the month of October as it relates to the proportion of swimmers and waders present in each sector.

Comparison of June and October:
Mean sediment accumulation in October was significantly higher than mean sediment accumulation in June (Paired Samples T-Test = 2.743, $p<0.014$). All transects either experienced an increase in sediment accumulation during October (Backdoors, Keyhole, Witches Brew), or similar rates of sediment accumulation (Channel) (Fig. 18). This is also shown in the regression analysis from each month, October has a higher intercept value and steeper slope when compared to June (October: $y = 2.045 + x (0.133)$, $p<0.02$; June: $y = 1.348 + x (0.025)$, $p<0.054$). Both sedimentation in June and October produced strong correlations between the proportion of visitors swimming and wading in each area and the sediment accumulation within traps (Figures 16, 17, & 18.

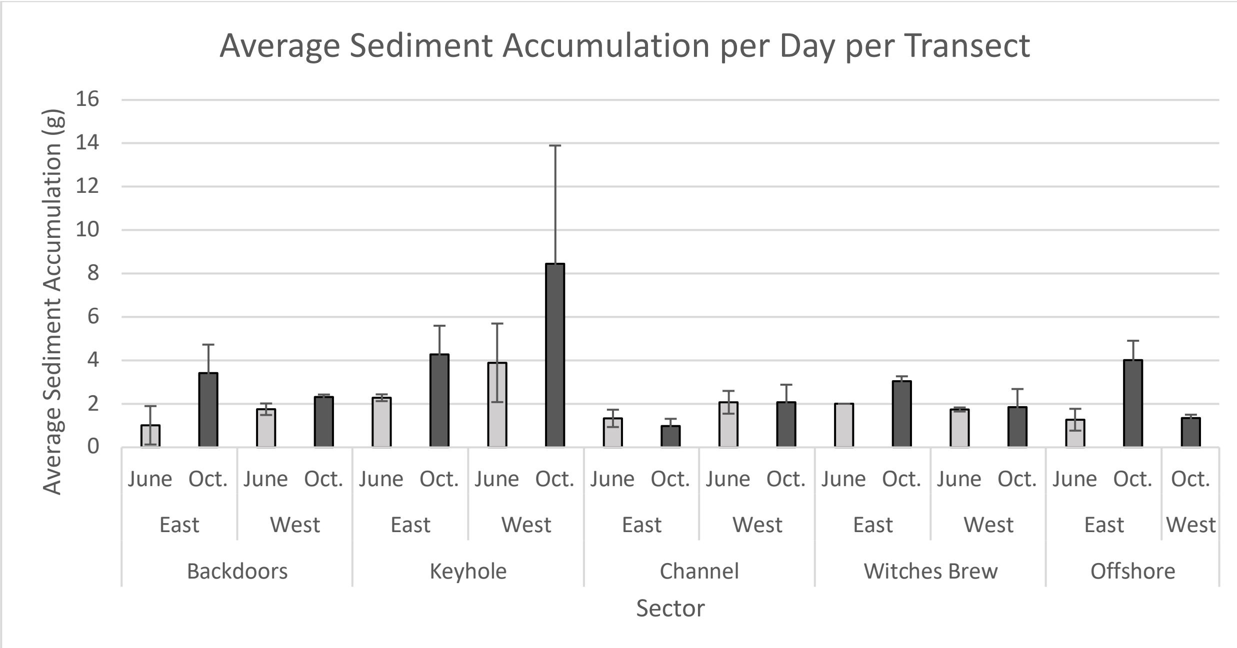


Figure 18. Average sediment accumulation per day per transect averaged between a sediment trap positioned closer to shore (west) and one positioned closer towards the ocean (east) trap along the 15 m transect. Error bars represent ± 1 standard error.

Coral Colony Surveys: Visual coral surveys were performed on 4 December, 2018 documenting coral species and size along each of the eight inshore transects (see Appendix E for raw data).

Thirteen species of hard coral were recorded within eight inshore transects of the HBNP. Percent cover by species of the total coral cover in descending order are listed. Rice Coral (*Montipora capitata*, 41.4%), Ringed Rice Coral (*Montipora patula*, 24.7%), Brown Lobe Coral (*Porites evermanni*, 22.5%), Sandpaper Coral *(Psammocora nierstraszi*, 6.6%), *Lobe Coral (Porites lobata*, 2.3%), Cauliflower Coral (*Pocillopora meandrina*, 2.3%), Porkchop Coral (*Pavona* duerdeni, 0.08%), Ocellated Coral (*Cyphastrea ocellina*, 0.08%), Corrugated Coral (*Pavona varians*, 0.05%), Brigham's Coral (*Porites brighami*, 0.02%) and Stellar Coral (*Psammocora stellata*, 0.02%) (Fig. 19 & Table 4). Plate and Pillar Coral (*Porites rus*) and Blue Rice Coral (*Montipora flabellata*) were present, but did not fall within transects. The HBNP is dominated by Rice Coral, *M. capitata,* Ringed Rice Coral, *M. patula*, and Brown Lobe Coral, *P. evermanni*. Despite having low overall coral cover within the inner reef flat, visual surveys recorded high species diversity. Many of these species found on the reef flat are mounding or encrusting in skeletal form and are found on vertical faces or within crevices of the reef substrate. There were no species present that exhibit a more delicate skeletal form (thin branching, lace or plating).

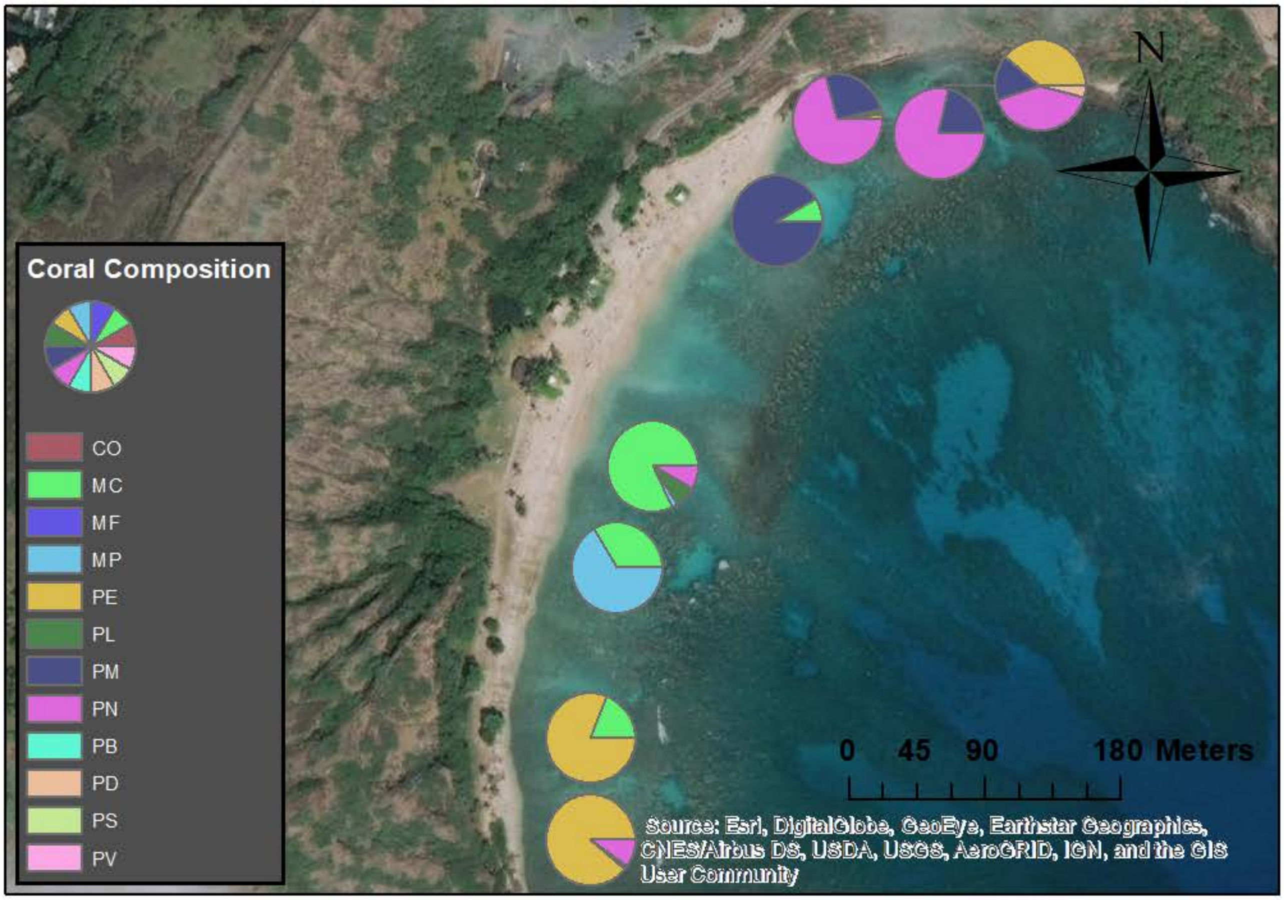


Figure 19. Coral composition at each inshore transect. Refer to Table 4 for abbreviation of scientific names in legend for common names and coral cover totals.

Table 4. Coral cover (m^2) represented in each of the permanent transects within the HBNP as of December, 2018. (Abbreviation of scientific names in parentheses).

	Coral Cover (m^2) per Transect (Abbreviation of scientific names in parentheses)							
	Backdoors East	Backdoors West	Keyhole East	Keyhole West	Channel East	Channel West	Witches Brew East	Witches Brew West
Ocellated (CO)	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00
Rice (MC)	0.00	0.00	0.00	0.02	6.52	3.12	1.18	0.00
Blue Rice (MF)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ringed Rice (MP)	0.00	0.00	0.00	0.00	0.18	6.28	0.00	0.00
Brigham's (PB)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Porkchop (PD)	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Brown Lobe (PE)	0.19	0.00	0.01	0.00	0.00	0.00	4.99	0.72
Lobe (PL)	0.00	0.00	0.01	0.00	0.60	0.00	0.00	0.00
Plate and Pillar (PR)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cauliflower (PM)	0.08	0.11	0.14	0.23	0.01	0.01	0.02	0.01
Sandpaper (PN)	0.20	0.40	0.39	0.00	0.65	0.00	0.00	0.08
Stellar (PS)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corrugated (PV)	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Number of Species Per Transect	4	2	4	2	6	4	4	3
Total Coral Area per Transect (m^2)	0.490	0.510	0.550	0.240	7.98	9.42	6.19	0.820
Percent Coral Cover per Transect (%)	0.650	0.680	0.740	0.320	10.6	12.6	8.26	1.09

Coral cover within each transect (75 m^2) differed greatly across the reef flat (Fig. 20). Channel West transect had the highest coral cover (12.56%), followed by Channel East transect (10.63%) and Witches Brew East transect (8.26%) (Fig. 20). All other transects had coral cover equal to or less than 1% of the total substrate composition. Both Channel transects were dominated by large Rice (*M. capitata*) and Ringed Rice (*M. patula*) corals (Table 4) growing on vertical surfaces. All other transects were dominated by Brown Lobe Coral (*P. evermanni*). Keyhole West (0.32%) was the transects with the lowest live coral cover. No significant correlations were found between coral cover at each transect and the proportion of visitors to each transect (Fig. 21), the rates of sedimentation at each transect, or the rates of coral trampling (from skeleton experiments) at each transect. Investigation into other drivers of coral distribution and abundance will be continued into year 2 of the study.

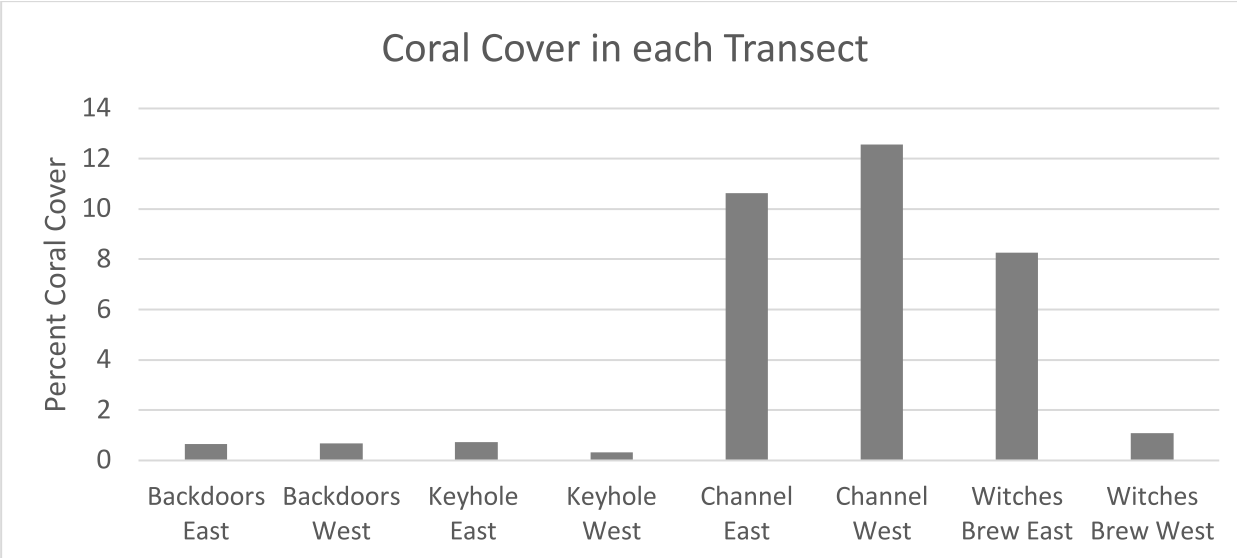


Figure 20. Total coral cover in each inshore transect of the Hanauma Bay Nature Preserve. Cover was documented in December, 2018 within 5 m x 15 m transects (75 m^2 area of substrate). All corals greater than 5 cm in diameter were recorded.

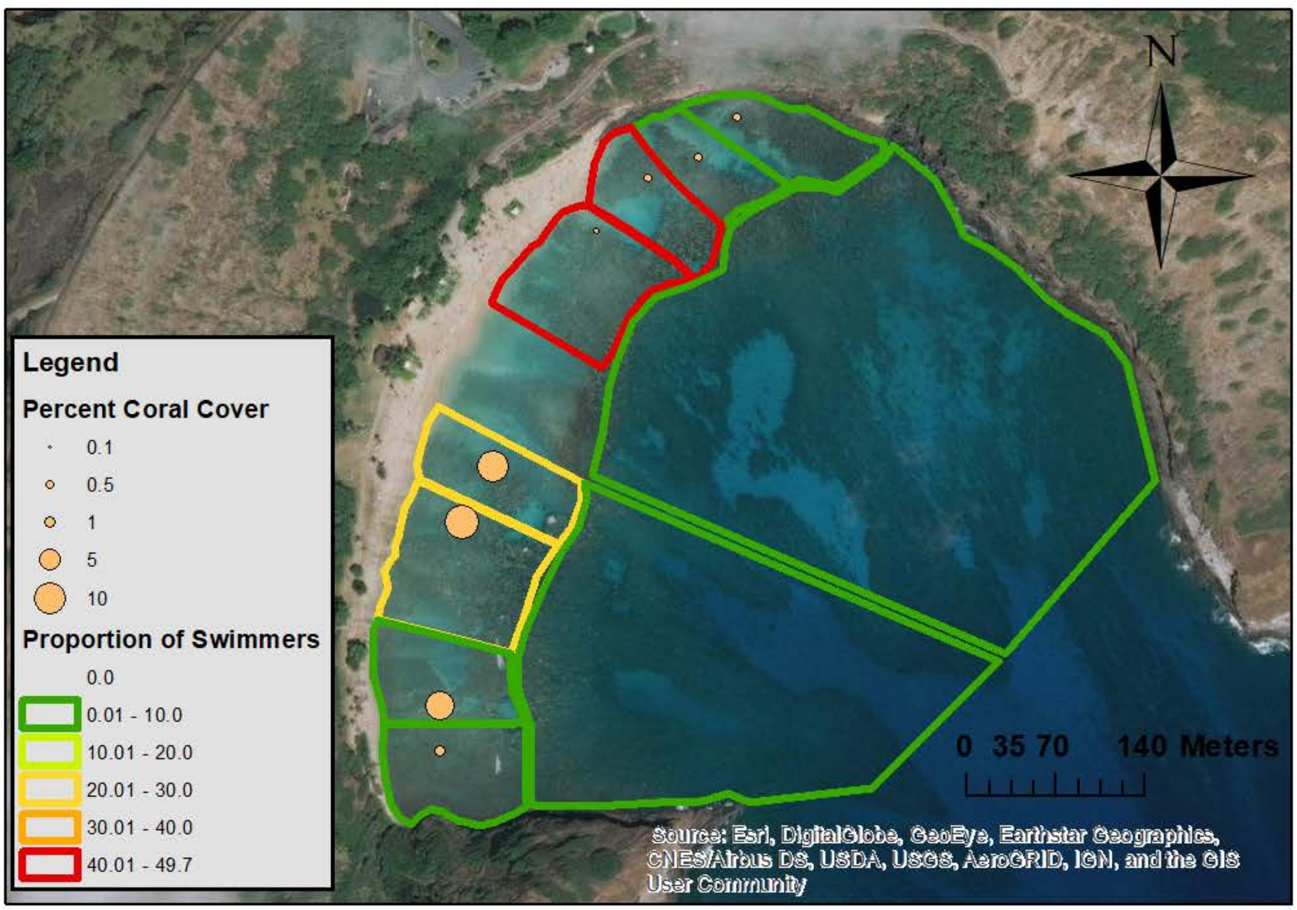


Figure 21. Percent coral cover at each inshore transect as it relates to the proportion of visitors present in each sector of Hanauma Bay.

Future plans include long-term monitoring of transects with the use of semi-permanent eyebolts marking the corners of each transect (OCCL permit in process). In addition to monitoring eight inshore transects, we are requesting to mark two offshore transects directly outside of the reef flat environment. The semi-permanent marking of transects ensures precise replication of surveys.

Coral Recruitment Surveys: Future plans include long term permanent plots that will track growth and survival of recruits over time (OCCL permit in process). Coral recruitment surveys will be performed throughout the summer months (2019) documenting levels and patterns of coral recruitment within the inner reef flat. Results will be compared to recruitment levels on the outer reef. Recruitment will be assessed *in situ* using fluorescent lighting.

Detailed Descriptions and Outcomes of Research Activities:
Quarter 4-Task 4: Analysis of CRAMP Sites (Appendix F)
Annual surveys of CRAMP stations were conducted on 2 October, 2018.

Comparison of HBNP CRAMP sites over time.
The Coral Reef Assessment and Monitoring sites at the Hanauma Bay Nature Preserve were established in 1999. At both 3 m (10') and 10 m (33') depth, ten-10 m permanent (fixed) transects were relocated. Along each transect, 20 non-overlapping images (50 x 69 cm total reef area per photo with 50 randomly selected points per image) are used to quantify percent cover, richness and diversity of corals, algal functional groups and substrate cover (Brown et al., 2004).

Until 2012 coral cover at the 3 m CRAMP station declined (Fig. 22). In more recent years (2017, 2018) coral cover has increased from 9.6% (± 0.01%) in 2012 to 14.7% (± 0.02%) in 2018. For the past two years' coral cover has remained stable.

Throughout the early 2000s, coral cover at the deep (10 m) CRAMP station was between 22% - 26% (Fig. 22). In 2012, coral cover was documented at 30.0% (± 0.05%), indicating an increase in coral cover throughout the late 2000's. Between 2012 and 2017 coral cover at the deep site was reduced by half, likely as a result of the 2014/2015 widespread bleaching event that effected Hawaiian waters. From 2017 to 2018, coral cover has increased from 15.6% (± 0.04%) to 18.3% (± 0.03%).

Both shallow and deep CRAMP stations have experienced a decline in coral cover since the initial survey in 1999. The shallow station (Fig. 22, grey) first reported lower coral cover (22.9%) than the deep CRAMP site (27.2%, black). This is typical statewide where coral cover typically increases with depth. Sites <10 m in depth have an average total coral cover of 17.4% (±15.3), while deeper sites (>10 m) average 27.8% (±24.1) (Rodgers 2001). The shallow station also shows a faster estimated rate of decline ($y = -0.0058x + 0.2289$, $R^2 = 0.64$) when compared to the deep site ($y = -0.0039x + 0.2719$, $R^2 = 0.3639$). The calculated trend line for the shallow CRAMP site shows a decline in coral cover of 0.58% per year despite an increase in coral cover of almost 5% between the 2012 and 2018 survey. The calculated trend line for the deep CRAMP site shows a decline in coral cover of 0.39% per year. Regardless of the negative sloping best fit lines at both stations, in the last year, coral cover has increased at both (non-significant between 2017 and 2018 surveys).

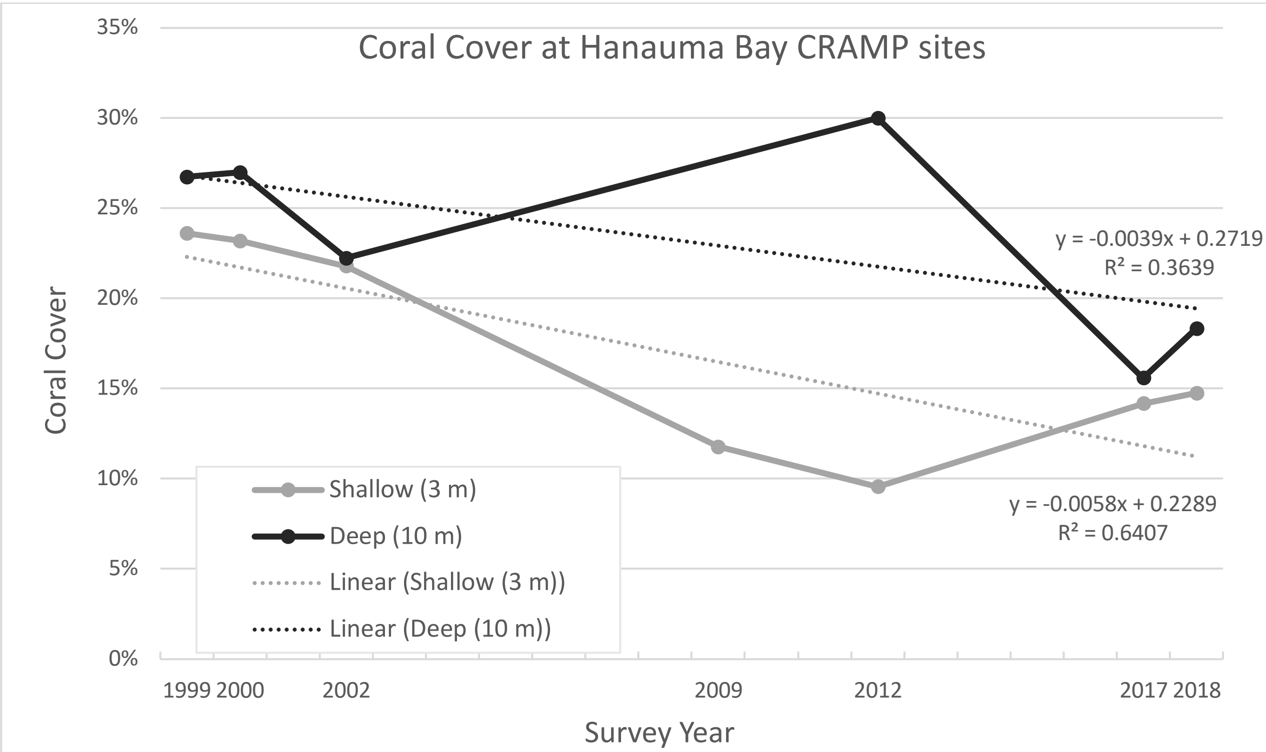


Figure 22. Coral cover observed at shallow (3 m, grey) and deep (10 m, black) CRAMP stations at the HBNP on seven survey years between 1999 and 2018. A linear regression was calculated and best fit lines were fixed to the coral cover trajectory.

Detailed Descriptions and Outcomes of Research Activities:
Quarter 4-Task 5: Analyze temperature data from inner reef flat (Appendix G).

Current temperature patterns and comparison between seasons.
Seawater temperature data spans from July, 2015 to March, 2019. Temperature was recoded at fifteen-minute intervals using HOBO Water Temperature Pro v2 Data Loggers (Onset, Wareham, MA, USA). The loggers were secured in 6" x 12" hand-poured concrete "rocks" that mimic the benthic substrate and protect the loggers from solar irradiance and associated heating (Bahr et al., 2016) while provide concealment from human disturbance. Loggers are located in Backdoors, Keyhole (2), Channel, and at the 3-meter Coral Reef Assessment and Monitoring (CRAMP) site. All loggers were placed at 3 ft. depth, with the exception of the CRAMP site logger at 9 ft. depth.

Summer 2015 and the following winter 2016 was 0.5 °C to 1 °C warmer than the following summers (Fig. 23). No clear patterns were distinguished when temperature data was compared among sites or between summer and winter months (Table 5, Appendix G).

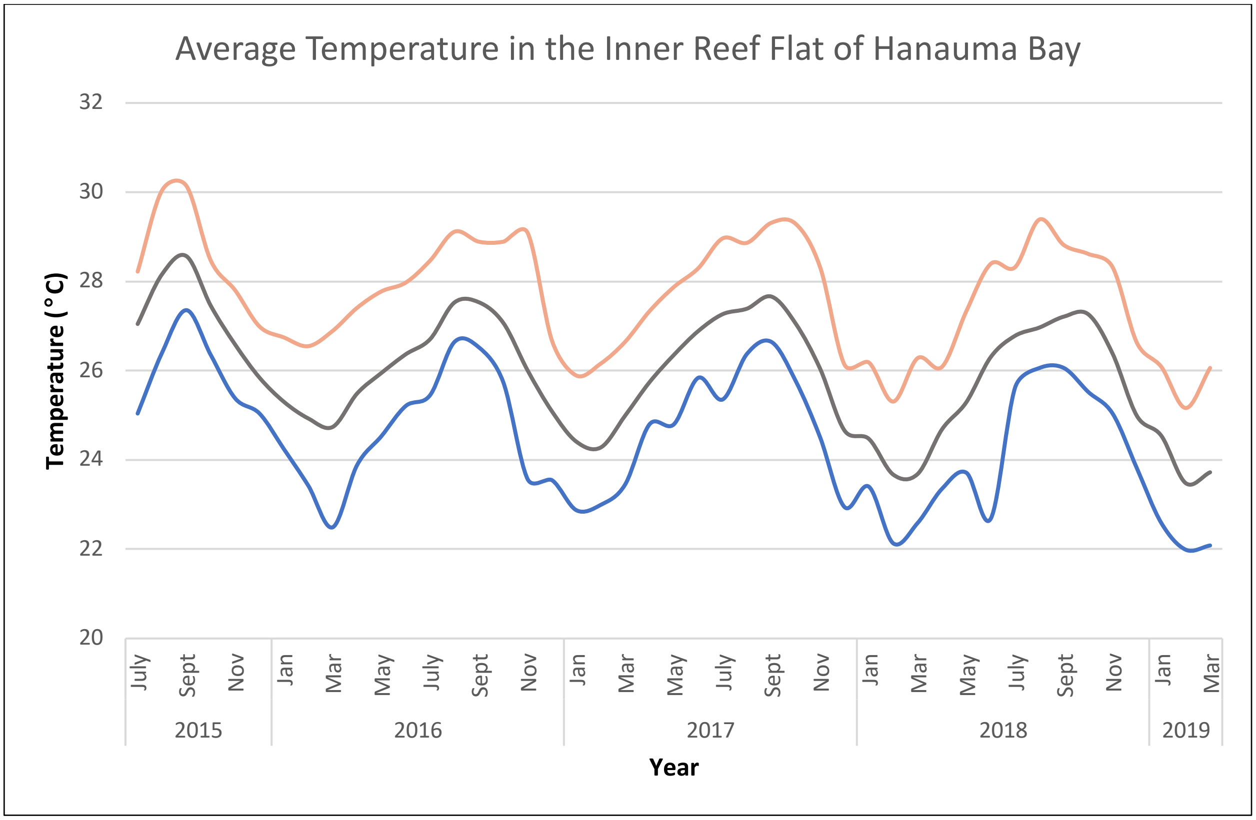


Figure 23 Temperature averaged over four data loggers located in the inner reef flat of Hanauma Bay, O'ahu, HI. The highest temperature (red line), lowest temperature (blue line), and average temperature for each month are shown. Temperature was recorded at fifteen-minute intervals using HOBO Water Temperature Pro v2 Data Loggers (Onset, Wareham, MA, USA).

Table 5. Temperature (°C) average, minimum and maximum during summer months, and during winter months within Backdoors, Keyhole, Channel, and the offshore CRAMP stations from July 2015 till March 2019. SD=Standard Error.

	Backdoors			Keyhole			Channel			CRAMP 3m		
	Average	Max	Min	Average	Max	Min	Average	Max	Min	Average	Max	Min
All Data	26.1	27.3	25.1	25.8	27.4	24.5	25.7	27.3	24.4	25.7	26.6	24.6
SE	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3
SUMMER	27.7	28.9	26.6	27.4	28.9	26.3	27.3	28.7	26.2	27.1	27.9	26.4
SE	0.2	0.4	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
WINTER	25.0	26.1	23.8	24.7	26.3	23.3	24.5	26.2	23.1	24.4	25.4	23.2
SE	0.2	0.1	0.3	0.2	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.3

Predictive assessment of bleaching impacts and patterns

The NOAA National Centers for Environmental Prediction's El Niño-Southern Oscillation (ENSO) Alert System (issued April 11, 2019) remains at a weak El Niño Advisory status and will likely continue through the Northern Hemisphere summer (65% chance) and into fall 2019 (50-55% chance) (https://coralreefwatch.noaa.gov/satellite/analyses_guidance/enso_bleaching_99-99_ag_20140507.php). Stronger El Niño events are occurring in greater frequency leading to more coral bleaching events with less time for recovery between events. In preparation for stronger El Niño events, temperature data loggers (HOBO Water Temperature Pro v2 Data Loggers, Onset, Wareham, MA, USA) have been placed in all major sectors within the HBNP and will continue to be downloaded annually.

During the 2015 bleaching event, Rodgers et al. (2017) documented bleaching within the HBNP and found bleaching occurrence and recovery to be closely associated with water circulation patterns. Areas closer to a channel (Backdoors and Channel sectors Fig. 3) had higher seawater turnover rates leaving the seawater cooler in temperature and the corals less stressed. For sites that did not have high turn-over rates (Keyhole and Witches Brew), higher prevalence of bleaching was documented, and in Witches Brew, pale colonies persisted 3 months after the bleaching event. Overall, high recovery was seen throughout the reef flat (Fig. 24). While bleaching was high (47.0%) within the HBNP, mortality was lower (9.8%) than at many other Hawaiian Island sites. Scientists predict bleaching events to become more frequent and severe over time (Hughes et al. 2018). Continued monitoring of these inshore sites, along with long-term monitoring stations, will continue in preparation for future bleaching events.

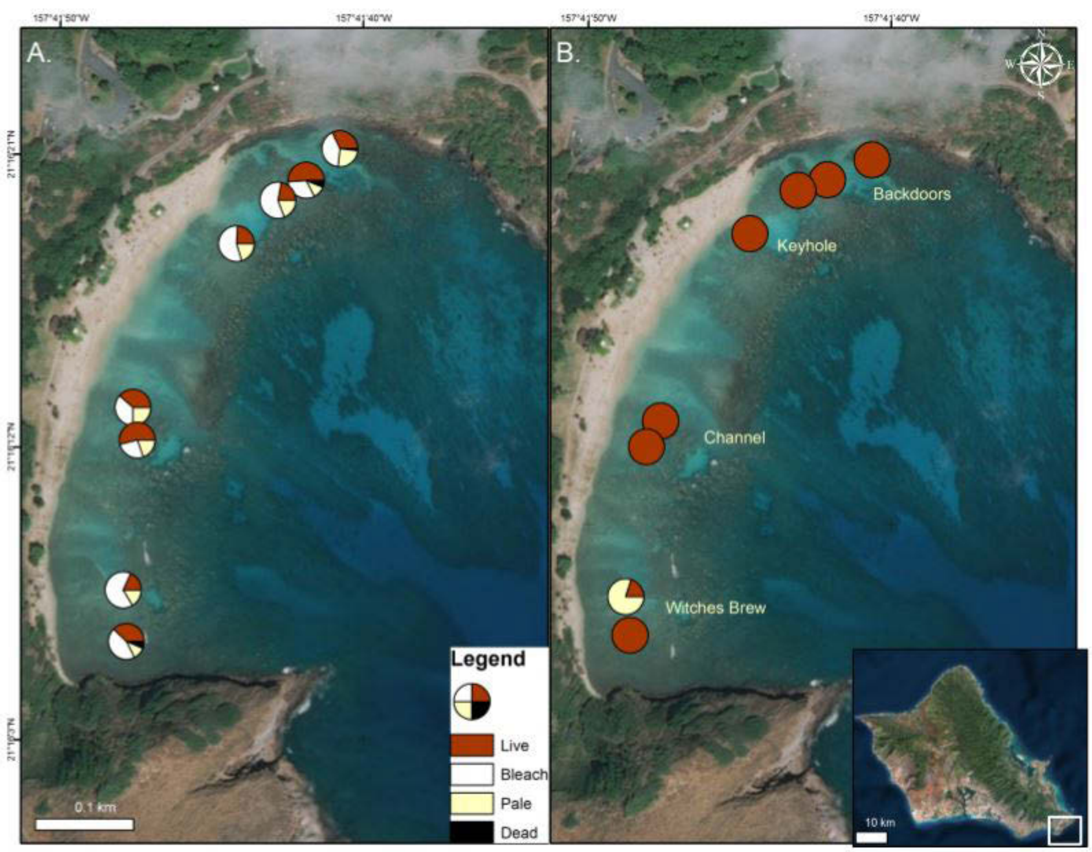


Figure 24. Coral conditions in the Hanauma Bay Nature Preserve, Oʻahu, HI in October 2015 (A) and January 2016 (B). Proportion of surveyed corals are shown as normal (red), bleached (white), pale (yellow) and dead (black). Surveys were conducted and temperature loggers deployed at each of the two stations within the four sectors. Photo credit: Quickbird Digital Globe. (Rodgers et al., 2017).

Discussion of Findings

The inner reef flat of the HBNP is the most heavily snorkeled coral reef in Hawaiʻi. Of the 2,500 to 3,500 visitors per day, approximately 97% stay within the inner reef flat and do not venture out to deeper waters. This past year, a series of observational and manipulative experiments have been performed to identify the present level of disturbance to the inner reef flat environment, and whether or not this level of disturbance in sustainable. In addition to short-term experiments, analysis of long-term data sets and comparisons to historical literature provides insight to the state of the HBNP under differing visitor pressure and rules.

The most common concern voiced by Hanauma Bay advocates is the number of people standing, stepping, or crawling on the inner reef flat, and, how they believe trampling is the cause of the observed sparse coral cover. Coral skeletons were used to mimic live coral colonies growing on the reef flat to quantify trampling pressure by measuring the breakage of skeletons over two thirty-day studies. Simultaneously, the number of snorkelers in each area were quantified to relate the amount of breakage determined in the coral skeletons to the levels of snorkeling traffic across each area. In the two replicate coral trampling studies, partial breakage of coral skeletons and full colony loss increased with increasing visitor presence (Figs. 9 & 10). The most popular snorkeling area, Keyhole sector, had the highest rate of partial coral colony breakage and full colony loss in both June and October studies. This is strong evidence of the link between coral fragmentation and usage. However, human trampling may not be the sole contributor to coral skeleton breakage. In year two of the biological carrying capacity study, a follow-up experiment physically excluding humans and/or fish predators from coral skeletons will be performed to quantify the skeletal loss generated by each influence.

Other factors contributing to coral growth are water clarity and sedimentation also correlated with human use. When visitors walk in the sand or kick vigorously, sand and particulates can be dispersed in the water column. Once deposited back onto the reef flat, it can act as a 'sandpaper', scraping corals, or it can act as a smothering agent causing the coral to divert energy from growth to sediment removal. To determine if this disturbance was present in the HBNP, (1) visual water quality measurements (secchi disk) were compared between open (visitors present) and closed (no visitors) days and (2) the amount of sediment depositing to the reef flat was quantified. In both October and June, human counts were found to weakly correlate with secchi distance measurements. As the numbers of swimmers and waders in an area increased, the water clarity decreased. This correlation was found to be slightly stronger in October than in June. Additionally, average visual water clarity distance was 2.8 yards greater in June and 3.0 yards greater in October on days when the HBNP was closed (Tuesdays) as compared to days when it was open to the public. Number of visitors in each sector was one of many factors contributing to visual water clarity, others included the degree of tidal fluctuation (tidal coefficient), wind direction, wind speed, wave height, and cloud cover. Non-parametric correlation tests found environmental variables to be more influential to visual water clarity in June than in October. A similar pattern was found for sediment accumulation. Correlations found that as the proportion of visitors swimming and wading over each transect increased, the sediment accumulation within the transect also increased. However, visitor counts could only partially explain the variability in sediment accumulation. Fluctuations in sediment accumulation can result from human activity, wave energy, biomass of bioeroders or other factors.

Long-term data sets of both resource fish density (Friedlander et al., 2018) and coral cover (CRAMP data set) show a trend of depreciating populations within the Hanauma Bay Nature Preserve. Friedlander et al. (2018) found decreases in density of resource fishes since 1982, when prior to this time, resource fishes were increasing steadily (Fig. 2). It is unknown whether the change in this population trajectory is correlated with (1) a natural carrying capacity of the population that climaxed 15 years following MLCD designation, (2) the 3 million people visiting Hanauma Bay per year over the 1980’s, (3) other environmental phenomenon, or, (4) a combination of several of these factors. The Coral Reef Assessment and Monitoring Program (CRAMP) has been detecting an overall decline in coral cover at the 3 m. depth and 10 m. depth sites since 1999 (Fig. 22). In the past year, coral cover at both sites remained stable, yet the overall the population trajectory remains in decline.

The ecology of the benthic habitat on the inner reef flat was not comprehensively surveyed until 1998, and therefore, benthic composition prior to the peak in visitor counts (1980’s) is unknown. Easton and Olson (1976) provide evidence through radiocarbon dating of reef cores that vertical growth on the inner reef flat of Hanauma Bay has been “stunted” by the lowering of sea-level. The highest growth rates found on the inner reef flat during this study were of lateral or downward growth into channels or pockets in the reef. A follow up study used reef accretion data gathered from Easton and Olson’s (1976) coral cores coupled with the physical properties of wave action to provide evidence that coral communities at the shallow sites of Hanauma Bay are constrained by aerial exposure during low tide events (Grigg, 1998). The previous carrying capacity report documented an average of 0.80% coral coverage on the inner reef flat(Brock & Kam, 2000). The survey conducted in December, 2019 found an average of 3.2% coral cover throughout the inner reef flat along transects within similar habitat studied by Brock & Kam (2000) (Table 6).This indicates an increase in coral cover from 2000 to 2019 in Channel and Witches Brew sectors, while Keyhole sector has remained unchanged (Table 6). Coral composition present on the reef flat is similar to that found in 1990. As our observations found, Brock and Kam (2000) noted, “corals within the inner reef flat are most often seen growing in depressions or vertical surfaces of the reef.” In the second year of the carrying capacity study, exclusion cages will be placed on the reef flats to determine which drivers are responsible for these growth patterns. By separating impacts of low tide, desiccation, sand scour, trampling, and fish predation, the cause of coral growth on horizontal surfaces can be determined. Field experiments using dead coral skeletons and live coral fragments (applying for permit) will determine how growth and trampling differs between treatments (1) excluding humans and fish/invert predators, (2) excluding humans while allowing predators, and, (3) exposure to both humans and predators (permit pending). An assessment of the substrate in each treatment will document coral recruitment and survival, benthic composition, and sedimentation throughout the year.

Table 6. Comparison of inner reef flat coral cover on comparable transects between the Brock and Kam (2000) carrying capacity study and the current 2019 carrying capacity study.

Site Names		Percent Coral Cover		Number of Species Present	
2019	2000	2019	2000	2019	2000
Keyhole East	**11**	0.736	0.0200	4	1
Keyhole West	**14**	0.324	0.200	2	3
Channel East	**17**	10.6	0.900	6	3
Witches Brew East	**18**	8.27	2.00	4	3
Witches Brew West	**18**	1.09	2.00	3	3

Currently, there is not sufficient evidence to support the statement that declines in coral cover and resource fish density are the exclusive result of visitor presence at the HBNP. However, we have supporting evidence that human use is a contributing factor. This evidence includes:

- Water clarity increased an average of 30% on days the HBNP is closed to the public. Human use explains part of the decreased visibility.
- The breakage rate of corals is strongly related to the level of swimmers and waders in each sector.
- The greater the number of visitors in the water the lower the percent coral cover.
- Sedimentation levels are clearly related to the number of visitors in the water in each sector. This increases the chance of smothering and scour for corals and recruits.

The spatial distribution and abundance of corals on the shallow reef flat reflect the historical chronic impact from human use.

- Corals grow in cracks and crevices and on vertical surfaces inaccessible to trampling impacts.
- Low coral cover in high use regions.
- High coral cover in areas beyond depths that can be accessed by snorkelers and waders.
- Coral morphologies (lobate, encrusting) conducive to high impact areas.
- Species of corals in exposed areas that exhibit stronger skeletal strengths.

Factors besides human use are also contributing to low coral cover, sedimentation, and reduced water clarity.

- Wind direction and speed and tides are strongly correlated with water visibility.
- The 2014/15 statewide bleaching event reduced coral cover by 10% on the HBNP reef flat. Although the long-term monitoring stations show a severe drop following this bleaching event, the last two years have been stable.
- The reef flats in the sectors with low coral cover also have low spatial complexity reducing available substrate for coral growth and recruitment.

Increasing duration, severity, and frequency of coral bleaching events pose the most imminent threat to the biological sustainability of the HBNP. With this comes a significant economic threat to the state of Hawai`i. The 2014/15 bleaching event showed lower coral mortality (9.8%) in the HBNP as compared to West Hawaiʻi (30-86%) or Kāneʻohe Bay (20%). This may be due to a number of factors including location, circulation patterns, or prior warming exposure. It is important to minimize any other anthropogenic impacts that may create additive synergistic effects. Maintaining optimum coral health can provide an added level of protection when environmental impacts occur. Sound management strategies based on scientific research will increasingly play a more important role. Data from this research can assist managers in making predictions to support planning efforts and implement effective conservation actions.

Management & Educational Recommendations

There has been great effort and expense applied to promoting the tourist industry, but sparse resources have been allotted to investigating the impact of the industry on the resources. Direct and indirect impacts result from increased tourist use of marine resources. Changes in diversity and abundance of fish populations can result from artificial feeding. Habitat destruction from trampling can affect fish nurseries, habitat for flora and fauna, recruitment sites and coral populations. Problems involving enforcement, insufficient data, regulatory unresponsiveness, loopholes in regulations, political will, multiple jurisdictions and new fishing technology complicate matters.

Various management strategies have been used throughout Hawaiʻi to address a plethora of problems related to these types of impacts. These include spatial and temporal solutions as well as involving socio-economic factors. These include:

- limiting access
- controlling the type of activities that can occur in the protected areas
- designating specific days and times for use
- dispersing use among larger areas
- providing additional sites
- educating users
- exploring other options
- involving community groups
- rotating opening/closing periods
- self-monitoring of commercial users
- using visitor industry influence
- community reef tenure
- closed seasons
- no-take zones
- user fees at popular tourist marine reserves
- marine recreational fishing license for fees and reporting purposes
- increase size of marine protected areas
- additional MPA's
- increased research

Many of these solutions have been implemented at the HBNP with anecdotal success. Successive components of the carrying capacity study will include examination of the temporal and spatial aspects of these changes and their correlation to biological, environmental, and anthropogenic factors. For example, we will determine whether fish populations changed following the cessation of fish feeding and whether biological shifts occurred in relation to visitor use. It is extremely difficult to manage the resource since it is challenging to quantify. This is why it is imperative to manage the people instead.

Current recommendations to address coral sustainability and data gaps at the HBNP include:

- Place several large screen monitors around the periphery of the Sea Grant education video viewing room. While the education video is playing, each monitor will display the educational video with subtitles in various common languages. Provide signs above each monitor in said languages so visitors can orient themselves to watch the video in their language. Providing an easy way for people to view the video in their own language may be more effective than having to seek out a headset in said language.
- Place informational signs within the education center describing ongoing research within the bay: CRAMP, recruitment modules, biological carrying capacity study. Knowing about ongoing research will educate visitors and encourage them to protect coral reef resources.
- Disperse users among other activities. These may include non-fee based controlled nature hikes, children's programs, ocean films etc. All activities will provide education about the Hawaiian ecosystem or history.
- Place educational information signs along the sidewalk (Fig. 27) leading up to the ticket windows so visitors have another chance to become familiar with the reef environment while they wait in line for tickets. Signs should include information on the living reef environment and step-by-step instructions for how to enter the Bay and proceed with snorkeling. Provide signs in both English and Japanese and other languages common of visitors). Cover sidewalk to provide shade for visitors and signs (Fig. 28). If sidewalks are covered before entering the park and information is present, visitors will have another opportunity to understand how they can help protect the natural resources within HBNP and themselves. See next page for example of ‘Ahihi-Kina‘u Natural area reserve (NAR) on Maui.
- Place educational information signs along the beach entrance and walkways, reiterating safe snorkel practices (see next page for example signs Figures 29 through 33). Signs should be in both English and Japanese (and other languages common of visitors). ‘Ahihi-Kina‘u NAR has a memorable saying “Protect yourself, protect the reef. Enter the ocean only where sandy: Never Stand Unless On Sand.”
- Create an informational webpage and resources for visitors to reference prior to arriving at the Bay. (Ex. https://dlnr.hawaii.gov/ecosystems/nars/maui/ahihi-kinau-2/)

- Educational materials and displays should include information on climate change (CC) impacts on coral reefs with clear direction on actions to reduce carbon. The National Parks Service has a CC response strategy, action plan, and regional policies and strategies that include science, adaptation, mitigation, and communication.

No recommendation is included at this time to decrease the number of visitors to the HBNP. This is based on the level of coral breakage found in this year of the carrying capacity study and a prior study showing the impact to growth and survivorship of corals along a gradient of human use (Rodgers 2001). The previous study shows coral mortality was low at a level of 50,000 visitors annually and at 200,000 visitors/yr corals did not survive. Visitor counts at the HBNP in the 2016-’17 fiscal year was 842,439. This level of use greatly exceeds levels previously studied on the Big Island, and a reduction below this level is unrealistic. Although corals cannot survive in some areas of the reef flats, there are healthy populations present in areas inaccessible to trampling even in high use areas. Larger coral populations exist in low use areas such as Witches Brew, on vertical surfaces in the Channel, and in deeper waters just offshore. Thus, the best strategies to protect corals while allowing for a realistic level of visitation are outlined above.

Figure 25. Informational sign at ‘Āhihi-Kīna‘u nature reserve on Maui.

Figure 26. Informational signs at entrance of ʻĀhihi-Kīnaʻu nature reserve on Maui with shaded areas to read signs. This could be installed along the walkway leading up to the ticket booth so visitors have another chance to familiarize themselves with safe snorkeling practices.

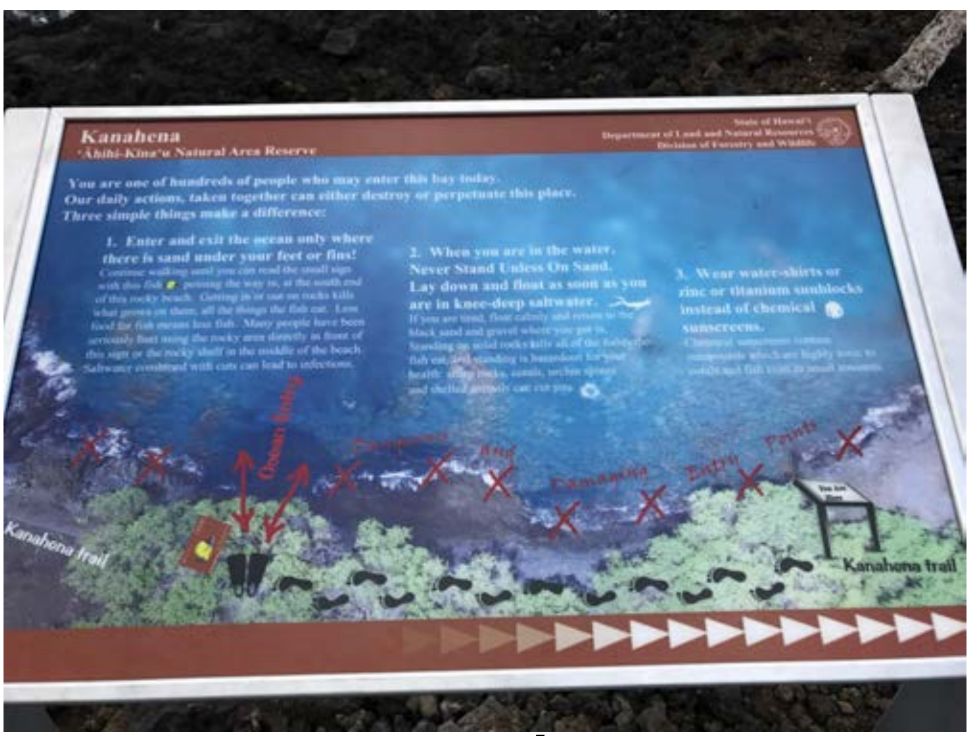


Figure 27. Informational signs, like these at ʻĀhihi-Kīnaʻu nature reserve on Maui, should be placed near the beach showing/reminding visitors where it is safe to enter the ocean and safe areas to snorkel.

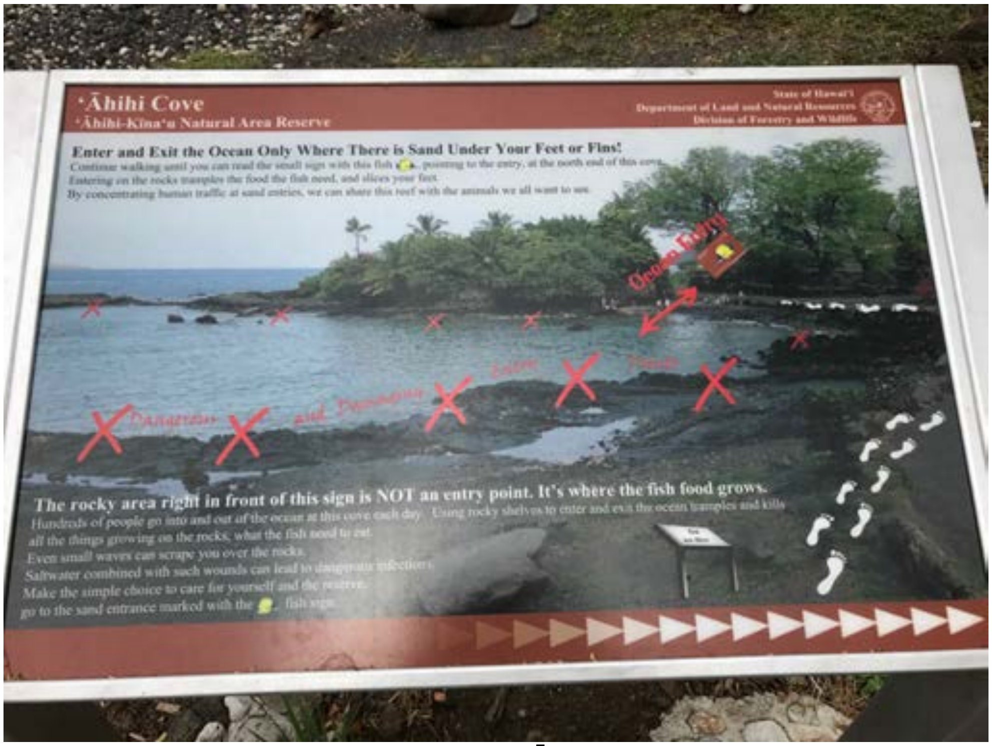


Figure 28. Informational signs, like these at ʻĀhihi-Kīnaʻu nature reserve on Maui, should be placed along the beach showing/reminding visitors where it is safe to enter the ocean and safe areas to snorkel.

Figure 28. Informational sign at ʻĀhihi-Kīnaʻu nature reserve on Maui reminding visitors to "Never stand unless on sand."

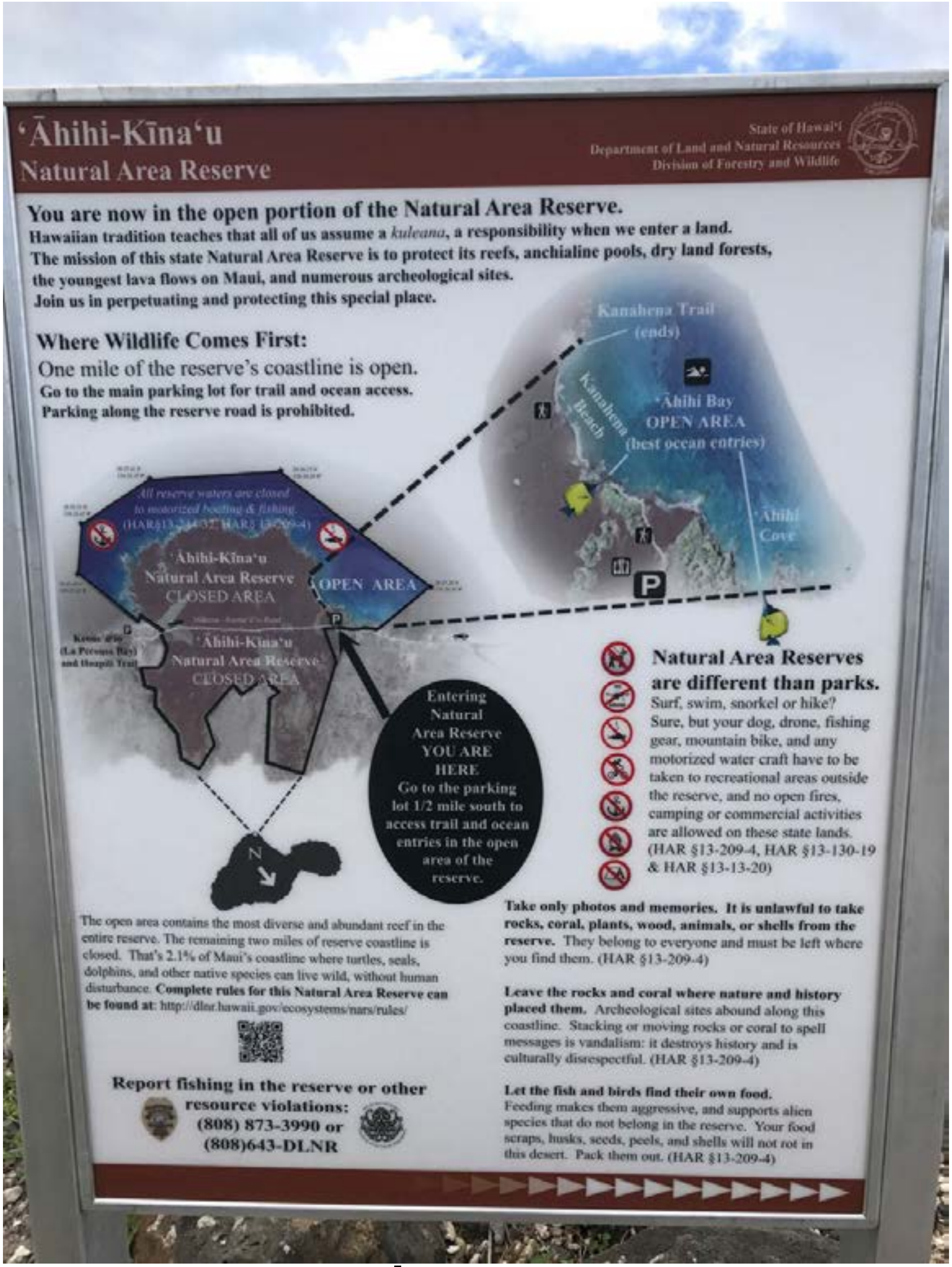


Figure 30. Informational signs, like at 'Āhihi-Kīna'u nature reserve on Maui, should be placed near the beach showing/reminding visitors where it is safe to enter the ocean and safe areas to snorkel.

ACKNOWLEDGEMENTS

We are extremely grateful to the City and County of Honolulu for supporting this research. These surveys would not have been possible without the help of Coral Reef Ecology Lab members and volunteers: Anke Roberts, Michael Feeley, Ron Bregman, Hope Ushiroda-Garma, Heather Parsons, Tiara Drabble, Rolandon Adde, Keisha Bahr, Anita Tsang, Ji-Hoon Justin Han, Andrew Graham, Rebecca Weible, Ashley McGowan, Yuko Stender, Angela Richards Dona and Leah Shizuru.

Budgetary Spending:

Description	**Awarded**	**Total Expended**	**Available Balance**
Biological Carrying Capacity of Hanauma Bay Nature Preserve			
Project date 01/1/2018-12/31/2018			
Itemized Budget - Total Project Costs		Expenditures	
Categories			
A. Salaries			
Research Technician (Sarah Severino)	25,920	42,434	0
Total Personnel	**40,987**		
B. Supplies	4,467	3,021	0
Total Materials and Supplies Costs	**4,467**		
C. Total Direct Costs	45,454		
D. Indirect Costs 10%	4,545	4,545	0
E. Total Direct and Indirect Costs	50,000		
F. Amount of This Request	**50,000**	**50,000**	0

A. Salary and Fringe

Stipend for Sarah J. L. Severino began 5/01/2018 and continues throughout this second quarter period. No fringe benefits are associated with a UH stipend.

B. Materials and Supplies

Materials were purchased for human count experiments and direct human impact monitoring experiments. Three time-lapse outdoor cameras were purchased to acquire data on the number of visitors in each sector of the HBNP to determine the relationship with the percent loss of coral skeleton due to trampling and various other parameters. PVC pipe, caps and concrete were purchased for building 30 sediment traps. Various equipment was purchased for securing and labeling experimental units (epoxy, zip ties, etc.). Equipment purchased for completing visual surveys include fishing weights, waterproof paper, etc. The following table is a breakdown of the 1st through 3rd quarter materials and supplies costs:

Trans. No.	Trans. Date	Vendor	Description of Goods/Services	Total Cost Amount
1	4/15/2018	Home Depot	PVC caps for sediment traps	$16.21
2	4/25/2018	Amazon	camera, batteries, memory card	$115.19
3	5/3/2018	Amazon	camera	$89.00
4	5/4/2018	Amazon	memory card	$13.60
5	5/6/2018	Lowes	sediment trap supplies	$83.33
6	5/7/2018	Amazon	label tape	$7.00
7	5/10/2018	Amazon	epoxy, weights	$43.10
8	5/10/2018	Amazon	waterproof paper	$329.20
9	5/23/2018	Lowes	Metal brass brush	$15.60
10	5/23/2018	West Marine	Epoxy	$92.13
11	5/25/2018	Amazon	Camera, memory card, batteries	$118.59
12	6/21/2018	Amazon	External Hard drive	$94.23
13	9/14/2018	Amazon	Cable Ties	$32.49
14	12/13/2018	UH ITS Site License	SPSS Statistical Package License	$150.00
15	1/3/2019	Aqualung	BC	$224.50
16	1/3/2019	Apexs	Regulator - 1st stage	$222.50
17	1/3/2019	Aqualung	2nd stage	$76.50
18	1/3/2019	Aqualung	Console instrument	$109.50
19	1/3/2019	Aqualung	Compass Intrument	$39.00
20	1/3/2019	Aqualung	Trim Pocket	$6.50
21	1/3/2019	Aqualung	Trim Pocket	$6.50
22	1/3/2019	Aqualung	Dive Computer	$195.00
23	1/3/2019	Aqualung	Knife	$24.50
24	1/3/2019	Cyanea	Mask	$48.00
25	1/3/2019	Sea Star	Fins	$19.00
26	5/1/2019	UH Dive Office	UH Scientific Diver Course	$850.00
			TOTAL:	$3,021.17

D. Indirect costs

The indirect cost rate for 2018 has been negotiated between the State of Hawaiʻi and the University of Hawaiʻi at 10%.
http://www.ors.hawaii.edu/index.php/rates/83-quick-links/100-sponsor-specific-rates

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Appendix A. Annotated Bibliography and Timeline

Hanauma Bay Annotated Bibliography

Bailey-Brock, J., Brock, R., Kam, A., Fukunaga, A., & Akiyama, H. (2007). Anthropogenic disturbance on shallow cryptofaunal communities in a marine life conservation district on Oahu, Hawaii. *International review of hydrobiology*, *92*(3), 291-300.

- LOCATION: Hanauma Bay, Oʻahu HI
- TYPE: Field Study
- In Text Citation: (Bailey-Brock et al. 2007)
- SUMMARY:
    - Analysis of cryptic invertebrate communities in coral rubble and sand from Hanauma Bay.
    - Rubble collected from areas used by waders had a greater diversity of cryptofauna than sand habitats.
        - Rubble may provide a greater variety of microhabitats and protection from tramping.
    - Found that disturbance by human trampling on shallow sands reduces the species richness of cryptofauna.
- Materials and Methods:
    - Five locations in three sections of the Bay were sampled July 1999.
        - Two 1-liter samples at depths of 0.5-0.6 m.
        - Three replicate cores collected within 30 cm of each of two sites and depths.
            - Site 1: Channel- shallow and deep.
            - Site 2: Backdoors- shallow and deep.
- Discussion:
    - The total infaunal taxa and abundance was greater in coral rubble samples than for any sand samples.
    - Large differences in diversity and abundance of taxa from sand samples in shallow vs. deep sites suggests that anthropogenic disturbance as well as physical disturbance shapes the composition of infaunal communities.
    - Sand-feeding goatfishes spend considerably more time feeding over sands in water depths of 2-4 m, than in sands at shallower depths (0.5-1.5 m) in Hanauma Bay on days when the Bay is closed to visitors.
- Conclusion:
    - Despite management efforts to conserve biological resources, wading and disturbance in the shallow sand areas have reduced the biodiversity and abundance of the interstitial fauna.
    - In areas too deep for waders, the biodiversity and abundance of interstitial and cryptofauna was found to be greater in Hanauma Bay than at other locations.

Brock, R., & Kam, A. (2000). Carrying capacity study for the Hanauma Bay nature preserve: final report. *Honolulu: Department of Parks and Recreation*. Carrying Capacity Study for the Hanauma Bay Nature Preserve Final Report

- LOCATION: Hanauma Bay, Oʻahu HI
- TYPE: Carrying Capacity Study
- In Text Citation: (R. E. Brock and Kam 2000)
- SUMMARY:
    - Background of Hanauma Bay:
        - Formation of the bay-geology.
        - History of ownership of the bay.
        - History of human activities becoming more popular in the bay.
        - Tourism and Hanauma Bay.
        - Negative impact on marine resources within the bay due to physical disturbance/trampling, humans entering water and shedding suntan oil and bacteria, human urine, bird feces, etc.
    - GOAL: Determine the relationship between human use of the Hanauma Bay Nature Preserve as measured by the number of users and level of disturbance of marine biota and water quality for the

purpose of managing the number of Park visitors at levels which protect and maintain the integrity of the Bay's marine communities.

- First Year Objectives:
    - Conduct initial overview inventory of marine biological resources and terrestrial influences affecting the Bay.
        - 6mo report: identifying marine biological resources and related social conditions, and recommend a preliminary level of use for the Bay based on the initial data.
        - 1yr report: recommendations on the level of use of the Bay is made based on the data to date.
    - Establish a scientific methodology for monitoring and analyzing the marine biological resources and water quality of the Bay.
    - Establish field experiments to determine the levels and sources of indicator bacteria and impact of human trampling on benthic biota.
    - Estimate basalt/coralline sediment at different depths in sand deposits to reconstruct changes in terrigenous input of the Bay.
    - Review related research and comparative analyses with data from the Bay and other resource areas similar to the Bay.
    - Prepare recommendations addressing resource management needs, practices and standards relating to continued monitoring, gathering and analyzing data from the Bay.
- The National Park Service (1997) has developed a framework protocol for determining human carrying capacity for application in parks; this process is known as the visitor experience and resource protection framework or VERP. VERP Framework Foundation:
    - Element 1: Assemble an Interdisciplinary Project Team: Includes both those who plan and those that implement a plan.
    - Element 2: Public Involvement Strategy.
    - Element 3: Develop Statement of Park Purpose, Significance, and Primary Interpretative Themes; Identify Planning Constraints.
    - Element 4: Analyze Park Resources and Existing Visitor Use.
    - Element 5: Describe a Potential Range of Visitor Experiences and Resource Conditions.
    - Element 6: Allocate the Potential Zones to Specific Locations in the Park.
    - Element 7: Select Indicators and Specify Standards for Each Zone; Develop a Monitoring Plan.
    - Element 8: Monitor Resource and Social Indicators.
    - Element 9: Take management Action.
- Materials and Methods:
    - Water Chemistry Sampling
    - Inventory and Monitoring of Marine Communities
        - Fish -25m transects.
        - Epibenthic -4x25m areas
        - Exposed sessile benthic forms (Corals/Sponges/ Macrothalloid Algae) - Point-Intersect method quadrats- 50 such points in 6 one-meter frames placed five-meters apart along the 25m fish transect.
        - Within each biotope, a number of permanently marked stations are stablished and quantitative studies conducted at each include a visual enumeration of fish, counts along benthic transect lines and cover estimate in benthic quadrats.
        - Notes taken on number, size and location of any threatened or endangered species (spinner porpoises, humpback whales or green sea turtles).
    - Visitor Use
        - Used daily log from toll gate separated by residents and non-residents.
        - Counts were taken various days of the week and time of the day.
            - If in the ocean, notes were taken on their activity: wading, swimming, viewing fish and location within the bay.

        - Bay was divided into (1) the inner Bay which included all shallow reef areas from shore to the fringing reef crest, and (2) areas seaward of the inner bay. Inner Bay was divided into three sections: the eastern third, the central third and western third.
    - Experiments to Determine Impact of Human Trampling on Benthic Biota
        - Design of experiment differentiates the impact of grazing fishes from human trampling on inner reef benthic communities.
            - 3 experimental treatments: (1) areas of bottom subject to human trampling and fish grazing (natural present situation), (2) an experimental are where human trampling does occur but fish grazing continues, and (3) where neither human trampling nor fish grazing can occur (using wire pens to keep herbivores out).
    - Basalt/Coralline Determinations
        - Driving 3.8 cm diameter x 122 cm long clear plastic tube into the sand.
        - In the laboratory sand samples are removed from different sections of the core, dried in an oven until constant weight, acidified to remove the carbonate (coralline) fraction, rinsed, re-dried and reweighed. The difference in the two weights represents the coralline fraction and the remainder is the basaltic fraction. Changes in these data may be used to infer changes in the input of basalt which may be related to changes in storm water runoff.
- Results and Discussion
    - Human Use:
        - Figure 1. Daily total number of visitors at the Hanauma Bay Nature Preserve from May 1, 1999 through April 30, 2000. Pg. 14
        - Figure 2. Monthly visitor counts depicted as total counts, residents, and non-residents.
        - Table 1. Breaks visitor logs into high use periods (summer months) and low use periods (winter/spring) and then breaks down into % on the beach, in water, wading, swimming, and outside of reef.
    - Water Quality:
        - Samples taken at High-high and Low-low per sample day. Surface, mid-water, and bottom (0.3 m to 1 m above substrate).
            - Comparison of a Tuesday (no visitors) with a Wednesday (visitors).
            - 40 locations through the bay, 27 taken along three mauka - makai transects and represent surface and deep samples. 10 from mid-water and 3 sample sites from areas with groundwater input evident along the shoreline at low tide.
            - Total Nitrogen and Orthophosphates higher in shallow sections with visitors. Figure 5 & 6.
            - Turbidity was higher in shallow sections with visitors, Figure 8.
        - Cost to process first series of water samples = $12,000
        - Pg. 20, Figure 3 shows sample sites. Table 2 shows mean water quality for each site.
    - Human Trampling
        - Benthic algal growth is much greater (will probably be significantly greater) in caged treatments (where substratum is not available for either human trampling or herbivorous fish grazing).
        - Algal growth was not much different from adjacent areas where people walk in treatments open to grazing fish but away from trampling (Pg. 52).
    - Microbial Studies:
        - Did not perform.
    - Marine Communities and Biotopes:
        - Sand Biotope- dominated by sand.
        - Boulder Biotope
            - Seaward of Witches Brew and along the submarine cliff near Toilet Bowl.
        - P. compressa

            - 2 deep locations.
        - P. lobata
            - Dominant biotope.
        - Spurs and Grooves
        - Inner Reef Flat
    - There is no biological evidence from this preliminary point in this study to suggest that the number of visitors should be increased or decreased over present levels.
        - Current use in year 2000 was 3,000 visitors per day.
- For Brock's Baseline he uses:
    - (1) Water quality sampling (ammonia nitrogen, nitrate+nitrite nitrogen, total nitrogen, total phosphorous, chlorophyll-a, nephalometric turbidity, dissolved oxygen, temperature, pH, salinity, silica and orthophosphorus.
    - (2) Inventory and Monitoring of Marine Communities: define major zones or biotopes present in the study area. Fish and benthic were taken within each biotope—never produced in a report.
    - (3) Assessed Visitor Use of Hanauma Bay
    - (4) Experiments
        - - Assessing the effects of fish feeding
        - -Determine impact of human trampling on benthic biota—cage experiment—never produced in a report.
        - -Basalt/Coralline Determinations in the Sand
- Assessment of Inner reef flat conditions:
    - "Four permanently marked sampling stations were established in the inner reef biotope. These are station 11 (east of the "keyhole" swimming area), station 14 (just west of the "keyhole"), station 17 offshore of the middle lifeguard tower and station 18 offshore of the west bathrooms. All of these stations were established at depth from 0.2 to about 1.5 m. Other than the coralline alga, *Porolithod onkodes*, most macroalgae or limu are not obvious in this biotope. Coralline algae have a mean of 1 species per transect and a mean coverage of 4%. Seaweed or limu have a mean of four species per transect and a mean coverage of 1.6%. Corals are most often seen along the sides of depressions in the reef. The average number of coral species per transect is 3 and the mean coverage is 0.8%. Coral species seen in the inner reef biotope sample sites include *Porites lobata, Montipora verrucosa, Cyphastrea ocellina, Pocillopora meandrina,* and *P. damicornis.* Over the course of the May 1999-June 2000 sample period, there has been no change in the coverage of corals at these four inner reef flat stations."

      "The most obvious species on the inner reef flat at Hanauma Bay are the fishes. The most abundant species include the sergeant major or mamo (*Abedefduf abdominalis*), chub or nenue (*Kyphosus bigibbus*), convict tang or Manini (*Acanthurus triostegus*), ringtail surgeonfish or pualo (*Acanthurus blochii*), blackspot sergeant or kupipi (*Abudefduf sordidus*), brown surgeonfish or ma'I'I'I (*Acanthurus nigrofuscus*), saddle back wrasse or hinalea lauwili (*Thalassoma duperrey*), and bluelined surgeonfish or ta'ape (*Lutjanus kasmiral*). The mean number of species seen per transect is 19 and the mean number of individual fishes censused per tranect is 153 individuals. In terms of estimated standing crop, the average biomass per transect on the inner reef flat station is 410 g/m^2. Over the year, the most important contributors to this biomass were the nenue (*Kyphosus bigibbus*), pualo (*Acanthurus blochii*), Manini (*Acanthurus triostegus*), eyestripe surgeofish or palani (*Acanthurus dussumieri*) , orangespine surgeofish or umaumalei (*Naso lituratus*), ta'ape (*Lutjanus kasmira*), mamo (*Abudefduf abdominalis*), stareye parrotfish or ponuhunuhu (*Calotomus carolinus*), redlip parrotfish or palukaluka (*Scarus rubroviolaceus*), spectacle parrotfish or uhu uliuli (*Scarus perspicillatus*) and blue trevally or omilu (*Caranx melampygus*). A list of the species of fishes encountered in the inner reef area is given in Table 6."

      "The standing crop of fish is significantly greater (P>0.0002) on Wednesdays (mean = 655 g/m^2) over the preceding Tuesdays (mean biomass = 381 g/m^2). This result is probably related to the feeding activities that were occurring on the days with visitors present, and were not occurring on the days when they were absent."

- MAJOR FINDINGS:
    - Turbidity was higher in shallower sections with more visitors (Figure 8).
    - Algal growth was not much different from adjacent areas where people walk in treatments open to grazing fish but away from trampling (Pg. 52).
    - Found that there was no biological evidence from their preliminary findings that the number of visitors should be increased or decreased over present levels.
- QUESTIONS:
    - Where is the report of their findings from cage experiments?

Brock, R. (1997). Hanauma Bay: A proposed study to determine human impact both today and in the future. (pg. 1-8)

- LOCATION: Hanauma Bay, Oʻahu HI
- TYPE: Proposal for Carrying Capacity Study
- In Text Citation: (R. E. Brock 1997)
- SUMMARY:
    - Proposal for carrying capacity study.
        - 1990 surveys found more than 6,700 visitors per day coming to the bay, but many estimates were between 10,000 and 12,000 people per day.
    - Proposed METHODS:
        - Permanent biological monitoring stations established in all major biotopes.
            - Monthly monitoring
        - Routine water quality monitoring
        - Hand operated coring attempted for marine sands of Hanauma Bay.
            - Looking for input from land- basaltic fraction.
            - Assumption that sedimentary material in a core is laid down sequentially through time with minimal reworking.

Brock, V. E. (1954). A preliminary report on a method of estimating reef fish populations. *The Journal of Wildlife Management*, *18*(3), 297-308.
A preliminary Report on a Method of Estimating Reef Fish Populations

- LOCATION: Hanauma Bay, Oʻahu HI
- TYPE: Method Development
- In Text Citation: (V. E. Brock 1954)
- SUMMARY:
    - Counted the number and species of fish present within Hanauma bay and various other locations.
- Materials and Methods:
    - Swim along a 500-yard line laid across the sea floor and count fish seen.
        - Survey distance was 1,500 ft. length by 20 ft. wide = 60,000 ft^2
    - Recorded estimated length, names of fish, family, notes on water depths, nature of bottom, and associated flora and invertebrate fauna.
    - A transformation of lengths into weights was made by the equation: $W = A (L^3)$
        - W = weight, L = estimated length, A = a species constant based on known weights nd lengths for the species involved.
- Results:
    - The pattern of distribution of species for the Hanauma Bay Station indicated that it was essentially a "windward" area.
        - *Zebrasoma flavenscens* was not common.
        - The weight of the fish in a school of opelu, *Decapterus pinnulatus* accounts for a large portion of the miscellaneous species.
    - Table 1. Hanauma Bay survey on 9/11/52
        - Number of fish counted = 819
        - Calculated weight Pounds = 137

- Mean weight of fish = 0.17
    - Calculated pounds per acre = 100
    - Bottom = ½ over sand some rock and coral.

Brown, E. K., Cox, E., Jokiel, P. L., Rodgers, S. K. U., Smith, W. R., Tissot, B. N., Coles, S. L. & Hultquist, J. (2004). Development of benthic sampling methods for the Coral Reef Assessment and Monitoring Program (CRAMP) in Hawai'i. *Pacific Science*, *58*(2), 145-158.

- LOCATION: Main Hawaiian Islands
- TYPE: Method Development
- In Text Citation: (Brown et al. 2004)
- SUMMARY:
    - Longer transects had higher variability than shorter (10m) transects.
    - A within-habitat stratified random sampling design was implemented for the CRAMP design.
    - Fixed transects were chosen to reduce temporal variance and allow efficient resurveying under the high-wave-energy field conditions.
    - Method was designed to detect an absolute change of 10% in benthic cover with high statistical power using 50 points per frame, 20-30 frames per transect, and 8-10 transects per depth.
    - Fixed photoquadrats with high precision and high resolution were included in the design to allow detailed monitoring of coral/algal growth, recruitment and mortality.
    - OBJECTIVE OF CRAMP: Evaluate the conditions of the reef communities throughout the main Hawaiian Islands by describing spatial and temporal variation in Hawaiian reef communities in relation to natural and anthropogenic forcing functions.
        - CRAMP sites will continue to be monitored at regular intervals over the next century and will form the basis for evaluating long-term change on Hawaiian coral reefs.
    - 10 fixed transects at each 3m and 10m depth.
    - 5 randomly selected photoquadrats at each depth contour were established with one pin in each corner to ensure accurate repositioning of the frame.

Bryan, W. B., & Stephens, R. S. (1993). Coastal bench formation at Hanauma Bay, Oahu, Hawaii. *Geological Society of America Bulletin*, *105*(3), 377-386.

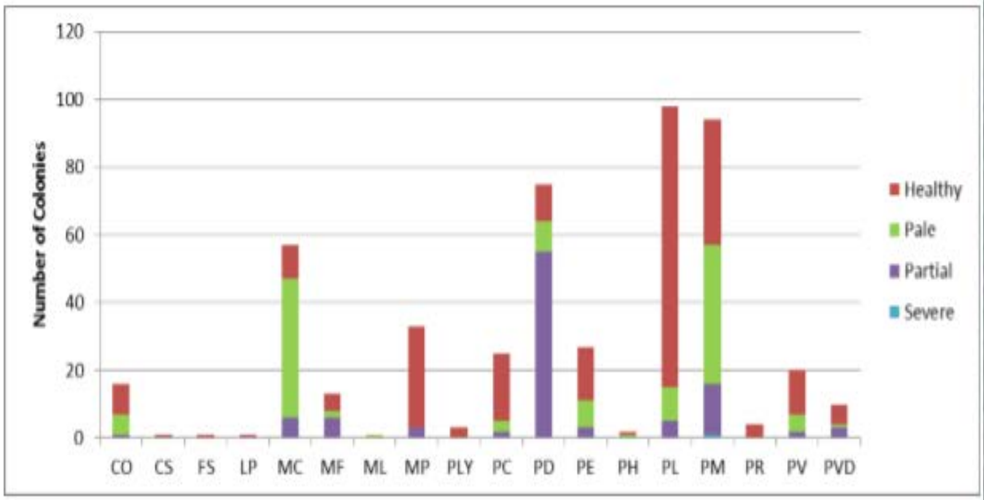
- LOCATION: Hanauma Bay, Oʻahu HI
- TYPE: Geological Field Study
- In Text Citation: (Bryan and Stephens 1993)
- SUMMARY:
    - Suggests that the formation of the bench at Hanauma Bay is the result of strongly differential rates of cliff retreat above and below the sharp wetting boundary associated with daily high tides.
    - Salt weathering above the level of daily wetting by high tides is a major factor in the cliff retreat that has formed the bench in Hanauma Bay. The bench reflects the daily upper limit of wetting by the present era.

Clark, A. M. (2016). Hawaii's Sustainable Marine Tourism Challenges and Opportunities. Hawaii Division of Aquatic Resources PowerPoint Presentation.

- LOCATION: Hanauma Bay, Oʻahu HI
- TYPE: PowerPoint Presentation
- In Text Citation: (Clark 2016)
- SUMMARY:
    - Hanauma Bay info:
        - 1988: 3 million visitors per year, 10-12,000 visitors per day. Feeding fish up to ½ ton bread per day.
        - Present: 3,000 – 5,7000 visitors/day, ban of fish feeding, entrance fee and parking limitations, mandatory visitor education/friends group.

DAR Coral Bleaching Survey (2014), Brian Neilson, DLNR-Division of Aquatic Resources

- LOCATION: Hanauma Bay, Oʻahu HI
- TYPE: Field Study on Coral Bleaching
- In Text Citation: (Neilson 2014)
- SUMMARY:
    - Coral Bleaching Rapid Response Surveys Sept-Oct 2014
        - 47% of coral colonies within Hanauma Bay exhibited signs of bleaching.
            - CO, MC, MF, PD, PE, PL, PM and PV.
        - <1% showed signs of severe bleaching.
        - Bleaching was much less severe at Hanauma Bay compared to windward O'ahu sites.
        - 14 out of the 18 coral species surveyed exhibited signs of bleaching

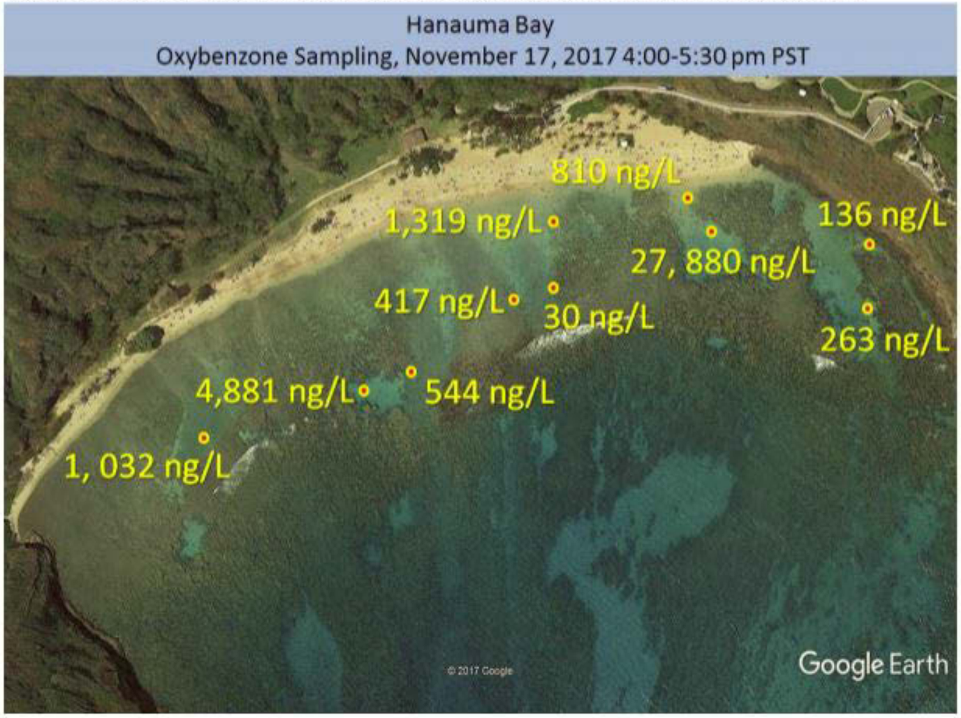


Downs, C. A., (2018). Baseline Measurement of Seawater for Oxybenzone Contamination at the Hanauma Bay Marine Life Conservation Districts. 7p.

- LOCATION: Hanauma Bay, Oʻahu HI
- TYPE: Field Study
- In Text Citation: (Downs 2018)
- SUMMARY:
    - Sampled 10 sites within Hanauma to provide baseline survey for oxybenzone pollution in the Bay.

- Concentrations of oxybenzone ranged from 30 ng/L to 27,880 ng/L.

Concentration of Oxybenzone at each of sample sites in Hanauma Bay, Oahu, Hawaii.



Easton, W. H., & Olson, E. A. (1976). Radiocarbon profile of Hanauma Reef, Oahu, Hawaii. *Geological Society of America Bulletin*, *87*(5), 711-719.

- LOCATION: Hanauma Bay, Oʻahu HI
- TYPE: Field Study
- In Text Citation: (Easton and Olson 1976)
- SUMMARY:
    - 10 core holes through an active fringing reef within the bay provided 63 samples for which C^{14} dates were determined. The ages indicated that…
        - The reef started growing about 7,000 years ago.
        - Most of its vertical growth was during the interval from 5,800 to 3,500 radiocarbon years ago. Average upward growth at this time was 1 m/ 300 yr.
        - During the last 3,000 years, it advanced seaward at the rate of 1 m/ 45 years.
    - "Reef growth is primarily lateral or eve downward in channels and pockets, rather than directly upward, and so a vertical bore hole could pass down through a former wall of material of the same age for a distance, and it also could pass from older into younger material as it descends through an overhanging mass."
- INTRO:
    - Core taken from drill holes through the reef were dated by radiocarbon in order to determine (1) the age, (2) the pattern and rate of growth, (3) the reliability for radiometric dating of random samples from reefs, (4) the approximate time of the latest volcanic eruption before reef growth began, (5) the rate of rise of sea level, and (6) how consistent the dates are when using different chemical techniques and different materials from the same level.
- DISCUSSION:
    - "During the past 3,000 yr, the reef grew seaward about 70 m and shoreward about 40 m, but the central area remained essentially unchanged."
        - Has the inner reef flat been stunted by lowering of sea-level. At a time when sea-level was higher, it grew vertically, but this paper suggests it can no longer grow vertically due to the lower sea-level that exists in the present.
- CONCLUSIONS:

- Hanauma Bay Reef started to grow at least 7,000 radiocarbon years ago.
- The reef consists largely of massive and branching corals intergrown with calcareous algae. In general, corals are most abundant in lower portions of the reef, and calcareous algae are most abundant in higher portions of the reef.
- Between 3,500 radiocarbon years and the present, sea level and reef growth have risen at the rate of 1 m in 3,5000 yr.
- Reef growth is primarily lateral or eve downward in channels and pockets, rather than directly upward, and so a vertical bore hole could pass down through a former wall of material of the same age for a distance, and it also could pass from older into younger material as it descends through an overhanging mass.
- Single or sparse samples taken without knowledge of or regard to the geological features of reefs resembling Hanauma Reef are of doubtful value in determining the age of the reef.

Friedlander,A., Donovan, M., Koike, H., Murakawa, P., & Whitney, G. (2018). Spatial and temporal trends in Hawai'i's marine protected areas. *Aquatic Conservation: Marine and Freshwater Ecosystems*. 48p. Under Review.

- LOCATION: Main Hawaiian Islands
- TYPE: Metadata Analysis
- In Text Citation: (A. Friedlander et al. 2018)
- SUMMARY:
    - Twenty-five datasets, representing 1,031 individual surveys conducted through Hawaii since 2000 were used to compare fish assemblage characteristics amongst a subset of MPAs using a regulation-based protection classification scheme.
    - Fully and highly protected areas had significantly greater resource fish biomass compared with areas with intermediate, or low protection.
    - Long-term monitoring of select MPAs showed mixed and complex trajectories. Resource fish biomass increased after the establishment of the Hanauma Bay MLCD in 1967 but plateaued after ~15 years, followed by changes in assemblage structure from fish feeding and invasive species.
- RESULTS:
    - There were significant increases in resource fish biomass in Hanauma Bay after initial protection.
    - In early years (1960-70s) in Hanauma Bay, goatfishes (Mullidae) and parrotfishes (Scaridae) were most prevalent. In the late 1970s, chubs (Kyphosidae) showed a strong influence until the late 1990s, which likely resulted from an inc. in fish feeding during the time. Once fish feeding was banned in 1999, the family composition reverted to something resembled that in the 1960s, but with the addition of two invasive species from the families Serranidae (*Cephalophus argus*) and Lutjanidae (*Lutjanus kasmira*).

Friedlander, A. M., Brown, E. K., & Monaco, M. E. (2007). Coupling ecology and GIS to evaluate efficacy of marine protected areas in Hawaii. *Ecological Applications*, *17*(3), 715-730.

- LOCATION: Main Hawaiian Islands
- TYPE: Interpretation of Orthorectified Aerial Photography
- In Text Citation: (A. M. Friedlander, Brown, and Monaco 2007)
- SUMMARY:
    - A number of fish assemblage characteristics (e.g., species richness, biomass, diversity) vary among habitat types, but where significantly higher in MLCDs compared with adjacent fished areas across all habitat types.
    - Size of protected area was positively correlated with a number of fish assemblage characteristics.
- METHODS:
    - NOAA acquired and visually interpreted orthorectified aerial photography, IKONOS satellite imagery, and hyperspectral imagery for the near-shore waters (to 25 m depth).
    - Fish sampling methodology:
        - At each location standard underwater visual belt transect survey methods were taken in 25 m x 5 m transects.

Gardner, E. A. (1999). A Victim of Its Own Success: Can User Fees Be Used to Save Hanauma Bay. *Ocean & Coastal LJ*, *4*, 81.

- LOCATION: Hanauma Bay, Oʻahu HI
- TYPE: Literature Review of History behind user fees at Hanauma Bay
- In Text Citation: (Gardner 1999)
- SUMMARY:
    - The statutory purposes of establishing a MLCD are “specific to protecting and conserving marine resources.” In contrast, the objective for establishing an underwater park is to “enhance recreational activities.” These two objectives can conflict, and often lead to the detriment of the environment through over use, as demonstrated by the recent history of Hanauma Bay. The DLNR has suggested that recreational objectives should be a “secondary benefit” within MLCDs.
        - Direct quote from discussion of literature review.

Grigg, R. W. (1998). Holocene coral reef accretion in Hawaii: a function of wave exposure and sea level history. *Coral Reefs*, *17*(3), 263-272.

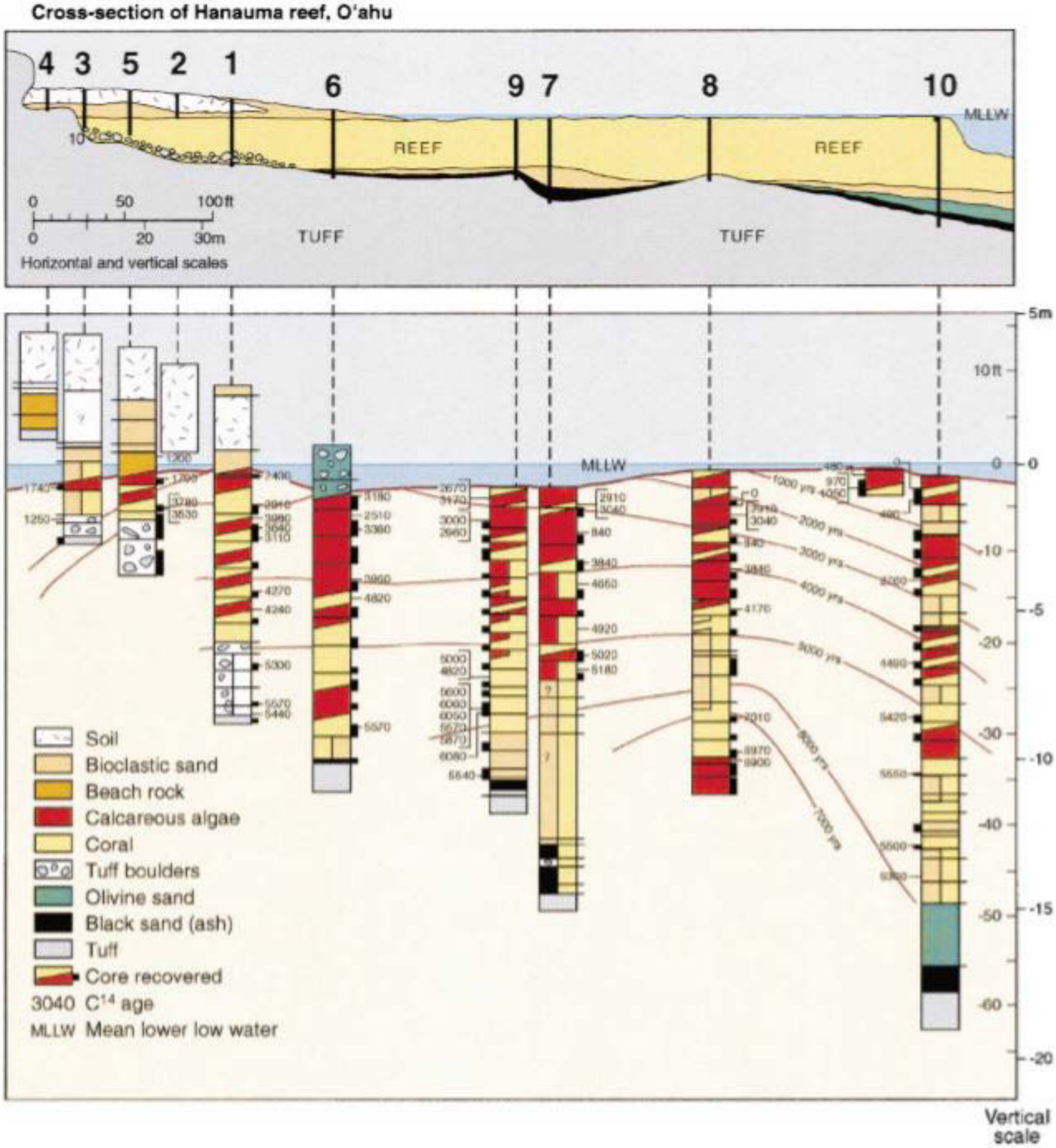
- LOCATION: Oʻahu HI including Hanauma Bay
- TYPE: Field Study
- In Text Citation: (Grigg 1998)
- SUMMARY:
    - At wave sheltered stations in Hanauma Bay and Kaneohe Bay, rates of long term reef accretion are about 2.0 mm/yr.
- METHODS:
    - Four stations on the island of Oahu were chosen for study situated along a gradient of increasing exposure to significant wave energy.
        - Checker Reef in Kaneohe Bay
        - Hanauma Bay, Channel area and offshore, cores taken near keyhole.
        - Mamala Bay
        - Sunset Beach
    - Hanauma was the second-most sheltered site from wave energy selected for the study.
    - In 1967 10 cores were drilled through the shallow fringing reef by Easton and Olson. This work showed that the reef at Hanauma began growing about 7000 yr ago at 15 m depth when rising sea level flooded the bay. Initially rate of accretion was high (averaged 4.5 mm/y). Horizontal accretion seaward at the reef crest was even greater, averaging almost 20 mm/y. During the last 3000 years accretion has slowed to 1 mm/y. In the middle of the reef flat, the youngest dated material was found to be 2000 to 3000 years old, suggesting that sea level reached its present level at this time and prevented the growth of younger material, or that a higher sea level existed for a time in the middle Holocene allowing younger growth to accrete by that subsequently sea level fell back to its current level and physical and biological erosion removed younger material. Overall during the last 7000 years accretion is averaged at 2.0 mm/y.
- RESULTS:
    - Communities at the shallow site at Hanauma Bay are constrained by subaerial exposure.
    - 12 m depth community at Hanauma Bay was dominated by *Porites compressa* and *Porites lobata.* Their relative abundances are 55% and 45 %, respectively. The growth rate of *P. lobata* at this depth was 8.13 mm/y, about twice the rate of vertical reef accretion measured by Easton and Olson (1996).

Table 1 Community structure and growth of coral reefs at sites selected for study. Attributes of community structure are based on one 50 m transect at each station. Annual coral growth rates are averages of 10 colonies

Site	Depth (m)	Coral cover %	Coral diversity (H′)	Algal cover %	Bare limestone %	Sand %	Dominant coral, algae	Coral growth (mm/y)
Kaneohe Bay	1	2 ± 5	0.16	5	1	95	P.c.	Negligible
	2–5	69 ± 20	0.35	9	3	19	P.c. M.v.	7.66
Hanauma Bay	1	< 1	< 0.01	90	10	0	P.o.	Negligible
	12	73 ± 14	0.87	0	5	10	P.c. P.l.	8.13
Mamala Bay	1	6 ± 3	0.15	90	5	5	P.m.	Negligible
	12	10 ± 5	0.35	2	40	40	P.l.	10.1
Sunset Beach	1	9 ± 8	0.53	60	20	0	P.l.	Negligible
	12	15 ± 13	0.68	20	65	0	P.m.	8.08

P.l., *Porites lobata*; P.c., *Porites compressa*; M.v., *Montipora verrucosa*; P.m., *Pocillopora meandrina*; P.o., *Porolithon oncodes* (coralline algae)

Cross-section of Hanauma reef, O'ahu



Hanauma Bay Attendance Year 2016 & 2017

- LOCATION: Hanauma Bay, Oʻahu HI
- TYPE: Summary Table
- In Text Citation: (Hanauma Bay Attendance 2017)
- SUMMARY:
    - July appears to be the busiest month.
    - February appears to be the slowest month.
    - Approximately 3,000 visitors per day.

Hanauma Bay Nature Preserve
Daily Attendance Summary

FISCAL YEAR JULY' 15 - JUNE' 16

Month	Visitors Monthly #	Visitors Daily Avg #	Visitors YTD #
JUL	87,385	3,236	87,385
AUG	82,986	3,074	170,371
SEPT	50,059	2,176	220,430
OCT	59,728	2,389	280,158
NOV	56,584	2,176	336,742
DEC	70,225	2,809	406,967
JAN	68,955	2,652	475,922
FEB	47,301	2,365	523,223
MAR	74,659	2,872	597,882
APR	64,419	2,478	662,301
MAY	61,743	2,375	724,044
JUN	79,983	3,076	804,027
TOTAL	804,027		

FISCAL YEAR JULY' 16 - JUNE' 17

Month	Visitors Monthly #	Visitors Daily Avg #	Visitors YTD #
JUL	87,180	3,353	87,180
AUG	86,193	3,315	173,373
SEPT	62,682	2,411	236,055
OCT	66,134	2,449	302,189
NOV	60,227	2,409	362,416
DEC	67,886	2,611	430,302
JAN	67,129	2,685	497,431
FEB	58,208	2,531	555,639
MAR	74,953	2,776	630,592
APR	69,820	2,685	700,412
MAY	66,894	2,573	767,306
JUN	75,133	2,890	842,439
TOTAL	842,439		

Hanauma Bay Case Study (1989)

- LOCATION: Hanauma Bay, Oʻahu HI and various other sites.
- TYPE: Case Studies
- In Text Citation: (Hanauma Bay Case Study 1989)
- SUMMARY:
    - MLCD's are established to meet two competing goals: 1) to provide for the conservation of the resource, and 2) to promote the use of a resource.
- INTRODUCTION:
    - Site-specific problems:
        - Sedimentation: erosion of topsoil caused by disturbance of vegetation from people walking and other upland areas are sources of sedimentation.
        - Runoff: from paved parking lot carrying oily residues, rat, mongoose and domestic animal wastes to the bay waters. Water at this time was running from shower stalls directly into the bay in a steady stream. Direct drainage of wastewater from the food/snorkel gear rental concessions.
        - Water Quality: Often have high levels of fecal coliform bacteria. Sewer backups are frequent at restrooms down at beach. High levels of bacteria are presumably caused by bird and animal wastes and possibly from cesspools. – this is not necessarily a health hazard to humans, but instead they are indicative of potential health risks.
        - Garbage: Lots of plastic garbage found on shoreline.
        - Reef Trampling: Since the majority of snorkelers that go to Hanauma are new to the ocean environment, they sometimes cling to the reef for support or do not know any better than to step on it. "Although early benchmark data on the live coral populations of the inner reef are scarce, the continuous trampling across the reef is considered damaging to what little live coral is left."

Hanauma Bay Coral Cover (1999 & 2000)

Summary of coral cover within the bay.

- LOCATION: Hanauma Bay, Oʻahu HI
- TYPE: Tables from photocopy of unknown source (pg. 162)
- In Text Citation: (Hanauma Bay Coral Cover 2000)
- SUMMARY:
    - Dominant coral species were P. lobata, M. patula, P. eydouxi, P. meandrina.

Video Transect data (3 m):

Species	% Cover: 1999 Mean	1999 SD	2000 Mean	2000 SD	Diff.
Cyphastrea ocellina	0.0	0.0	0	0	0.0
Fungia scutaria	0	0	0	0	
Leptastrea purpurea	0.0	0.0	0	0	0.0
Montipora flabellata	0.3	0.5	0.2	0.4	-0.1
Montipora patula	0.3	0.7	0.8	1.8	0.5
Montipora studeri	0	0	0	0	
Montipora capitata	0.0	0.1	0	0	0.0
Pavona duerdeni	0	0	0	0	
Pavona maldivensis	0	0	0	0	
Pavona varians	0	0	0.1	0.2	0.1
Pocillopora damicornis	0	0	0	0	
Pocillopora eydouxi	0	0	0.8	1.9	0.8
Pocillopora ligulata	0	0	0	0	
Pocillopora meandrina	0.7	0.7	0.8	0.8	0.1
Porites brighami	0	0	0	0	
Porites compressa	0.0	0.0	0	0	0.0
Porites evermanni	0	0	0	0	
Porites lichen	0	0	0	0	
Porites lobata	22.3	8.8	23.1	9.0	0.8
Porites rus	0	0	0	0	
Psammocora nierstraszi	0	0	0	0	
Unknown Coral	0	0	0	0	
Total Coral	23.6	9.1	25.8	9.4	2.2
Species Richness:	8		6		-2
Species Diversity:	0.28		0.48		0.20
Macroalgae	0.9	2.0	0	0	-0.9

Benthic Habitat Data: 3 m

	Depth (m)	Rugosity	Sediment Composition (% wt.) LOI	H_2CO_3	Sediment Grain Size (% wt.) Gravel	Coarse	Fine	Silt
Mean	3	2.00	4.65	46.51	20.42	68.56	10.82	0.20
S.D.		0.35	0.34	0.88	4.00	2.83	1.16	0.01

Hanauma Bay Hawaii Symposium. Nov, 19, 1983.

- LOCATION: Hanauma Bay, Oʻahu HI
- TYPE: Abstract/Summary of Symposium Talks
- In Text Citation: (Hanauma Bay Hawaii Symposium 1983)
- SUMMARY:
    - Bruce A. Carlson said that surveys of the fish fauna of Hanauma Bay prior to its establishment as a MLCD in 1967 are virtually non-existent.
        - DAR, formerly Div. of Fish and Game, began conducting surveys from 1967 to present of this symposium.

Hanauma Bay Nature Preserve Final Revised Environmental Assessment and Negative Declaration, 1996. Prepared by Wilson Okamoto & Associates, Inc.

- LOCATION: Hanauma Bay, Oʻahu HI
- TYPE: Impact Statement
- In Text Citation: (Wilson Okamoto & Associates 1996)
- SUMMARY:
    - Concerns about declining water quality in the bay due to increased siltation, freshwater runoff and litter have been expressed as early as 1970. In 1988, turbidity, trash and oil films were observed during user survey studies conducted by Wilson Okamoto and Associates, Inc. Soil runoff from the unpaved trafficked areas has also been implicated as a possible cause of increased turbidity in the bay.
    - Potential threats to the water quality observed in 1988:
        - Siltation from storm and shower runoff;
        - Freshwater mixed with soaps and lotions from open showers;
        - Sewage from periodically overflowing cesspools; and
        - Cooking oils and other waste from the concession which leach into the bay through cesspools.
    - Marine life Habitat
        - Corals account for a very small percentage of bottom cover within the nearshore waters of the fringing reef. The only coral present in any abundance is the common star coral *Cyphastrea ocellina*.
        - Coral cover increases in the -6 to -25 ft range, with total cover reaching about 45%.

- At depths of -25 ft and beyond corals dominate the bottom, covering close to 80% of the substrate. Dense thickets of finger coral predominate at these depths, but lobe coral is fairly abundant.

Harada, S. Y., Goto, R. S., & Nathanson, A. T. (2011). Analysis of lifeguard-recorded data at Hanauma Bay, Hawaii. *Wilderness & environmental medicine*, *22*(1), 72-76.

- LOCATION: Hanauma Bay, Oʻahu HI
- TYPE: Analysis of Rescue Events
- In Text Citation: (Harada, Goto, and Nathanson 2011)
- SUMMARY:
  - Lifeguard collected data documenting estimates of daily beach attendance and characteristics of rescue victims and events ranging from 2000-2007.
  - Lifeguards recorded attendance and activity at 12 pm, 2 pm, and 4 pm. The sum of the 3 daily estimates for the swimming and surfing groups were used to calculate daily counts of visitors entering the water and at risk for rescue.
- RESULTS:
  - Found an average of 7 rescues per 10,000 bathers.
  - Non-residents accounted for 88% of visitors and 98% of the rescue population.
  - 63.2% of rescues were made in "the slot" the swimming channel to offshore.

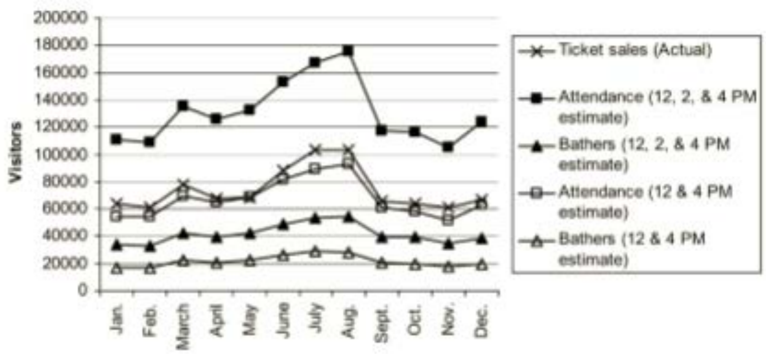


Figure 3. Comparison of lifeguard estimates of attendance and bathers with actual attendance based on ticket sales data averaged by month for years 2000 to 2007 at Hanauma Bay. Lifeguard estimates of attendance and bathers were calculated by summing estimates made at 3 available time points (12, 2, and 4 PM) and 12 and 4 PM time points. Lifeguard estimates summing all three and 12 and 4 PM time points differed from actual attendance by factors of 1.78 (SD = 0.08) and 0.91 (SD = 0.04), respectively. Trends in monthly ticket sales were highly correlated with lifeguard estimates of attendance (12, 2, and 4 PM, $R = 0.98$; 12 and 4 PM, $R = 0.98$) and bathers (12, 2, and 4 PM, $R = 0.97$; 12 and 4 PM, $R = 0.97$).

Jackson, J. (2007). Effects of Anthropogenic Physical Disturbance on Corals to Hanauma Bay. University of Hawaii at Manoa, Zoology Department. Hanauma Bay Directed Research Fall '07.

- LOCATION: Hanauma Bay, Oʻahu HI
- TYPE: Field Research Report and PowerPoint Presentation
- In Text Citation: (Jackson 2007)
- OBJECTIVE: Evaluate anthropogenic effects of visitors on corals inhabiting the relatively shallow area (0-3m) of the bay from the shoreline seaward out to 85m.
- SUMMARY:
  - Indicators examined: Percent coral cover, coral diversity (Shannon) and relative abundance of symbiotic organisms.
  - 5 transects in Keyhole, Channel, and Witches Brew inner reef.
  - Found coral cover to differ in the SW region from the NE and Center regions.
- METHODS:
  - 3 areas across the bay: Keyhole, Channel and Witches Brew
  - 5 Transects within each area
  - 85 m long, 5 m apart.
  - Photographs taken along transect every 5 m.

- Photos were broken into 120 squares, all squares containing living coral were counted. Ratio of squares containing coral vs. squares that did not = percentage of coral cover.
- Species were identified to lowest taxonomic group and counted. Invertebrate species were noted during the swim.

- RESULTS:
  - Shannon diversity index was determined by the total number of coral colonies per species. Combines the two quantifiable measures: (1) species richness (number of species in the community) and (2) abundance (total number of individuals in the sample).
    - SW had highest diversity index value (2.21) then NE (1.93), and Center (1.90).
  - Coral Species Abundance:
    - *Pocillopora meandrina* was most abundant in almost all regions, followed by *Porites lobata* and *Porites compressa*.
    - Coral cover was highest in the SW region (21%), followed by NE region (18%) and Center region (17%).
- Conclusion:
  - Most significant difference in coral diversity and cover was between SW and Center/NE regions
    - The SW area sees much less human traffic than center and NE regions.
    - The furthest SW transect held the greatest number of corals.
    - Claims the SW area has greater protection from surf and wind, less people because it has a less hospitable beach and less swimming space due to never having been dredged.
- Discussion:
  - Low coral abundance may not be entirely due to anthropogenic disturbance…
    - According to a geological study conducted by Easton and Olson in 1976, the rate of reef growth has slowed over the last 3,000 years and the youngest material from shallow limestone reef flat is approximately 480 +/- 100 years old.
    - Geological information indicates that during the past 300-500 years, corals have not been a dominant component of the near-shore shallow areas of Hanauma Bay (Bailey-Brock et al., 2007).

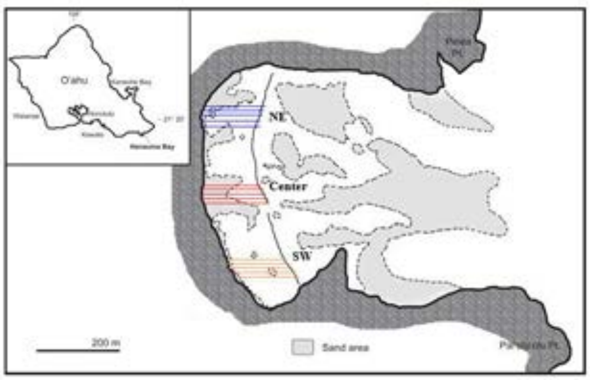
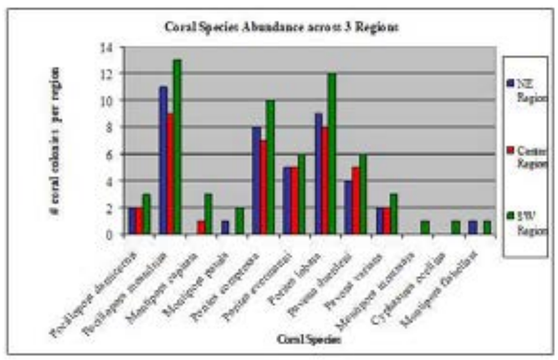


Figure 1: approximate locations of 3 sampled regions in Hanauma Bay
(map adapted from Bailey-Brock *et al* 2007)



Graph 2: Bar graph showing the abundance of each coral species identified across the three sampled regions of the Bay.

Coral Species	NE Region	Center Region	SW Region
Pocillopora damicornis	2	2	3
Pocillopora meandrina	11	9	13
Montipora capitata	0	1	3
Montipora patula	1	0	2
Porites compressa	8	7	10
Porites evermanni	5	5	6
Porites lobata	9	8	12
Pavona duerdeni	4	5	6
Pavona varians	2	2	3
Montipora incrassata	0	0	1
Cyphastrea ocellina	0	0	1
Montipora flabellata	1	0	1

Table 3: The total abundance of each coral species identified across the three sampled regions of the Bay.

Jayewardene, D. (2009). A factorial experiment quantifying the influence of parrotfish density and size on algal reduction on Hawaiian coral reefs. *Journal of Experimental Marine Biology and Ecology*, *375*(1-2), 64-69.

- LOCATION: Hanauma Bay, Oʻahu HI, Wawaloli & Keei, Big Island, HI
- TYPE: Field Study
- In Text Citation: (Danielle Jayewardene 2009)
- SUMMARY:
    - Small (<25 cm TL) parrotfishes at Hanauma:
        - Abundance = 2.9 ± 0.7 (#/ 100 m^2)
        - Biomass = 3.2 ± 1.1 (g/m^2)
    - Large (>25 cm TL) parrotfishes at Hanauma:
        - Abundance = 0.4 ± 0.1 (#/ 100 m^2)
        - Biomass = 2.3 ± 0.9 (g/m^2)
    - Both abundance and biomass of large and small parrotfishes at Hanauma were intermediate to the two other sites studied (Wawaloli – lowest, and Keei – highest).
    - Algal reduction rates at Hanauma were between 0-8% per day and were not significantly different between treatments where only small parrotfishes could graze, when compared to treatments available to all grazers.
- GOAL:
    - Use algal plots grown inside exclusion cages on reefs in the Main Hawaiian Islands to experimentally determine (1) how parrotfish density influence algal reduction rates and (2) whether large parrotfishes are more effective grazers than small parrotfishes.
- METHODS:
    - Parrotfish density at each site was empirically quantified using underwater visual census methods.
    - Between May 2005 – Oct. 2006, 6-8 separate visual surveys were carried out along 4 independent 4 x 4 x 25 m fixed belt transects at each site.
        - Number and size (length to nearest 5 cm)
        - Densities calculated from this by converting to weights using allometric length-weight conversion equation: $W = aSL^b$.
        - Background coral and algae abundance at each site was also recorded.
            - Photoquadrats along 10 randomly placed 20 m transects. 15 random images were taken per transect, and 20 random points analyzed per image.
    - Algal plots established at 10 m depth with fish exclusion cages.
        - Circular cages (30cm diameter) made of clothes wire frame covered with polypropylene mesh (1.3 cm x 1.3 cm) attached to substrate using cable ties. 16 cages at each site.
        - Cages placed for 8 months, after which algal biomass at all sites was higher within cages than on surrounding reef.
    - Algal plots exposed to grazing after 8 mo.
        - Half of cages had mesh removed completely, other cages had mesh replaced with 10.2 x 10.2 cm mesh to allow for small parrotfishes to graze.
        - Photoquadrats used to quantify algal reduction in experimental plots.
            - Daily photographs for 9 consecutive days after exposure.
            - 50 random points per image x3 for each image.
- RESULTS:
    - Algal community inside exclusion cages consisted primarily of filamentous spp. and grew to heights of 1-3 cm. Fleshy macroalgae were rare.
    - Algal reduction rates were positively related to both parrotfish density and size, and were up to 30% higher for large compared to small parrotfishes per unit biomass.
- DISCUSSION:
    - Across all sites, large parrotfishes were found to remove more algae per unit biomass compared to small parrotfishes.

Table 1
Density of small (<25 cm TL) and large (≥25 cm TL) parrotfishes at each of the three study sites expressed as number and biomass per unit area reef.

	Small parrotfishes (<25 cm TL)		Large parrotfishes (≥25 cm TL)	
	Abundance (#/100 m^2)	Biomass (g/m^2)	Abundance (#/100 m^2)	Biomass (g/m^2)
Wawaloli	0.6 ± 0.2	0.7 ± 0.3	0.1 ± 0.1	0.8 ± 0.4
Hanauma	2.9 ± 0.7	3.2 ± 1.1	0.4 ± 0.1	2.3 ± 0.9
Keei	4.0 ± 0.5	6.2 ± 0.7	0.9 ± 0.2	8.8 ± 1.6

Error values indicate ± SE.

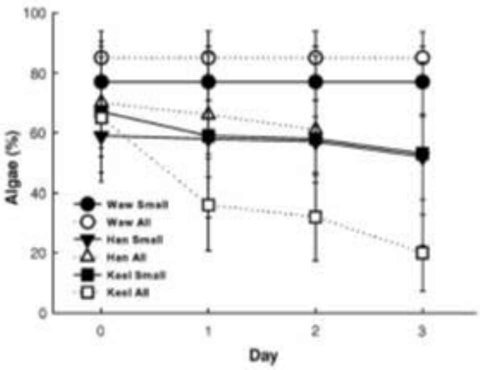


Fig. 3. Change in algal cover over a three day period in plots exposed to small (partial access plots) and all parrotfishes (full access plots) at the three study sites with different densities of parrotfishes. Error bars indicate ± SD.

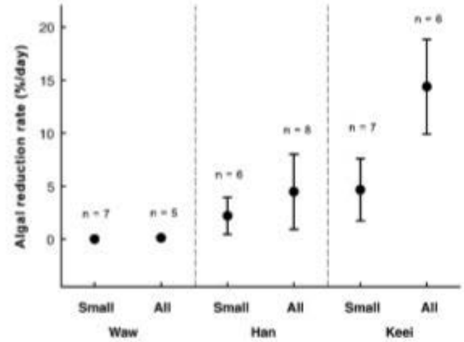


Fig. 4. Mean algal reduction rate (%/day) for plots exposed to small (partial access) and all parrotfishes (full access plots) at each of the three study sites. Error bars indicate 95% confidence interval.

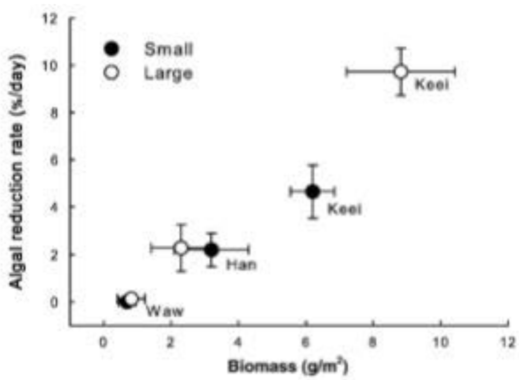


Fig. 5. Algal reduction rate (%/day) for small and large parrotfish in relation to their respective densities at each study site. Error bars for the y-axis and x-axis indicate ± SE.

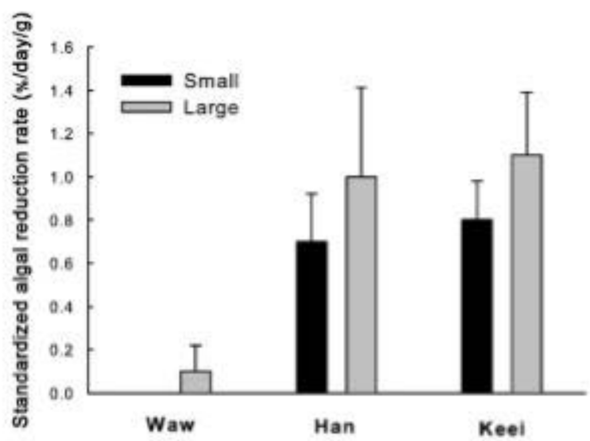


Fig. 6. The standardized algal reduction rate (%/day/g) for small and large parrotfish at the three study sites. Error bars indicate ± SE.

Jayewardene, D., Donahue, M. J., & Birkeland, C. (2009). Effects of frequent fish predation on corals in Hawaii. *Coral Reefs*, *28*(2), 499-506.

- LOCATION: Main Hawaiian Islands including a site at Hanauma Bay, Oʻahu HI
- TYPE: Field Study & Model
- In Text Citation: (D. Jayewardene, Donahue, and Birkeland 2009)
- SUMMARY:
    - Hanauma Bay Shallow:
        - 38 ± 6% total coral cover.
            - PC = 0% , PL = 19 ± 2 %, PM = 1 ± 0%
        - Bites:
            - # bites/m: PC = 0.2 ± 0.2, PL = 0 , PM = 0
            - # bites/ tile: small = 4 and large = 4

- Hanauma Bay Deep:
  - 25 ± 2 % total coral cover
    - PC = 3 ± 1 %, PL = 20 ± 2 %, PM = 0%
  - Bites:
    - # bites/m: PC = 1.3 ± 0.5, PL = 0.9 ± 0.5 , PM = 0.2 ± 0.2
- GOAL:
  - To determine the role that corallivory by *C. dumerilii* and *A. meleagris* plays in influencing coral community structure in the Main Hawaiian Islands.
- METHODS:
  - March 2004 – Aug. 2005
  - 12 sites on 9 shallow coral reefs.
    - 2 "open" sites: Portlock and Wawaloli Beach
    - 7 "partial" management prohibiting lay nets: Puako, Anaehoomalu Bay, Wawaloli Fisheries Management Area, Wawaloli $FMA_{shallow}$, Papwai, Keei, and $Keei_{shallow}$).
    - 3 "no-take" MLCD: Hanauma Bay, Hanauma $Bay_{shallow}$, and Kealakakua Bay.
  - Coral abundance
    - 15 random photoquadrats (40 x 60 cm) along each 10 randomly located 20 m transects at each site. 20 random points per photograph.
  - Abundance of fish bites
    - Surveyed 5 independent 20 m transects within each 1,000 m^2 area. 10 quadrats (0.5 x 0.5 m) were randomly placed along each transects.
- RESULTS:
  - Abundance of lesions from fish bites on corals was quantified at nine shallow reefs in the main Hawaiian Islands.
    - Average 117 bite scars/m^2 on *Pocillopora meandrina* tissue from the barred filefish *Cantherhines dumerilii*.
    - Average 69 bite scars/m^2 on *Porites compressa* tissue, and 4 bites/m^2 on *Porites lobata* tissue from the spotted puffer *Arothron meleagris*.
      - Frequency of these bites on *P. compressa* declined exponentially with increasing coral cover.
  - Nubbins of two size classes (102 cm and 4-5 cm) were transplanted into the field at 6 sites.
    - Small nubbins were entirely consumed.
    - ≥ 4 cm nubbins were partially consumed and could recover.
    - At sites with high cover of *P. compressa*, nubbins were not preyed upon. At sites with < 5% *P. compressa* cover, nubbins were preyed upon.
  - Recovery from bites:
    - Bite lesions on *P. compressa* by *A. meleagris* fully recovered in 42 ± 2 days.
    - A model of risk of over predation (a second predation event before the first is healed) decreased exponentially with increase coral cover and increased linearly with increasing lesion healing time.
      - If there is low coral cover due to a disturbance, the risk of predation limiting the recovery of a coral population is high.
- DISCUSSION:
  - Bite frequency decreased exponentially with increasing abundance of coral prey.
  - Increased risk of corallivory at low coral cover could indicate an Allee effect (a decline in population growth rate at low density), limiting the recovery potential of coral populations.

Jokiel, P. L., Brown, E. K., Friedlander, A., Rodgers, S. K. U., & Smith, W. R. (2004). Hawai'i coral reef assessment and monitoring program: spatial patterns and temporal dynamics in reef coral communities. *Pacific Science*, *58*(2), 159-174.

- LOCATION: Main Hawaiian Islands
- TYPE: Field Monitoring
- In Text Citation: (Jokiel et al. 2004)
- SUMMARY:
  - Hanauma Bay was surveyed in 1999, 2000, and 2002 at 3 m and 10 m depth:
    - 3 meter: 23.6 (1999), 25.8 (2000), 21.8 (2002) percent coral cover.
    - 10 meter: 26.7 (1999), 27.0 (1999), 22.2 (2002) percent coral cover.

Komatsu, M., & Liu, J. C. (2007). Cross-cultural Comparison Between Japanese and Western Visitors for the Effectiveness of the Hanauma Bay Education Programme. *Tourism Recreation Research*, *32*(3), 3-12.

- LOCATION: Hanauma Bay
- TYPE: Social Study
- In Text Citation: (Komatsu and Liu 2007)
- SUMMARY:
  - Assessment of cross-cultural differences between Japanese and Western visitors to the visitor education program.
  - The educational film was effective for both visitor groups in terms of attitudinal and behavioral improvement toward marine conservation in the Bay, as well as enhancing visitor experience.
  - Western visitors were more likely to report higher ratings for education program and more pre-knowledge about conservation when compared to Japanese visitors.
  - Some suggestions made on how to incorporate cultural sensitivity in managing tourism sites:
    - More should be done to prepare visitors to expect to view the educational film as a part of their visit to the Bay.
    - Content of the film could be revised. The conservation behaviors: 'stand only on sand' and 'observe but don't touch the reef' were less likely to be followed by both visitor groups, compared to the other two points: 'don't touch the turtle' and 'watch the fish but don't feed them.'

Lankford, S., Inui, Y., Whittle, A., Luna, R., & Tyrone, D. (2005). Sustainability of coastal/marine recreation: Modeling social carrying capacity for Hanauma Bay, Hawaii. University of Hawaii.

- LOCATION: Hanauma Bay, Oʻahu HI
- TYPE: Social Carrying Capacity Study
- In Text Citation: (Lankford et al. 2005)
- SUMMARY:
  - Findings of this study suggest that perceived crowding may be an indicator of actual user counts, and that crowding negatively influences satisfaction levels.
  - "The Bay is exceeding the social carrying capacity (as measured in this study) when more than 3,200 (+/- 200 users) people per day use the Bay."
  - According to this study the social carrying capacity is 3,200 visitors per day.
  - Majority of visitors are beginner or intermediate snorkelers.
- INTRODUCTION:
  - Physical capacity is the amount of space available for the activity based on design and use levels.
  - Ecological or biological capacity is the ability of the resource to withstand recreational use without unacceptable damage to ecological components such as the water quality, reef bio-diversity and fish diversity.
  - Facility capacity involves additions to the recreation environment intended to support visitor needs.
  - Social capacity is the number and distribution of visitors that provide minimal acceptable recreation experiences.

Table 3.5: Snorkeling Skills and Frequencies to Snorkel

Statements	Total (%)	Residents (%)	Visitors (%)	t-test Value	Prob.
How would you describe your snorkeling expertise? [a]					
Professional	1.1	2.0	1.0		
Expert	5.9	12.9	4.5		
Advanced	16.1	27.7	13.8		
Intermediate	29.9	24.8	30.9		
Novice/Beginner	47.0	32.7	49.8		
$\bar{X}$	4.2	3.7	4.2	-4.313	0.000 [c]
How often do you snorkel?					
Never	24.6	12.7	27.0		
Not Often	43.1	34.3	44.9		
Sometimes	21.0	27.5	19.7		
Often	8.6	16.7	7.0		
Very Often	2.6	8.8	1.4		
$\bar{X}$	2.2	2.7	2.1	5.268	0.000 [c]

[a] Five-point Likert where 1 = professional, 2 = expert, 3 = advanced 4 = intermediate and 5 = novice/beginner.

[b] Measured on five-point Likert where 1 = never and 5 = very often.

[c] t-value is significant at $p < 0.01$. Where it is significant the mean values of residents and visitors groups are statistically different.

Mak, J., & Moncur, J. E. (1998). Political economy of protecting unique recreational resources: Hanauma Bay, Hawaii. *Ambio*, 217-223.

- LOCATION: Hanauma Bay, Oʻahu HI
- TYPE: Review
- In Text Citation: (Mak and Moncur 1998)
- SUMMARY:
  - Great review of the politics behind Hanauma Bay prior to 1997.
  - TIMELINE:
    - 1928
      - Deeded by Hawaiian princess Bernice Pauahi Bishop to the City and County of Honolulu and made into a public beach park.
    - 1967
      - Designated Hawai'i's first Marine Life Conservation District.
    - 1975
      - Half-million visitors/year.
    - 1977
      - Estimate of "recommended optimal use level" for Hanauma Bay was 1363 persons per day, with 330 person allotted for upper picnic area, 408 for the lower grassy area and 625 on the sandy beach (Wilson Okamoto & Associates, Inc., 1977).
        - Estimates derived using the Bureau of Outdoor Recreation and the U.S. Corps of Engineers Beach Capacity Standards of 50 persons per acre for the upper picnic area and 160 square feet per person for the lower grassy area and the beach.
    - 1985
      - 1.6 million visitors/year. (Wilson Okamoto & Associates, Inc., 1977)
    - Late 1980's
      - 2.8 million visitors/year, or over 7,5000 persons per day (State of Hawaii (1980-1990))
    - 1989
      - City's Department of Parks and Recreation (DPR) presented to the City Council an 8-point management plan.
        - Prohibited all tour vehicles from dropping off visitors at the park.
    - 1990
      - Hanauma Bay User Committee proposed industry self-regulation as an alternative to the 1989 City regulation. Committee members agreed not to use HB on Sundays and major holidays for six months beginning Feb, 18, 1990. This eventually fell through.
    - 1990
      - June 12, 1990, the City Department of Parks and Recreation implemented the Hanauma Bay- General Plan.
        - Designed to restrict access to the bay, educate visitors on proper use of the bay, and improve facility at the bay.
        - Access to the park was restricted by…

        - Hiring traffic attendants to turn away cars after 300 stalls were filled and prevent illegal parking on the shoulders of the highway.
        - Prohibit tour companies from discharging passengers at the park past a 15-min sightseeing stop.
        - Closing the park on Wednesday mornings.
      - Education provided by the Friends of Hanauma Bay and the UH Sea Grant Extension Service co-operated to establish the Hanauma Bay Education Program (HBEP) August 1990.
  - 1994, January 4th
    - City implemented a new rule limiting cabs to one passenger drop of per day because tour companies would drop off bus loads of tourists nearby and tell them to cab it into Hbay.
  - 1994, October 31st
    - Smoking ban
  - 1994
    - Started trying to wean off fish feeding (Alan Hong & State of Hawaii)
  - 1995, July 1st
    - Charge admission to Hanauma Bay Nature Park
    - $5 nonresident tourist
    - Fees for commercial vehicles and taxis for the 15 min sightseeing.
    - Changes shortly after the bill passed…
      - Residents were charged $1
  - 1996, January 9th
    - User fee collection ended.
  - 1996, April 10th
    - Bill No. 1 reduced nonresident fees to $3 per person and everyone had to pay a $1 parking fee.

Maurin, P. (2008). *Informational exchanges among Hawaii marine stakeholders*.

- LOCATION: West Hawaii, Waianae, and Hanauma Bay, Oʻahu, HI
- TYPE: Review
- In Text Citation: (Maurin 2008)
- CHAPTER 5: Hanauma Bay MLCD
  - Road to Hanauma Bay was finished in 1927 making the bay more accessible to the public.
  - In 1964, a study by UH professor Ernst Reese estimated that 1,092 fish and 468 coral heads were being removed yearly.
  - “In 1997, yearly visitors to the Bay reached a peak of over 3 million.” “Eight acres of beach area were being used by 10,000 visitors a day, making the Bay a victim of its own success. Water quality was visibly affected. By the end of the day a sheen of suntan lotion could be observed on the surface, and turbid waters diminished the value of the experience for all visitors. Parking lots were regularly overcrowded, and reefs were used as rest areas for snorkelers.”
  - The stakeholders actively involved grew in 1990 to: Parks and Recreation, Honolulu City Council, Division of Land and Natural Resources, UH Sea Grant, Friends of Hanauma Bay, volunteers, residents, tourists

and, to a lesser degree, tour operators.

Table 4 – Timeline of Events at Hanauma Bay

Year	Event
1964	An activity survey at HB estimates a take of marine life in excess of a thousand fish specimens (1,092) and 468 coral heads per year by less than 12% of users.
1966	Proposal sent to the state Land Board recommending setting the Bay aside as an underwater sanctuary, based on 1964 HB activity survey.
1967	Designated as an Hawaii's first MLCD (no fishing, collecting of marine life or geological specimens)
1970	The Bay receives 209,997 visitors.
1980	Hanauma Bay yearly visitors surpass one million.
1981	City funds $1 million for infrastructure improvements and landscaping
1988	Visitor peak at 3.6 million per year, over 10,000 per day.
	Dept of Transportation enacts a ban on boats entering the Bay
1989	Newspaper articles detailing bay overuse and degradation appear in the front pages of Hawaii's largest newspaper.
	Sea Grant Extension proposes Education Program for the Bay.
1990	HB General Plan is drafted by the Honolulu Dept. of Parks and Recreation, recommending: Park hours for vehicular traffic, weekly half day closure of the Bay for maintenance, restriction of commercial tour activity, a visitor information center, control fish feeding, and the creation of HB Manager position.
	Grass-roots environmental organization Friends of Hanauma Bay founded to represent concerns of the local citizenry and to lobby the city government
	University of Hawaii at Manoa Sea Grant Extension Program develops the Hanauma Bay Education Program, with 1.5 FT staff and about 35 volunteers.
1992	New visitor center opens at the Bay
1993	City & County establishes a smoking ban at the Bay.
	Hanauma Bay Task Force presents its final report to state legislature, highlighting issues of environmental concern, including bay overuse, harmful bacteria levels in the water and not living up to the objectives of an MLCD.
1995	Entrance fee for non-residents enacted. Offices and concession built on upper park.
1996	City Council approves $3 admission fee for all out-of-state visitors over age of 12
1998	Hanauma Bay Education Center starts limited operations on the top park level and opens an informational beach kiosk, and staff expands to 3.5 staff and starts building up the volunteer base.
1999	Fish feeding ban enacted by City Council.
2000	Annual visitor levels drops to less than one million.
2002	New facilities open at the Bay ($13.5 million), including a large capacity theater showcasing educational film (translated into 7 languages), and park offices.
	HB Education Program grows to 5 FT staff and has over 75 volunteers.
2004	FOHB & Honolulu Visitors Bureau submit Smithsonian nomination for HB as example of sustainable tourism

Merrifield, M., & Aucan, J. (2009). Hanauma Bay Circulation Study Proposal.

- LOCATION: Hanauma Bay, Oʻahu, HI
- TYPE: Field Study Proposal
- In Text Citation: (Merrifield and Aucan 2009)
- SUMMARY:
    - Duration February 1, 2009 through January 31, 2012.
    - Seek to better understand the wave-generated rip currents at the inner reef as a function of incident wave and water level conditions. Would like to develop predictive tools to assess inner reef and outer bay circulations in response to different oceanic and meteorological conditions.
    - Use ADCP and drogues to measure the currents in Hanauma Bay.

Ong, L., & Holland, K. N. (2010). Bioerosion of coral reefs by two Hawaiian parrotfishes: species, size differences and fishery implications. *Marine biology*, *157*(6), 1313-1323.

- LOCATION: Hanauma Bay, Oʻahu, HI
- TYPE: Field Study
- In Text Citation: (Ong and Holland 2010)
- SUMMARY:
    - Bioerosion rates were more influenced by parrotfish size, rather than feeding mode.
    - Grazing by *Scarus rubroviolaceus* (a scraper) and *Chlorurus perspicillatus* (an excavator) encompassed 60% of the carbonate production of the fore reef area.

    - Densities of different size classes of *S. rubroviolaceus* and *C. perspicillatus* within Hanauma Bay are available in Figure 2 and feeding preferences in Figure 3.
- GOAL: Quantify the Bioerosion rates of two similarly sized Hawaiian parrotfishes with two different feeding modes (*Scarus rubroviolaceus*- a scraper and *Chlorurus perspicillatus*- an excavator).
- METHODS:
    - Visual Census:
        - Feb. – Oct. 2006
        - Census of distribution and abundance of *S. rubroviolaceus* and *C. perspicillatus* on fore reef and reef shelf.
            - Numbers and Sizes (visual estimation of fork length in cm) recorded.
        - Transects 10 m wide and variable length.
            - 13 transects were conducted on the fore reef (lengths 27 – 132 m, width 10 m; depth <5 m).
            - 14 transects were conducted on the reef shelf (lengths: 57-168 m, width 10 m; depth 5 – 10 m).
    - Feeding Rates:
        - Behavioral observations were conducted from Sept. – Oct. 2002 and Feb- April 2003, in order to estimate feeding rates.
- RESULTS:
    - Feeding modes did not affect bioerosion rates but that bioerosion rates were size dependent, with the largest individuals (*S. rubroviolaceus* 45-54 cm FL) bioeroding up to 390± 67 kg per individual per year.
    - Onset bioerosion happens at 15 cm in length for both species.
- DISCUSSION:
    - First study to provide estimates of bioerosion by large parrotfishes in Hawaii.
    - Fish size was found to be the paramount determinant of bioerosion rates for the two species observed.

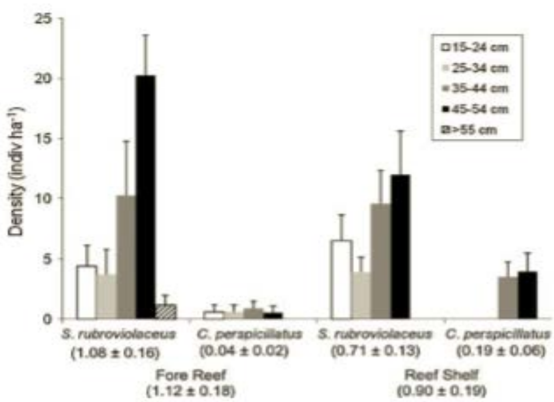


Fig. 2 Densities of *S. rubroviolaceus* and *C. perspicillatus* on the fore reef and reef shelf at Hanauma Bay. Calculated bioerosion rates (±SE, kg m^{-2} $year^{-1}$) for each species and for each reef zone are in *parentheses*

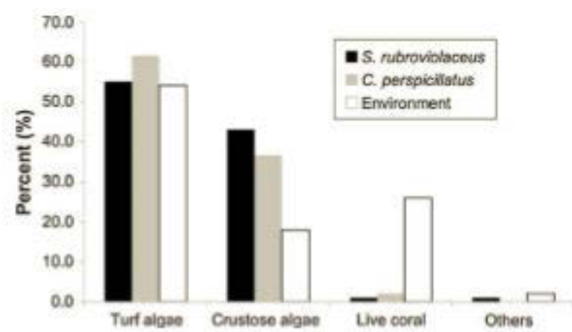


Fig. 3 Feeding preferences of *S. rubroviolaceus* ($n = 75$) and *C. perspicillatus* ($n = 82$) compared with availability in the environment ($n = 71$). Percent abundances of food type available in the environment are normalized for the size of the area of the fore reef and reef shelf

Oshiro, R., & Fujioka, R. (1995). Sand, soil, and pigeon droppings: sources of indicator bacteria in the waters of Hanauma Bay, Oahu, Hawaii. *Water Science and Technology*, *31*(5-6), 251.

- LOCATION: Hanauma Bay & Ala Moana Beach, Oʻahu, HI
- TYPE: Field Study
- In Text Citation: (Oshiro and Fujioka 1995)
- SUMMARY:
    - The major sources contributing to periodic high levels of bacteria in the waters of the Bay are contaminants of the beach sand, such as pigeon feces.
    - In contrast to the sand at Ala Moana Beach, the sand at Hanauma Bay was determined to contain considerably higher concentrations of fecal coliform, *E. coli*, and enterococci.
- METHODS:
    - Water samples collected from 3 sectors (east, middle, west).

    - Contaminants of sand such as land runoff (shower/cleaning water, rain) and mongoose and pigeon fecal droppings from Hanauma Bay were tested as possible contributors of indicator bacteria.
    - Standard membrane filtration technique was used to determine the conc. Of indicator bacteria in samples.
    - Selective media include mFC for fecal coliform, mTEC for *E. coli*, and mE for enterococci.
    - Sand samples were washed in equal volumes of 3.5% NaCl and mixed vigorously by hand, allowed to settle for 1-2 min, and supernatant was obtained. Two such elusions were required to remove more than 90% of bacteria from the sand. Supernatants were diluted and then membrane filtered.
- RESULTS:
    - Water samples:
        - Highest amount of fecal coliform in middle bay (1-103 CFU/100 ml), then eastern (0-45 CFU/100 ml), then western (1-8 CFU/100 ml).
        - Enterococci numbers at these same sites ranged from 2-24 CFU/100 ml at Hanauma Bay east, 0-104 CFU/100 ml at middle.
        - The highest concentrations of all indicator bacteria were recovered from the middle sector.
    - Sand samples:
        - Hanauma Bay sand contained much higher concentrations of fecal coliform, *E.coli*, and enterococci than the sand from Ala moana Beach.
        - In sand collected below two feet of water at Hanauma: 160 fecal coliform, 96 *E. coli* and 68 enterococci/100g.
        - In sand collected in surf zone at Hanauma: 320 fecal coliform, 44 *E. coli* and 192 enterococci/100g.
        - In dry sand at Hanauma: 184,000 fecal coliform, 160,000 *E. coli* and 32,000 enterococci/100g.
        - Farthest inland sands at Hanauma contained: 2,420,000 fecal coliform, 967,000 *E. coli* and 160,000 enterococci/100g.
- DISCUSSION:
    - As moisture content of the sand decreased and soil content increased (moving toward land), bacterial count increased.
    - In contrast to the sand at Ala Moana Beach, the sand at Hanauma Bay was determined to contain considerably higher concentrations of fecal coliform, *E. coli*, and enterococci.
        - Partially attributed to the high terrigenous content of sand at Hanauma.
    - Results of this study suggest that sand, contaminated with indicator bacteria, is the major source contributing to the periodic high levels of bacteria in the waters of Hanauma Bay.

Reynolds, E. (1990, May). Hanauma Bay baseline users survey. In *Proceedings of the 1990 Congress on Coastal and Marine Tourism* (Vol. 1, pp. 106-116).

- LOCATION: Hanauma Bay, Oʻahu, HI
- TYPE: User Survey
- In Text Citation: (Reynolds 1990)
- SUMMARY:
    - Survey involved two parts: (1) Counting the number of people and vehicles entering the park and the number of people walking down or riding the tram to the beach. (2) Questionnaire given on random basis to beach visitors.
    - Average number of visitors to the park per day was 6,707 with a range of 5,477 to 8,938, with 73.5% going down to the beach.
    - Recommended that his survey should be performed at least once a year in alternating seasons order to effectively manage people using the bay.

Rodgers, K. S., Bahr, K. D., Jokiel, P. L., & Donà, A. R. (2017). Patterns of bleaching and mortality following widespread warming events in 2014 and 2015 at the Hanauma Bay Nature Preserve, Hawai ʻi. *PeerJ*, *5*, e3355.

- LOCATION: Hanauma Bay, Oʻahu, HI
- TYPE: Field Study
- In Text Citation: (Rodgers et al. 2017)
- SUMMARY:

- Elevated temperature throughout the bleaching event was more influential in coral bleaching/mortality than high circulation or visitor use.
- In 2014, Hawai'i DAR coral bleaching assessments determined 47% of corals exhibited signs of bleaching in the HBNP--mortality was not documented.

- OBJECTIVE: understand the spatial extent of bleaching mortality in Hanauma Bay Nature Preserve (HBNP), O'ahu, Hawai'i to gain a baseline understanding of the physical processes that influence localized bleaching dynamics. Quantify bleaching prevalence and subsequent mortality within the four major sectors of the HBNP and define how they relate to temperature and currents.
- METHODS:
  - Coral Surveys:
    - 4 Sectors of HBNP: Backdoors(BD), Keyhole (KH, Channel (CH), and Witches Brew (WB).
    - 2- 15 m x 5 m transects were surveyed in each sector. Depths <1 m. All coral colonies within the 75 m^2 area were counted.
    - Recorded: Coral species, Colony size, and Percent of colony that was live, pale, bleached, and recently dead.
    - Sites were repeatedly found using handheld Garmin Geko 201 GPS unit, graphic and written documentation of positions using triangulation, and underwater photographic imagery of distinct initial and concluding coral colonies on each transect.
  - Temperature:
    - HOBO temp Pro v2 Data Loggers in each of the 4 sectors took temp every 15 min. to calculate a mean mid-day difference among transects.
    - Data were used to calculate mean mid-day differences among transect temperatures.
  - Currents:
    - Whittle (2003)
    - Nearshore current patterns were determined using lagrangian current drogues.
  - Stats:
    - Bleaching prevalence was analyzed using a GLM with sector as a fixed factor and transect nested within sector.
    - Temp was treated with a repeated measures mixed model by location with transect nested within locations.
- RESULTS:
  - Bleaching Prevalence
    - Highest bleaching found in *Pavona varians* & *Pocillopora meandrina*
    - Bleaching prevalence was sig. Different among sectors with highest levels at keyhole and witches brew compared to back doors and channel.
    - Colony size in all locations was similar, but number of colonies at WB was higher when compared to average number of colonies at BD and KH.
  - Coral Mortality
    - Highest mortality at WB and BD. Lower mortality at KH and CH.
    - Recovery was slowest at WB.
    - Highest mortality rates seen in *Porites lobata* and *Pocillopora meandrina*.

Rodgers, K. S. (2005). Evaluation of Nearshore Coral Reef Conditions and Identification of Indicators in the Main Hawaiian Islands. A Dissertation Submitted to the Graduate Division of The University of Hawaii. (1-218 pg).

- LOCATION: Main Hawaiian Islands
- TYPE: Field Studies
- In Text Citation: (Rodgers 2005)
- SUMMARY pertaining to Hanauma Bay:
  - Found organic values close to 5%, ranking in the upper range of the majority of the stations, yet have very low levels of the silt/clay fraction typical of sedimented areas.
  - The following are possible explanations for the high organics and low silt/clay found at Hanauma Bay…
    - Low contribution of terrigenous material from the surrounding watershed.
    - Past or current history of fish feeding.
    - High fish biomass.

	LOI (%)		$CaCO_3$ (%)		Terrigenous (%)	
MOLOKAʻI	mean	sd.	mean	sd	mean	sd
OʻAHU						
Hanauma 3m	4.7	0.3	46.5	0.9	48.8	1.7
Hanauma 10m	5.0	0.1	59.0	1.5	36.1	3.2

Sanderson, S. L., & Solonsky, A. C. (1980, January). A COMPARISON OF 2 VISUAL SURVEY TECHNIQUES FOR FISH POPULATIONS. In *PACIFIC SCIENCE* (Vol. 34, No. 3, pp. 337-337). 2840 KOLOWALU ST, HONOLULU, HI 96822: UNIV HAWAII PRESS.

- LOCATION: Hawaiian Islands including Hanauma Bay
- TYPE: Field Study
- In Text Citation: (Sanderson et al. 1980)
- SUMMARY:
    - Comparison of two visual census techniques for describing and quantifying fish communities. Techniques were compared in terms of replicability, observer bias, minimal number of replicate surveys required to adequately represent the species composition of a specific fish community, daily variations in data, and sensitivity to distinctions between fish communities.
        - Brock Method
        - Jones and Thompson Method
            - More variable results, but could be due to observer bias.
- METHODS:
    - 11 days of fieldwork at Hanauma in 1979.
- RESULTS:
    - Mean number of species recorded per Brock survey and the mean number recorded per Jones and Thompson survey was no different at Hanauma Bay.
    - Only results on comparison of methods. No results were given on fish biomass, abundance, or species richness.

Sano, M. E., Dickerson, B., Reynolds, B., Rosenfeld, C., Russell, S., Stender, G., Teshima-Miller, K. (1990). Hanauma Bay Ecological Survey: A Baseline Study Honolulu, Hawaii. *Marine Option Program, University of Hawaii.*

- LOCATION: Hanauma Bay, Oʻahu, HI
- TYPE: Field Study
- In Text Citation: (Sano et al. 1990)
- METHODS:
    - 5- 100 meter transects (except transect 1 was 50 m).
        - #1 was on inner reef flat, other 4 were located in deeper water.
    - Coral, invertebrates and algae were recorded
- RESULTS:
    - Transect #1: “Substrate was mostly reef rock, coral rubble, and a mixture of sand and coral rock. Very small patches of dead *Pocillopora sp.* were recorded. Three small patches (5-8 cm) of *Porites lobata* were also recorded, however, due to the nature of the point – intersecting method, they are not counted in the data assessment.” Some *Leptastrea purpurea* were seen.
    - Transect #2: 20.36% coverage of *Porites lobata. Pocillopora meandrina* was often present, but dead- so was counted in “other”.
    - Transect #3: All sand
    - Transect #4: Small patches of *Porites compressa* and *Pavona duerdeni*. *P. meandrina* was found along this transect, but was dead. *Montipora capitata* was the dominant species but had signs of bleaching. Several algae spp. were present.
    - Transect #5: *P. lobata* was the dominant species with small colonies of *P. compressa*.

        - Transect #6 & #7: Reef rock covered with algal mat.
- DISCUSSION:
    - *M. capitata* showed signs of bleaching on one transect and *P. meandrina* was found dead on several occasions.

Table 2

Average percent coverage of substrate

	Transect 1	2	3	4	5
Corals:					
Leptastrea purpurea	0.67	0.0	0.0	0.0	0.36
Montipora capitata	0.0	0.0	0.0	5.82	0.73
Montipora flabellata	0.0	0.0	0.0	0.0	0.36
Pavona duerdeni	0.0	0.36	0.0	0.0	0.0
Pavona varians	0.0	0.36	0.0	0.0	0.0
Pocillopora meandrina	0.0	0.73	0.0	0.37	0.73
Porites compressa	0.0	0.73	0.0	0.0	1.09
Porites lobata	0.0	20.36	0.0	0.73	6.18
Other invertebrates:					
Palythoa tuberculosa	0.0	1.45	0.0	0.0	0.36
Algae:					
Grateloupia filicina	0.0	0.0	0.0	0.44	0.0
Porolithon species	0.67	0.0	0.0	0.0	0.0
Sand	0.0	8.36	100.	41.45	20.73
Other *	98.67	67.64	0.0	50.90	68.36
Total average % of live coral	0.67	22.54	0.0	6.92	9.45

Figure 1. Map of study site with transect locations.

Sigall, B. (2013). Phone cable installation shut down Hanauma Bay. *Honolulu Star-Advertiser*.
- LOCATION: Hanauma Bay, Oʻahu, HI
- TYPE: News
- In Text Citation: (Sigall 2013)
- SUMMARY:
    - October 1956, trucks, barges, bulldozers and dynamiters came to Hanauma to extract coral to dig a trench for twin 1-inch cables.
    - Coral and water shot more than 60 ft into the air.
    - The water was filled with silt and covered in oil which did not clear till 10 days after the dredging stopped.

Smith, K. A., Rocheleau, G., Merrifield, M. A., Jaramillo, S., & Pawlak, G. (2016). Temperature variability caused by internal tides in the coral reef ecosystem of Hanauma bay, Hawai ʻi. *Continental Shelf Research*, *116*, 1-12.
- LOCATION: Hanauma Bay, Oʻahu, HI
- TYPE: Field Study
- In Text Citation: (Smith et al. 2016)
- GOAL:
    - Determine whether the proximity to a major semidiurnal internal tide generation site would lead to strong internal tide signatures within the bay, was verified by the presence of strong semidiurnal temperature variations in the lower layer during summer.
- METHODS:
    - March to June 2009
    - Currents, temp, and wave energy inside Hanauma bay were investigated using size Nortek acoustic Doppler current profilers (Aquadopps), two Nortek Acoustic Wave and Current profilers (AWACs) and a Hydroid REMUS-100 AUV.
    - All profilers recorded temp and pressure.
- CONCLUSIONS:
    - Semidiurnal internal tides generate over the ridge offshore of Makapu'u Point on the southeast corner of the island of O'ahu propagate into the shallow coral reef habitat of Hanauma Bay.
    - In spring (and likely winter) the energy associated with these internal tides causes fluctuations in currents but is accompanied by little change in temperature, due to the fact that the upper water column is well mixed.
    - In summer, intensified surface stratification allows the internal tide to cause temperature drops as large as 2.7°C in the bay.

- Semidiurnal temp drops due to the internal tide occur consistently twice a day throughout May and June in 15 m water and are even present occasionally at depths as shallow as 5 m.

Stamoulis, K. A., Delevaux, J. M. S., Williams, I. D., Friedlander, A. M., Reichard, J., Kamikawa, K., & Harvey, E. S. (2018-Draft). Incorporating fish behavior improves accuracy of species distribution models.

- LOCATION: Hanauma Bay, O'ahu, HI & Pūpūkea, O'ahu
- TYPE: Field Study
- In Text Citation: (Stamoulis et al. 2018)
- SUMMARY:
    - Compared the accuracy of species distribution models (SDMs) which include minimum approach distance (MAD) as a predictor with SDMs that do not. Comparisons were made at 2 marine reserves on O'ahu within and outside of the reserves.
    - MAD varied between sites and was lower inside reserves than in fished areas, providing a proxy of fish wariness.
    - MAD was correlated to estimate fishing pressure, and greatly improved accuracy of SDMs when included as a predictor.
- INTRO:
    - MAD- "minimum approach distance"
        - The distance between the diver and the fish at its closest point
    - Fishing pressure directly increases fish wariness and decreases *true* fish biomass, while increased fish wariness may decrease *observed* fish biomass, due to survey diver avoidance.
- METHODS:
    - Samples collected inside and outside of two no-take marine reserves on O'ahu, Hanauma Bay and Pūpūkea, from June 2016 to May 2017.
    - Transect locations were randomly selected within management type (reserve and open) on hard-bottom habitats using ArcGIS.
    - 5 x 25 m belt transects on SCUBA—3 min per transect.
    - Stero-Dov system used two Canon high-definition video cameras mounted 0.7 m apart on a base bar inwardly converged at 7° to provide a standardized field of view.
    - Measurements of fish length, distance (range) and angle of the fish from the center of the camera system were obtained from imagery.
        - From which they calculated MAD of all targeted reef fishes.
- RESULTS:
    - At Hanauma Bay there were 572 observations inside the reserve and 167 outside.
    - Three schools of greater than 50 individuals were recorded in Hanauma Bay reserve, the two large of the schools (n = 150, 75) consisting of *Acanthurus triostegus* and the third (n = 62) made up of *Acanthurus leucopareius.*
    - Both marine reserves had significantly higher biomass of targeted fishes.
        - Ratio of mean targeted fish biomass inside the reserve vs. outside was 4.9 for Hanauma Bay and 1.5 for Pūpūkea.
    - Reserve sites had lower MAD, though not significant.
    - When MAD was included as a predictor, models were able to explain ~20% more of the variability in targeted fish biomass.
    - MAD was significantly lower inside the reserve compared to open areas for Hanauma.
- DISCUSSION:
    - Fish body length had a positive relationship with MAD.
        - Optimal fitness theory predicts that as reproductive value increases, risk-taking should decrease (Clark, 1994).
    - MAD was positively correlated with estimated fishing pressure. Because high fishing pressure is associated with increased wariness and low biomass of targeted species, it is logical to assume maximum MAD where there is minimum biomass.

Stender, G., & Russell, S. (1991). Quantitative survey of fishes at Hanauma Bay, Oahu.

- LOCATION: Hanauma Bay, Oʻahu, HI
- TYPE: Economic Survey
- In Text Citation: (Stender and Russel 1991)
- SUMMARY:
    - 5- 100 m transects were conducted for fish surveys. Fish were counted 3 m out from either side of the transect tape.
    - Transect 1 (inner reef transect): A total of 139 fishes were observed, representing 28 spp. from 10 families. The average number of fishes per acre was 937.555 with an average biomass of 384.049 lbs. per acre.
        - Five dominant spp. by abundance were *Acanthurus triostegus, Thalassoma duperrey, Acanthurus xanthopterus Kyphosus bigibbus, Abudefduf sordidus,* and *Parupeneus multifasciatus.*
        - Five dominant spp. in biomass were *Acnthurus xanthopterus, Kyphosus biggibus, Chaenomugil leuciscus, Abudefduf sordidus,* and *Mugil cephalus*.
        - The 5 dominant spp. by abundance accounted for 68% of the standing crop.
    - See paper for fish survey results table.

van Beukering, P., & Cesar, H. S. (2004). Ecological economic modeling of coral reefs: Evaluating tourist overuse at Hanauma Bay and algae blooms at the Kihei Coast, Hawai'i. *Pacific Science*, *58*(2), 243-260.

- LOCATION: Hanauma Bay, Oʻahu, HI
- TYPE: Economic Survey
- SUMMARY:
    - The first ecological economic model of coral reefs in Hawai'i.
    - A survey on consumer and mostly on modeling economics.
    - The Hanauma Bay study showed that visitors are willing to pay much more for their experience (around $10) than they are currently doing and that the net benefits of the education program (around $100 million) greatly exceed the cost of the program (around $23 million) over time.
- Field survey methods:
    - Purpose was to determine the average profile of each user group in terms of actual expenditure, directly attributable to the diving or snorkeling trip, the consumer surplus for this experience, and the willingness to pay for a healthier marine environment.

Vieth, G. R., & Cox, L. J. (2001). Sustainable Use Management of Hanauma Bay. *Department of Natural Resources and Environmental Management*, CTAHR—July 2001 (2 p.).

- LOCATION: Hanauma Bay, Oʻahu, HI
- TYPE: Review
- In Text Citation: (Vieth and Cox 2001)
- SUMMARY:
    - Found that nonresident user fees, if high enough, can be used to reduce the actual use of Hanauma Bay to capacity--which they coin at 1363 people per day (1977 Hanauma bay beach park site development plan).
    - Surveys of 43 U.S. mainland residents who visited Hanauma Bay found that it would take a user fee of $30 to $40 per day to discourage people from using the bay.

Figure 1. Hanauma Bay capacity and use.

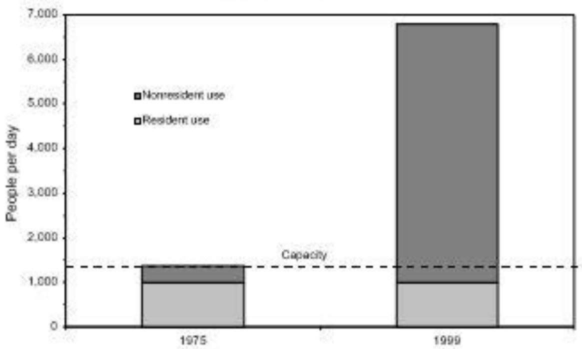
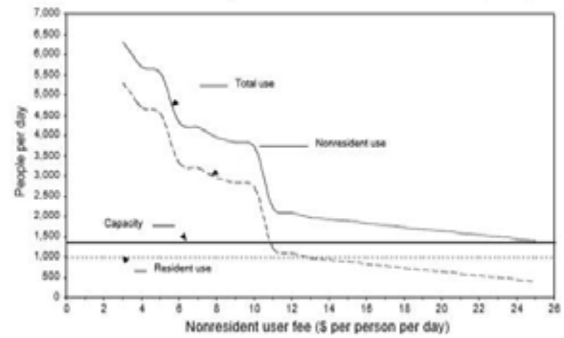


Figure 2. Hanauma Bay use with user fee and capacity.



Walton, M. M. (2013). Do marine protected areas facilitate coral reef ecosystem health? An investigation of coral disease and its associated factors in Oahu's marine life conservation districts (Doctoral dissertation, University of Hawai'i at Manoa).

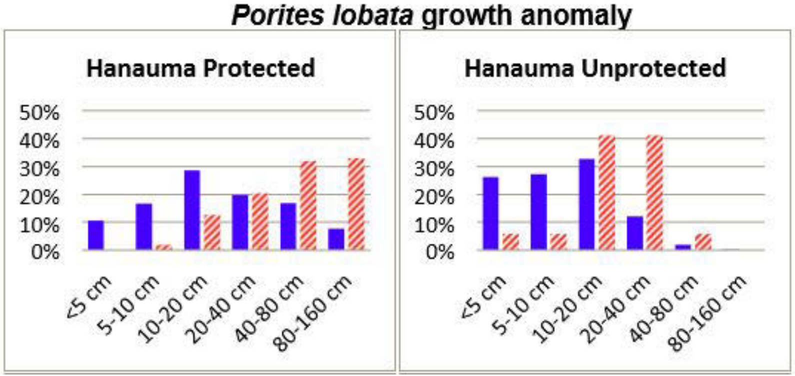
- LOCATION: Hanauma Bay, Oʻahu, HI
- TYPE: Field Study
- In Text Citation: (Walton 2013)
- SUMMARY:
  - Field surveys were used to quantify coral disease prevalence, coral cover, macroalgal cover, fish abundance and diversity, and coral community size structure at each of the sites. Inorganic-organic carbon fractions of sediments and sediment grain size categories were also measured.
- METHODS:
  - Coral colony density was documented along the 10 m line by counting and recording all the coral colonies whose centers fell within 1 m on either side of the transect line.
    - Colonies were identified to species and placed into a size class bin.
  - Disease assessments were conducted within the same transect and each coral with disease was photographed. Coral colonies with diseased lesions were classified by lesion type: tissue loss, discoloration, or growth anomalies.
  - Coral disease prevalence was calculated as the total number of colonies of a specific coral species with a specific lesion type divided by the total number of colonies of that species (both healthy and diseased).
  - Reef fish abundance and diversity were recorded using a visual belt transect survey method along a 25 x 5 m belt transect. Fish were identified to the lowest taxonomic group, tallied, and assigned an estimated total length (cm), then grouped into 6 trophic guilds: herbivores, mobile invertebrate feeders, sessile invertebrate feeders, piscivore, zooplanktivores, and detritivores.
  - Sediment samples were collected at each transect. Composition and grain size were performed.
- RESULTS:
  - Hanauma bay had two out of the five lesion types that showed significantly higher prevalency in the MLCD compared to the adjacent control site: *Porites lobata* growth anomaly and *Porites lobata* tissue loss.
  - Hanauma also appeared to have overall more lesion types and prevalence than Pupukea or Waikiki MLCD's
  - Coral and fish species richness and evenness was similar across all 3 MLCD locations.
  - Hanauma sediment was ~92% carbonate, ~6% Terrigenous and ~3% Organic.
  - Herbivores were the most trophic guild in Hanauma.
- DISCUSSION:
  - The types of disease present and how prevalent the diseases were differed significantly between locations.
  - Hanauma had the highest amount of silt.
- Appendix B:
  - Mean coral cover for 2012-2013 was 32.43% and similar levels were recorded in 1992 (34.65%) and 1976 (37.65%) at 30 ft depth.

Table 5. Mean prevalence of five common diseases across protection boundaries at the three study locations. Standard errors in parentheses. * indicates a significant difference across the protection boundary based on a Kruskal-Wallis test (p<0.05).

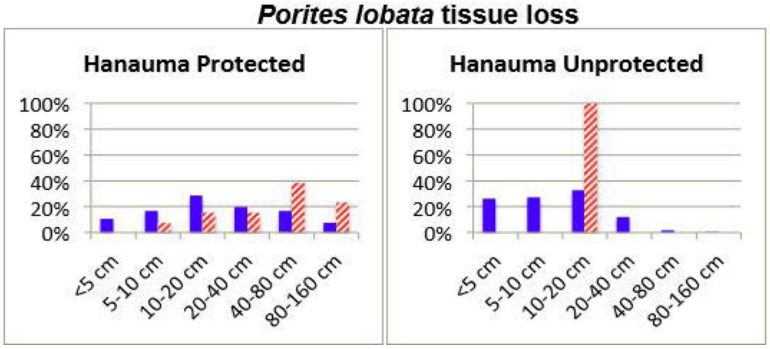
Hanauma

Lesion type	Protected	Unprotected
Porites lobata growth anomaly*	16.47 (1.79)	0.85 (0.36)
Porites lobata trematodiasis	10.83 (2.62)	2.77 (0.72)
Porites lobata tissue loss*	1.72 (0.50)	0.07 (0.04)
Porites lobata lesion with red filamentous alga*	3.64 (0.94)	5.67 (4.97)
Pocillopora meandrina tissue loss	3.04 (1.37)	3.62 (0.91)

***Porites lobata* growth anomaly**



***Porites lobata* tissue loss**



***Porites lobata* trematodiasis**

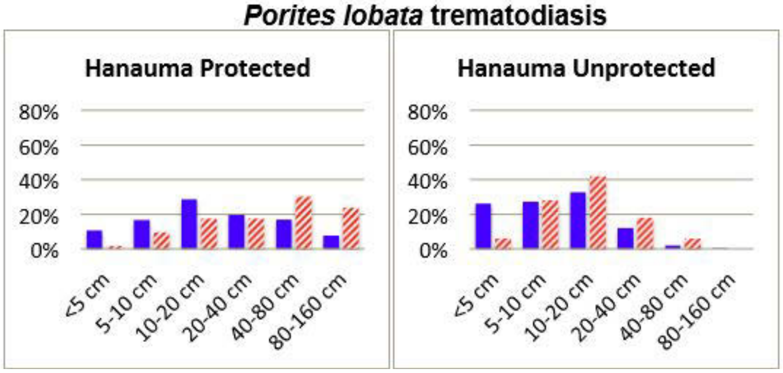


Table 11. Proportion (%) of organic, carbonate, and terrigenous materials. Sample statistics are overall mean ± standard deviation for each site.

Site	Organic	Carbonate	Terrigenous
Hanauma - Protected	3.1 ± 1.2	91.8 ± 7.7	5 ± 7.1

Table 12. Proportion (%) of sediment grain-size categories. Sample statistics are overall mean ± standard deviation for each site.

Site	Rubble	Gravel	Coarse sand	Fine sand	Silt
Hanauma - Protected	5.4 ± 2.0	24.6 ± 13.1	33.5 ± 9.0	21.2 ± 12.7	15.3 ± 9.7

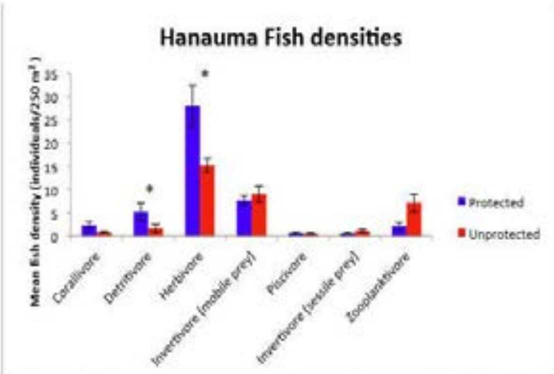


Figure 24. Blue and red bars represent mean fish density at the Hanauma sites for 7 different trophic guilds. Black lines indicate standard error and * indicates significant difference between protected and unprotected sites for that location (Kruskal-Wallis test, p<0.05).

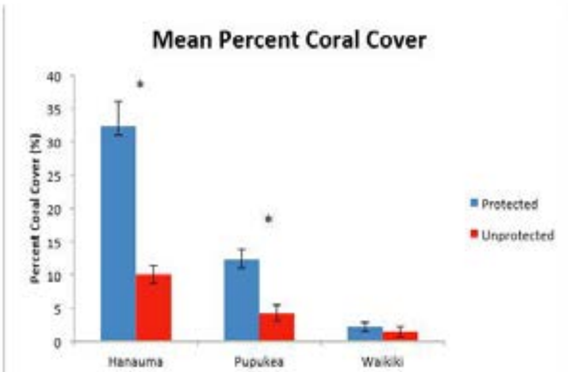


Figure 28. Blue (protected) and red (unprotected) bars represent mean percent coral cover at each of the locations. Black lines show standard error and * indicates significant difference between protected and unprotected sites for that location (Kruskal-Wallis test, p<0.05).

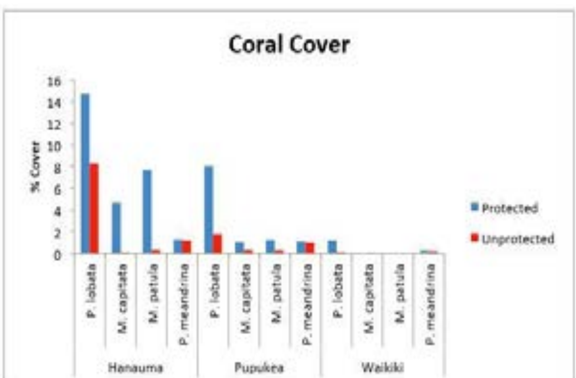


Figure 29. Blue (protected) and red (unprotected) bars represent mean percent coral cover for four of the most common coral species at each of the locations.

Table 18. Comparison with historical prevalence data from (Hunter 1999; Aeby et al. 2011c) for Hanauma sites. Prevalence is shown as a percentage followed by the standard error in parentheses where available.

Hanauma

	Porites Trematodiasis	*Porites* Growth anomaly	*Porites* Tissue loss
Hunter (Hanauma- Protected) 1992	N/A	41.7% (4.41)	N/A
Hunter (Hanauma- Protected) 1994	N/A	28.8% (8.98)	N/A
Hunter (Hanauma-Protected) 1998	N/A	35.0% (3.00)	N/A
Aeby (Hanauma Protected Deep) 2004-2005	0%	3.7%	1.1%
Aeby (Hanauma Protected Shallow) 2004-2005	1.4%	1.4%	1.4%
Aeby (Hanauma Unprotected) 2004-2005	4.4%	8.7%	1.6%
Walton (Hanauma-Protected) 2012-2013	10.8% (2.62)	16.5% (1.79)	1.7% (0.50)
Walton (Hanauma-Unprotected) 2012-2013	2.8% (0.72)	0.9% (0.36)	0.1% (0.04)

Table 19. Comparison with historical prevalence data from (Aeby et al., 2011c) for Pupukea sites. Prevalence is shown as a percentage followed by the standard error in parentheses where available.

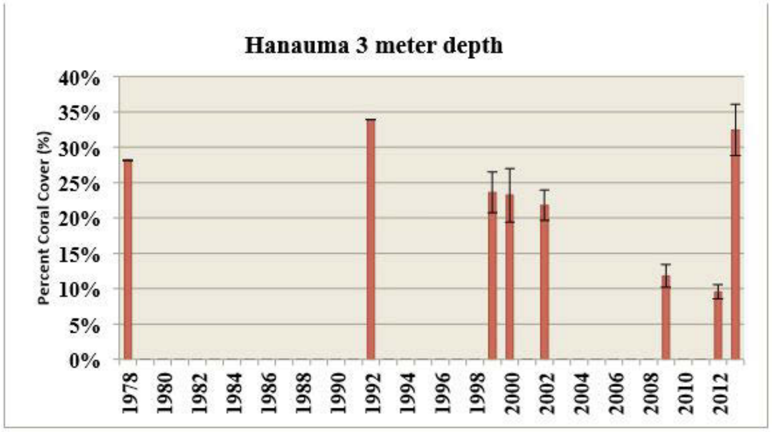


Figure 35. Historical data on mean coral cover at Hanauma Bay for a 3-meter depth spanning from 1978-2013. Data from 1978 (Anderson 1978), 1999 (Hunter 1999), 1999-2012 (CRAMP, unpublished), and 2013 (Walton, 2013). Where available standard error is shown with black bars. The data from (Walton, 2013) reports mean coral cover for surveys conducted at a mean depth of 5.5 meters.

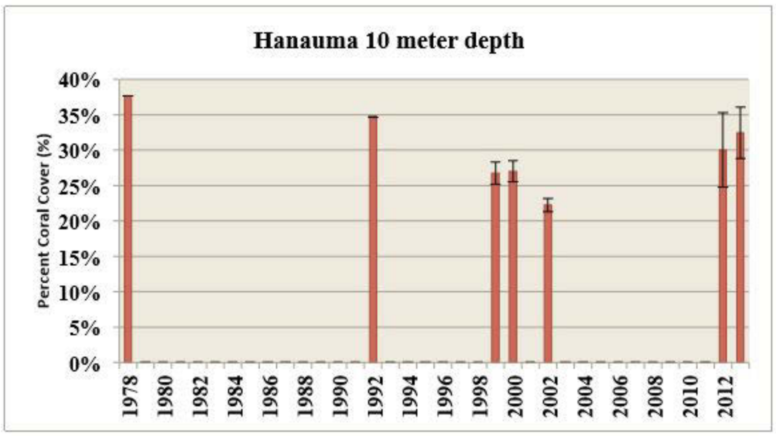


Figure 36. Historical data on mean coral cover at Hanauma Bay for a 10-meter depth spanning from 1978-2013. Data from 1978 (Anderson 1978), 1999 (Hunter 1999), 1999-2012 (CRAMP, unpublished), and 2013 (Walton, 2013). Where available standard error is shown with black bars. The data from (Walton, 2013) reports mean coral cover for surveys conducted at a mean depth of 5.5 meters.

Appendix C: Disease Prevalence Maps

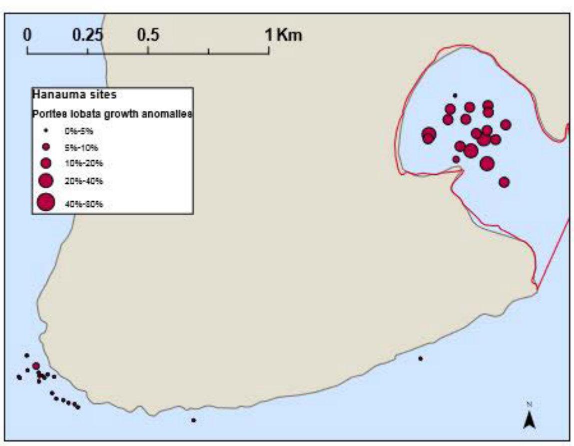


Figure 42. Prevalence of *Porites lobata* growth anomalies at the Hanauma sites. Red lines mark the boundary of the MLCD.

Wanger, J.R. (2001). Interpretive Education as a Conservation Tool at Hanauma Bay Nature Preserve, Hawaii. Master of Arts in Geography. University of Hawaii. 123p.

- LOCATION: Hanauma Bay, Oʻahu, HI
- TYPE: Social Study
- In Text Citation: (Wanger 2001)
- SUMMARY:
    - This thesis evaluates the degree of effectiveness of the Hanauma Bay Education Program as well as examines the historical events, decision making processes and interest group dynamics that have influenced the operation of HBEP.
- Interpretive Environmental Education at Hanauma Bay:
    - Trampling was in higher occurrence at all tidal levels when the education program was closed. While education program was open tramping presence appears to be around 6% of swimmers at low, average and high tide. Very low tide saw no tramplers while the education program was open.
- Conclusions:
    - Education efforts were found to contribute to increased awareness of rules and appropriate behavior within the preserve resulting in behavior modifications. This awareness, however, did not translate into an increased understanding of the Hanauma Bay environment.

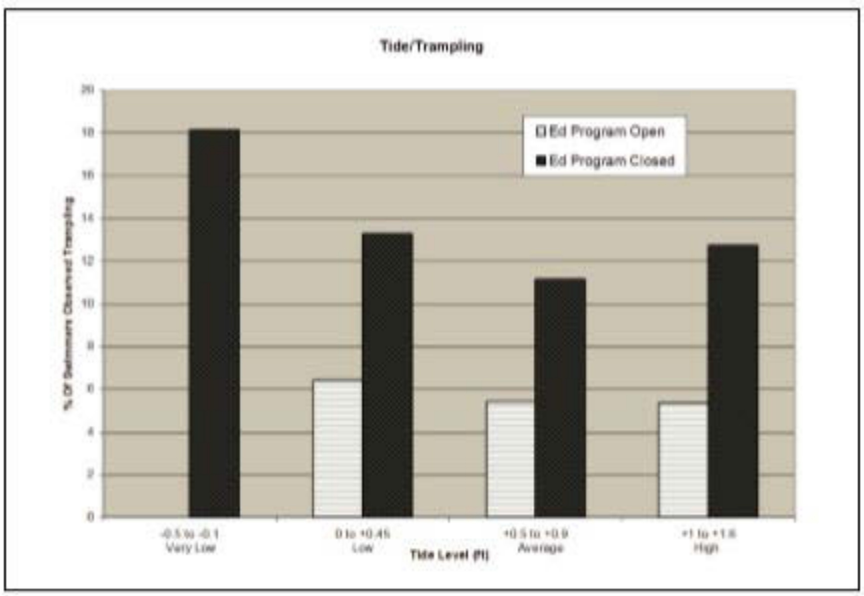


Figure 2. Trampling/ Tidal Aggregation. For each range of tide levels, average reef trampling levels are shown for both days when HBEP was open (n=218 observed trampling) and closed (n= 1,250 observed trampling). Error bars represent standard error between means. (Source: field observations, Open: 5/24, 27, 29 & Closed: 6/2, 7, 10). See data: ***Appendix I Tables 4 & 5.***

Wedding, L. M., Friedlander, A. M., McGranaghan, M., Yost, R. S., & Monaco, M. E. (2008). Using bathymetric LIDAR to define nearshore benthic habitat complexity: Implications for management of reef fish assemblages in Hawaii. *Remote Sensing of Environment*, *112*(11), 4159-4165.

- LOCATION: Hanauma Bay, Oʻahu, HI
- TYPE: Field Study
- In Text Citation: (Wedding et al. 2008)
- SUMMARY:
    - Lidar-derived rugosity (4 m grid size) was found to be highly correlated with in-situ rugosity and was concluded to be a viable method for measuring rugosity in analogous coral reef environments.
    - Lidar-derived rugosity was a good predictor of fish biomass and demonstrated a strong relationship with several fish assemblage metrics.
    - No raw data tables or graphs in the paper, only statistical data.
- GOALS:

    - Determine whether lidar technology can provide effective rugosity measures on a coral reef in Hawaii.
    - To Examine the relationship between reef fish assemblage characteristics and LIDAR-derived rugosity.
- METHODS:
    - 33 transects surveyed in May 2004 using a stratified random design.
        - Several on the inner and outer reef.
    - Fish assemblages were assessed in a 25 m x 5 m belt transect at a constant speed. Fish were identified to the lowest possible taxon. Total length of fish was estimated to the nearest cm.
    - Rugosity:
        - Measured with brass chain.
- RESULTS:
    - Lidar-derived rugosity at the 4 m grid size had a sig. positive association with the *in situ* rugosity.
    - *In-situ* rugosity demonstrated strong positive correlations with abundance, diversity, richness and biomass of fishes.

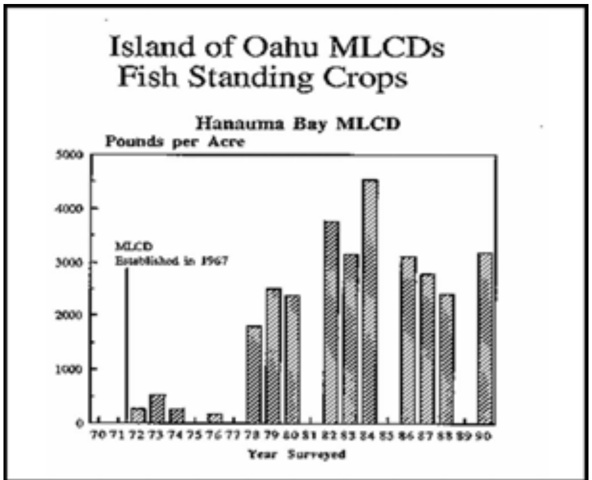
Whittle, A. G. (2003). *Ecology, abundance, diversity, and distribution of larval fishes and Schindleriidae (Teleostei: Gobioidei) at two sites on O'ahu, Hawai'i* (Doctoral dissertation, University of Hawaii at Manoa). Chapter 2.

- LOCATION: Hanauma Bay, Oʻahu, HI
- TYPE: Field Study
- In Text Citation: (Whittle 2003)
- SUMMARY:
    - Light traps deployed in Hanauma Bay over a 2.5 year period
        - Significantly more larval fishes caught in light traps moored over sand habitats vs. rubble, coral, or mixed habitats.
    - Currents measured with drogues
        - Pattern was shoreward and westerly.
    - Chapter 2: Physical Factors in Hanauma Bay
        - Examines the hypothesis that non-biological factors, such as substrate, currents, tides, lunar phase, season, waves, and temperature strongly affect larval ecology, abundance, diversity, and distribution.
- METHODS:
    - Light traps were deployed in 4 areas of Hanauma Bay over 33 nights between December 1999 and July 2002.
        - Tested the difference between different substrates: sand, coral, rubble, and mixed.
    - 6 drogues constructed of 1 m x 1 m x 0.5 m pvc piping with tarp tie-wrapped within the frame.
        - Drogues were individually marked with different color flags and weighted at the bottom with an 8 oz fishing weight.
        - Every 10 min. the position and angle of the drogue was recorded.
        - Recorded at incoming, outgoing, mixed tide, and calm days.
- RESULTS:
    - No significant lunar correlation with *Schindleria* catch data.
    - No significant lunar or monthly correlation with larval reef fish catch.
    - As the temperature and tidal range increased, the number of larval fishes caught increased.
    - The *Schindleria* had a negative relationship with sea surface temperature and significant positive relationship with tidal range.
- DISCUSSION:
    - Adults of photopositive species (Mullidae, Acanthuridae, Synodontidate, Gobiidae, Blennidae) are present inside the Bay, but were rare or non-existent in light trap catches—therefore populations of these spp. within the Bay are likely structured by post-settlement processes such as migration, competition and predation.
        - This theory could be tested by mark-recapture studies and observation of juvenile and adults.

Island of Oahu MLCDs Fish Standing Crops

- LOCATION: Hanauma Bay, Oʻahu, HI
- TYPE: Table

- In Text Citation: (Island of Oahu MLCDs Fish Standing Crops 1990)
- SOURCE: Elizabeth Kumabe, SeaGrant



As you can see, surveys taken shortly after the establishment of the MLCD in 1967 show very low fish populations within the bay. The impressive number and diversity of fish you see today is due to the Hanauma's protected status.

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Hanauma Bay Timeline

1928

- Deeded by Hawaiian princess Bernice Pauahi Bishop to the City and County of Honolulu and made into a public beach park. (Mak & Moncur, 1997)

1930's

- Wooden Stairs constructed along with other changes made to improve accessibility to the Bay (Brock, 2000)

1950-51

- Access road to the beach of Bay was built. 3 swimming areas were constructed along the bay's shoreline by blasting depressions in the coral rock and importing sand to improve the beach (Brock, 2000).

1954

- Brock- A preliminary Report on a Method of Estimating Reef Fish Populations
  - Counted the number and species of fish present within Hanauma Bay and various other locations.

1956

- Report by City Parks Superintendent released stated that 50,000 people annually had use the Bay in each of the years from 1950 to 1956. Prior use had been documented as 8,000 people a year (Hbay Website).
- 200 ft. wide channel was cut through the coral reef by Hawaiian Dredging to lay the first stage of underwater telephone cable linking Hawai'i and the West-Coast.

1967

- Designated Hawai'i's first Marine Life Conservation District. (Mak & Moncur, 1997)

1970

- Construction of 100 x 15 ft underwater boulder wall to lessen impact to the back began (Hbay Website).

1972

- Surveys, and mapping of underwater trails are conducted by the University of Hawai'i's Marine Options Program in preparation of underwater guided tours and a specimen showcase (Hbay Website).

1975

- Half-million visitors/year. (Mak & Moncur, 1997)

1977

- Estimate of "recommended optimal use level" for Hanauma Bay was 1363 persons per day, with 330 person allotted for upper picnic area, 408 for the lower grassy area and 625 on the sandy beach (Wilson Okamoto & Associates, Inc., 1977). (Mak & Moncur, 1997)
  - Estimates derived using the Bureau of Outdoor Recreation and the U.S. Corps of Engineers Beach Capacity Standards of 50 persons per acre for the upper picnic area and 160 square feet per person for the lower grassy area and the beach.

1981

- Limited parking stalls to 390 spaces. Commercial operators agree to limit visitor trips to the Bay on weekends to alleviate crowding problems (Hbay Website).

1985

- 1.6 million visitors/year. (Wilson Okamoto & Associates, Inc., 1977) (Mak & Moncur, 1997)

Late 1980's

- 2.8 million visitors/year, or over 7,5000 persons per day (State of Hawaii (1980-1990)) (Mak & Moncur, 1997)

1987

- Park visitation peaks at a record 3,600,000 visitors for the year (Timeline from Liz Kumabe).
- A 1,000-gallon oil spill from an inter-island barge closes the bay for one day. (Timeline from Liz Kumabe).

1988

- 3 million visitors per year (average 10-12,000 per day)(Clark, 2016).
- Feeding fish up to ½ ton of bread per day (Clark, 2016).

1989

- City's Department of Parks and Recreation (DPR) presented to the City Council an 8-point management plan. (Mak & Moncur, 1997)
    - Prohibited all tour vehicles from dropping off visitors at the park.

1990, February 18th

- Hanauma Bay User Committee proposed industry self-regulation as an alternative to the 1989 City regulation. Committee members agreed not to use HB on Sundays and major holidays for six months beginning Feb, 18, 1990. This eventually fell through. (Mak & Moncur, 1997)

1990, June 12th

- June 12, 1990, the City Department of Parks and Recreation implemented the Hanauma Bay- General Plan. (Mak & Moncur, 1997)
    - Designed to restrict access to the bay, educate visitors on proper use of the bay, and improve facility at the bay.
    - Access to the park was restricted by…
        - Hiring traffic attendants to turn away cars after 300 stalls were filled and prevent illegal parking on the shoulders of the highway.
        - Prohibit tour companies from discharging passengers at the park past a 15-min sightseeing stop.
        - Closing the park on Wednesday mornings.
    - Education provided by the Friends of Hanauma Bay and the UH Sea Grant Extension Service co-operated to establish the Hanauma Bay Education Program (HBEP) August 1990.

1994, January 4th

- City implemented a new rule limiting cabs to one passenger drop of per day because tour companies would drop off busloads of tourists nearby and tell them to cab it into Hbay. (Mak & Moncur, 1997)

1994, October 31st

- Smoking ban (Mak & Moncur, 1997)

1994

- Started trying to wean off fish feeding (Alan Hong & State of Hawaii) (Mak & Moncur, 1997)

1995, July 1st

- ~1,305,038 visitors this year (C & C records)
- Charge admission to Hanauma Bay Nature Park (Mak & Moncur, 1997)
    - $5 nonresident tourist
    - Fees for commercial vehicles and taxis for the 15 min sightseeing.
    - Changes shortly after the bill passed…
        - Residents were charged $1

1996, January 9th

- User fee collection ended. (Mak & Moncur, 1997)
- ~1,321,971 visitors this year (C & C records)

1996, April 10th

- Bill No. 1 reduced nonresident fees to $3 per person and everyone had to pay a $1 parking fee. (Mak & Moncur, 1997)

1998

- ~1,160,796 visitors this year (C & C records)
- Hanauma Bay Begins closing every Tuesday to allow for park maintenance (Timeline from Liz Kumabe).

1999, November 1st

- ~1,120,534 visitors this year (C & C records)
- Ban on fish feeding in the bay was imposed (Brock, 2000).
    - Website says July 15th, 1999
- Carrying Capacity Study ~3,000 people per day showed no evidence of decline in the fish and coral communities per Brock 2000 carrying capacity study.

2000

- ~1,114,863 visitors this year (C & C records)
- Brock – Carrying Capacity Study for the Hanauma Bay Nature Preserve Final Report
- Coral Reef Assessment and Monitoring Program (CRAMP) began surveys.

2000-2007

- Harada et al., 2011- Analysis of Lifeguard-Recorded Data at Hanauma Bay, Hawaii
    - Lifeguards recorded attendance and activity at 12 pm, 2 pm, and 4 pm and recorded characteristics of rescue victims and events ranging from 2000-2007.

2001

- ~964,910 visitors this year (C & C records)
    - Closure of the park due to remondeling caused lower attendance.
- Vieth & Cox- Sustainable Use Management of Hanauma Bay
    - Found that nonresident user fees, if high enough, can be used to reduce the actual use of Hanauma Bay to capacity—which they coin at 1363 people per day (1977 Hanauma Bay beach park site development plan).

2003

- ~981,961 visitors this year (C & C records)
- Wittle (2003)- Ecology, Abundance, Diversity, and Distribution of Larval Fishes and Schindleriidae (Teleostei: Gobioidei) and Two Sites on O'ahu, Hawai'i
    - Light traps over a 2.5 year period

        - Significantly more larval fishes cause in light traps moored over sand habitats vs. rubble, coral, or mixed habitats.

2008

- ~898,969 visitors this year (C & C records)
- Wedding et al.- Using bathymetric lidar to define nearshore benthic habitat complexity: implications of management of reef fish assemblages in Hawaii.

2010

- ~833,792 visitors this year (C & C records)
- Ong & Holland- Bioerosion of coral reefs by two Hawaiian parrotfishes: species, size differences and fishery implications
    - Census of distribution and abundance of *S. rubroviolaceus* and *C. perspicillatus.*

2014, Sept & Oct

- ~791,859 visitors this year (C & C records)
- DAR Coral Bleaching Survey
    - 47% of coral colonies within Hbay exhibited signs of bleaching.
    - <1% showed signs of severe bleaching.
    - Bleaching was much less severe at Hbay compared to windward Oahu sites.
    - 14 out of the 18 coral species surveyed exhibited signs of bleaching

2015, Sept & Oct

- ~803,000 visitors this year (C & C records)
- Rodgers et al., 2017- Patterns of bleaching and mortality following widespread warming events in 2014 and 2015 at the Hanauma bay Nature Preserve, Hawai'i
    - Coral Surveys
    - Temperature Surveys
    - Current Patterns

2016

- ~804,027 visitors this year (C & C records)
- Clark, Division of Aquatic Resources, 2016
    - 3,000-5,700 visitors per day (~1 million per year).
    - No commercial operations on weekends or holidays.
    - Park closed one day a week (Tuesdays)
    - Mandatory visitor education.
    - Entrance fee and parking limits.

2017

- ~842,439 visitors this year (C & C records)

Appendix B. Human counts data.

Table 1. Visual human count data from June 2018 field studies.

SWIM

	8:00 AM					11:00 AM					2:00 PM						
Date:	Backdoors	Keyhole	Channel	Witches Brew	Offshore	Backdoors	Keyhole	Channel	Witches Brew	Offshore	Backdoors	Keyhole	Channel	Witches Brew	Offshore	Observer:	Notes:
1-Jun	4	38	19	0	0	17	58	39	4	0	1	24	16	1	0	SS	Monk seal on keyhole beach at 2 pm.
1-Jun	-	-	-	-	-	19	57	38	2	0	1	22	13	1	0	TD	
1-Jun	-	-	-	-	-	29	43	50	5	0	1	24	13	1	0	RA	
4-Jun	7	33	46	12	-	5	53	40	14	1	-	-	-	-	-	SS	Counts taken at 10 am are recorded as 8 am.
4-Jun	7	34	43	18	-	5	62	56	11	1	-	-	-	-	-	DS	
6-Jun	0	42	20	3	2	10	70	59	5	0	18	78	54	12	0	SS	
6-Jun	-	-	-	-	-	10	73	53	6	0	18	75	45	17	0	TD	
7-Jun	0	13	12	0	4	12	56	47	9	3	7	51	46	0	2	SS	
8-Jun	2	37	25	2	0	7	75	76	6	4	1	38	36	0	9	SS	
8-Jun	-	-	-	-	-	8	80	87	5	4	1	34	62	0	9	RA	
10-Jun	0	14	18	2	6	5	53	49	1	11	-	-	-	-	-	SS	Counts taken at 1 pm are recorded as 11 am.
10-Jun	0	17	18	2	6	5	48	25	1	13	-	-	-	-	-	DS	
16-Jun	1	58	19	2	0	20	39	32	0	0	7	44	55	5	0	SS	Monk seal on Keyhole Beach during 8 am and 11 am counts.
17-Jun	0	23	17	0	3	8	80	46	8	2	19	47	71	6	6	SS	Monk seal on Keyhole beach during 2 pm counts.
17-Jun	0	22	23	0	3	7	72	57	8	2	12	42	43	9	5	DS	
20-Jun	8	40	50	3	4	22	99	83	3	16	7	40	44	6	6	SS	City and County workers counted approximately 500 visitors prior to 7 am.
20-Jun	-	-	-	-	-	-	-	-	-	-	5	32	34	11	7	TD	
20-Jun	-	-	-	-	-	-	-	-	-	-	12	31	54	6	7	RA	
28-Jun	6	35	24	0	0	23	74	59	0	0	0	55	38	0	1	SS	

Table 1 cont. (2/3)

WADE

	8:00 AM					11:00 AM					2:00 PM						
Date:	Backdoors	Keyhole	Channel	Witches Brew	Offshore	Backdoors	Keyhole	Channel	Witches Brew	Offshore	Backdoors	Keyhole	Channel	Witches Brew	Offshore	Observer:	Notes:
1-Jun	0	34	14	0	-	13	53	32	8	-	0	62	28	0	-	SS	Monk seal on keyhole beach at 2 pm.
1-Jun	-	-	-	-	-	13	71	24	9	-	0	58	25	0	-	TD	
1-Jun	-	-	-	-	-	6	41	58	8	-	0	52	32	0	-	RA	
4-Jun	9	50	52	0	-	4	73	61	4	-	-	-	-	-	-	SS	Counts taken at 10 am are recorded as 8 am.
4-Jun	10	39	58	0	-	4	66	68	8	-	-	-	-	-	-	DS	
6-Jun	0	37	19	0	-	3	76	45	1	-	5	74	33	1	-	SS	
6-Jun	-	-	-	-	-	3	75	65	1	-	8	94	52	3	-	TD	
7-Jun	0	34	25	4	-	4	60	24	0	-	7	63	29	1	-	SS	
8-Jun	0	28	29	0	-	2	66	64	1	-	1	45	38	0	-	SS	
8-Jun	-	-	-	-	-	2	57	44	1	-	1	42	39	0	-	RA	
10-Jun	1	40	44	2	-	0	68	45	1	-	-	-	-	-	-	SS	Counts taken at 1 pm are recorded as 11 am.
10-Jun	1	32	33	2	-	0	58	73	1	-	-	-	-	-	-	SD	
16-Jun	0	31	22	0	-	10	55	42	0	-	2	87	53	1	-	SS	Monk seal on Keyhole Beach during 8 am and 11 am counts.
17-Jun	0	24	24	0	-	13	73	57	3	-	4	54	45	0	-	SS	Monk seal on Keyhole beach during 2 pm counts.
17-Jun	0	25	17	0	-	8	73	37	3	-	9	75	50	0	-	DS	
20-Jun	0	29	31	3	-	3	107	81	6	-	9	101	55	3	-	SS	City and County workers counted approximately 500 visitors prior to 7 am.
20-Jun	-	-	-	-	-	-	-	-	-	-	9	74	42	3	-	TD	
20-Jun	-	-	-	-	-	-	-	-	-	-	4	33	27	2	-	RA	
28-Jun	0	43	26	2	-	11	116	67	10	-	0	70	45	0	-	SS	

Table 1 cont. (3/3)

BEACH

Date:	8:00 AM Backdoors	8:00 AM Keyhole	8:00 AM Channel	8:00 AM Witches Brew	8:00 AM Offshore	11:00 AM Backdoors	11:00 AM Keyhole	11:00 AM Channel	11:00 AM Witches Brew	11:00 AM Offshore	2:00 PM Backdoors	2:00 PM Keyhole	2:00 PM Channel	2:00 PM Witches Brew	2:00 PM Offshore	Observer:	Notes:
1-Jun	0	57	27	2	-	3	111	53	3	-	0	92	41	6	-	SS	Monk seal on keyhole beach at 2 pm.
1-Jun	-	-	-	-	-	3	165	48	9	-	0	165	51	6	-	TD	
1-Jun	-	-	-	-	-	3	118	44	16	-	0	134	32	4	-	RA	
4-Jun	13	99	95	19	-	0	112	72	13	-	-	-	-	-	-	SS	Counts taken at 10 am are recorded as 8 am.
4-Jun	3	105	75	18	-	0	116	94	11	-	-	-	-	-	-	DS	
6-Jun	0	89	45	3	-	3	122	118	9	-	0	125	63	8	-	SS	
6-Jun	-	-	-	-	-	3	130	128	10	-	0	140	69	12	-	TD	
7-Jun	0	35	35	0	-	2	152	63	10	-	0	139	74	2	-	SS	
8-Jun	0	68	54	0	-	4	112	71	6	-	2	84	53	2	-	SS	
8-Jun	-	-	-	-	-	6	107	74	3	-	2	88	42	2	-	RA	
10-Jun	0	77	30	0	-	1	111	72	12	-	-	-	-	-	-	SS	Counts taken at 1 pm are recorded as 11 am.
10-Jun	0	60	23	0	-	1	115	63	12	-	-	-	-	-	-	SD	
16-Jun	0	80	31	0	-	0	120	74	1	-	0	137	71	4	-	SS	Monk seal on Keyhole Beach during 8 am and 11 am counts.
17-Jun	0	57	36	0	-	4	160	98	10	-	1	110	65	0	-	SS	Monk seal on Keyhole beach during 2 pm counts.
17-Jun	0	49	40	0	-	1	135	68	14	-	1	81	59	5	-	DS	
20-Jun	0	120	30	0	-	0	210	90	6	-	1	84	60	8	-	SS	City and County workers counted approximately 500 visitors prior to 7 am.
20-Jun	-	-	-	-	-	-	-	-	-	-	3	89	59	14	-	TD	
20-Jun	-	-	-	-	-	-	-	-	-	-	1	57	64	9	-	RA	
28-Jun	0	71	42	4	-	6	139	71	3	-	0	116	58	2	-	SS	

Table 2. Visual human count data from October 2018 field studies.

BEACH

Date	7:00 AM									8:00 AM								
	Backdoors East	Backdoors West	Keyhole East	Keyhole West	Channel Null	Channel East	Channel West	Witches Brew East	Witches Brew West	Backdoors East	Backdoors West	Keyhole East	Keyhole West	Channel Null	Channel East	Channel West	Witches Brew East	Witches Brew West
5-Oct	0	0	1	19	0	3	-	0	0	0	0	18	31	21	24	-	5	1
8-Oct	0	0	14	17	10	5	1	0	0	0	0	20	50	20	28	7	0	0
10-Oct	0	0	15	36	15	27	12	0	0	0	0	17	42	30	26	18	0	1
11-Oct	0	0	3	19	8	16	3	0	0	0	0	11	28	24	23	9	0	0
12-Oct	0	0	3	19	14	10	3	0	0	0	0	27	35	8	16	8	1	0
14-Oct	0	0	0	6	2	23	11	5	0	0	0	1	18	16	18	20	2	0
20-Oct	0	0	5	20	10	6	4	0	0	0	0	17	34	6	18	6	0	0
21-Oct	0	0	7	16	4	6	8	0	0	0	0	5	12	6	13	5	0	0
24-Oct	0	0	5	20	2	7	9	2	0	0	0	2	29	9	14	9	0	0

Date	11:00 AM									2:00 PM								
	Backdoors East	Backdoors West	Keyhole East	Keyhole West	Channel Null	Channel East	Channel West	Witches Brew East	Witches Brew West	Backdoors East	Backdoors West	Keyhole East	Keyhole West	Channel Null	Channel East	Channel West	Witches Brew East	Witches Brew West
5-Oct	0	0	21	72	23	28	-	4	0	0	0	12	52	24	26	-	0	0
8-Oct	0	0	28	49	18	36	17	6	0	0	0	27	86	64	36	24	7	5
10-Oct	0	0	5	12	20	22	21	2	0	0	0	16	64	17	30	20	6	3
11-Oct	0	0	51	58	31	27	29	0	0	0	0	22	61	21	32	15	1	0
12-Oct	0	3	25	65	33	36	26	3	2	0	0	33	68	34	21	22	2	1
14-Oct	0	4	27	97	26	25	31	2	2	0	0	13	44	25	20	16	2	2
20-Oct	0	0	12	63	22	18	10	4	2	0	0	7	45	23	21	7	0	0
21-Oct	0	0	15	92	20	24	21	2	0	0	0	7	45	10	19	11	0	2
24-Oct	0	0	18	65	21	28	19	4	2	0	0	17	66	25	15	9	13	0

Table 2 cont. (2/3)

WADE

Date	7:00 AM									8:00 AM								
	Backdoors East	Backdoors West	Keyhole East	Keyhole West	Channel Null	Channel East	Channel West	Witches Brew East	Witches Brew West	Backdoors East	Backdoors West	Keyhole East	Keyhole West	Channel Null	Channel East	Channel West	Witches Brew East	Witches Brew West
5-Oct	0	0	2	17	1	1	-	0	0	0	5	10	19	1	5	-	1	0
8-Oct	0	0	6	8	6	5	0	0	0	0	0	16	61	13	9	15	0	0
10-Oct	0	0	3	14	0	11	1	0	0	0	0	6	35	14	21	6	0	0
11-Oct	0	0	2	9	8	9	0	0	0	0	0	4	7	5	27	7	0	0
12-Oct	0	0	4	2	0	10	4	0	0	0	0	12	18	12	13	2	1	0
14-Oct	0	0	2	4	0	13	4	0	0	0	0	4	23	0	12	11	0	0
20-Oct	0	0	2	2	0	3	2	0	0	0	1	3	14	7	5	5	0	0
21-Oct	0	0	3	5	0	0	4	0	0	0	0	7	15	5	12	2	0	0
24-Oct	0	0	1	3	0	2	3	0	2	0	0	8	21	10	4	7	0	0

Date	11:00 AM									2:00 PM								
	Backdoors East	Backdoors West	Keyhole East	Keyhole West	Channel Null	Channel East	Channel West	Witches Brew East	Witches Brew West	Backdoors East	Backdoors West	Keyhole East	Keyhole West	Channel Null	Channel East	Channel West	Witches Brew East	Witches Brew West
5-Oct	0	0	12	59	29	35	-	1	0	2	0	21	50	28	30	-	0	0
8-Oct	0	11	21	107	32	28	19	6	0	2	4	39	76	37	21	16	0	0
10-Oct	5	0	20	80	31	21	12	4	2	0	7	26	55	36	12	4	5	0
11-Oct	0	0	18	68	35	26	17	0	0	0	1	21	50	22	25	10	4	0
12-Oct	0	0	26	49	21	43	15	2	0	0	3	12	37	22	7	5	0	0
14-Oct	0	7	17	64	10	18	6	4	0	0	1	10	30	22	3	14	0	0
20-Oct	0	0	6	52	31	19	8	0	0	0	0	5	32	15	15	6	0	0
21-Oct	0	2	22	45	19	17	8	1	0	0	0	10	59	20	7	7	0	0
24-Oct	0	0	32	52	22	15	11	5	0	0	3	14	59	17	27	12	2	0

Table 2 cont. (3/3)

SWIM

Date	7:00 AM											8:00 AM										
	Backdoors East	Backdoors West	Keyhole East	Keyhole West	Channel Null	Channel East	Channel West	Witches Brew East	Witches Brew West	Offshore East	Offshore West	Backdoors East	Backdoors West	Keyhole East	Keyhole West	Channel Null	Channel East	Channel West	Witches Brew East	Witches Brew West	Offshore East	Offshore West
5-Oct	0	0	5	6	0	0	-	2	0	0	0	0	0	9	28	7	7	-	2	2	2	4
8-Oct	0	0	18	16	5	5	0	0	0	0	0	0	7	5	34	8	7	6	4	0	0	0
10-Oct	0	3	7	11	6	4	1	0	0	0	0	6	5	11	25	16	20	7	1	0	0	0
11-Oct	0	0	8	5	1	5	0	0	0	0	2	0	0	9	18	4	11	9	0	0	0	0
12-Oct	0	0	5	6	0	8	2	0	0	0	0	0	0	12	10	1	18	7	0	2	2	0
14-Oct	0	0	1	1	3	7	3	0	0	0	2	0	0	0	22	0	22	16	2	0	5	14
20-Oct	0	2	14	17	10	11	0	0	0	7	0	0	0	3	15	5	10	5	0	0	0	10
21-Oct	0	1	8	15	0	7	0	0	0	0	0	0	4	2	15	0	7	0	0	0	4	6
24-Oct	0	0	11	10	2	7	8	0	0	0	0	3	7	13	18	12	24	14	0	0	0	0

Date	11:00 AM											2:00 PM										
	Backdoors East	Backdoors West	Keyhole East	Keyhole West	Channel Null	Channel East	Channel West	Witches Brew East	Witches Brew West	Offshore East	Offshore West	Backdoors East	Backdoors West	Keyhole East	Keyhole West	Channel Null	Channel East	Channel West	Witches Brew East	Witches Brew West	Offshore East	Offshore West
5-Oct	0	2	36	57	22	30	-	7	0	11	2	0	0	15	27	10	18	-	2	0	8	4
8-Oct	3	7	31	49	19	14	22	10	0	0	2	2	10	38	35	9	17	29	3	0	8	8
10-Oct	5	10	26	50	39	50	18	11	4	1	2	0	8	25	59	28	15	11	6	2	4	2
11-Oct	0	1	22	45	19	32	23	2	0	3	0	0	15	28	41	11	23	13	5	0	1	0
12-Oct	0	9	15	55	31	23	14	7	4	4	0	0	3	24	49	21	14	9	7	0	0	0
14-Oct	0	6	29	56	28	34	16	7	2	13	18	0	4	15	42	18	16	12	2	0	6	2
20-Oct	3	3	9	29	13	27	9	6	2	12	4	0	0	11	43	12	13	12	0	0	2	8
21-Oct	2	16	7	33	2	29	21	0	0	2	1	1	0	4	24	8	13	15	2	0	14	1
24-Oct	0	10	29	70	41	46	21	11	5	0	0	0	0	13	31	4	10	6	2	2	0	0

Appendix C. Coral trampling breakage data.

Table 1. June coral breakage surveys (number of coral skeletons remaining within each transect).

	31-May	4-Jun	5-Jun	6-Jun	7-Jun	8-Jun	9-Jun	10-Jun	11-Jun	12-Jun	14-Jun	16-Jun	17-Jun	19-Jun	20-Jun	21-Jun
Observer	**AR**	**AR**	**SS**	**SS**	**SS**	**SS**	**RB**	**SS**	**AR**	**SS**	**AR**	**SS**	**SS**	**SS**	**S**	**RB**
Backdoor East	Too Shallow	7	7	7	7	7	7	7	6	7	6	7	7	7	7	5
Backdoor West	Too Shallow	7	7	6	6	6	6	6	6	6	5	4	4	4	4	4
Keyhole East	7	7	6	6	6	5	5	5	5	5	5	5	5	5	5	5
Keyhole West	6	5	5	5	5	5	5	5	4	4	4	4	4	4	4	3
Channel East	7	7	7	7	7	7	7	7	7	7	7	5	5	5	5	3
Channel West	Too Shallow	6	6	6	6	6	6	6	6	6	6	6	6	5	5	3
Witches Brew East	Too Shallow	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Witches Brew West	Too Shallow	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Offshore	5									5				5	5	

Table 2. October coral breakage surveys (number of coral skeletons remaining within each transect).

	2-Oct.	5-Oct.	8-Oct.	9-Oct.	10-Oct.	11-Oct.	12-Oct.	14-Oct.	16-Oct.	19-Oct.	20-Oct.	21-Oct.	23-Oct.	24-Oct.	26-Oct.	30-Oct.
Observer	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS
Backdoor East	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	6
Backdoor West	7	7	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Keyhole East	7	7	6	6	6	6	5	5	5	5	5	5	5	5	5	3
Keyhole West	7	7	7	6	6	6	6	5	4	4	4	4	4	4	4	4
Channel East	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	6
Channel West	7	7	7	6	6	6	6	6	6	6	6	6	6	6	6	6
Witches Brew East	7	7	7	7	7	7	7	7	6	6	6	6	6	6	6	6
Witches Brew West	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Offshore	7			7				7	7				7			7

Table 3. June coral skeleton measurements taken before and after placement in the field for 30 days. Measurements were acquired using ImageJ software from top-down photographs (black: no data, orange: larger area after experimental period (due to algae overgrowth, yellow: % loss data).

Transect	Order	Spp. Start	Spp. Final	Top- Down Area (cm^2)			% Loss	% Loss per Day
				5.29.18	6.5.18	6.26.18		
Backdoors East	1	M	M		9196.4	6751.9	26.6	1.3
	2	P	P		7147.9	6434.7	10.0	0.5
	3	M	M		6321.0	5279.2	16.5	0.8
	4	M	-		3499.4	0.0	100.0	4.8
	5	M			6325.3	4448.7	29.7	1.4
	6	P	P		3741.2	3900.7	0.0	0.0
	7	M	M		4855.1	2115.6	56.4	2.7
Backdoors West	1	M	M		12045.9	5707.5	52.6	2.5
	2	P	-		5816.1	0.0	100.0	4.8
	3	M	-		7808.3	0.0	100.0	4.8
	4	P	P		6938.1	6605.0	4.8	0.2
	5	M	M		6850.2	3799.2	44.5	2.1
	6	M	M		5339.2	5504.2	0.0	0.0
	7	M	-		20520.2	0.0	100.0	4.8
Keyhole East	1	P	P	5159.2		3709.0	28.1	1.0
	2	P	P	5830.0		8807.3	0.0	0.0
	3	M	-	6349.8		0.0	100.0	3.6
	4	M	M	8386.7		5119.3	39.0	1.4
	5	M	-	6359.6		0.0	100.0	3.6
	6	M	-	7270.0		0.0	100.0	3.6
	7	M	M	7522.7		7338.9	2.4	0.1
Keyhole West	1	M	-	7851.2		0.0	100.0	3.6
	2	P	P	5278.8		2269.6	57.0	2.0
	3	M	-	6135.9		0.0	100.0	3.6
	4	M	-	4114.4		0.0	100.0	3.6
	5	P	-	4068.4		0.0	100.0	3.6
	6	M	M	5527.8		3413.6	38.2	1.4
	7	M	M	6598.7		3325.1	49.6	1.8

Table 3 cont. (2/2)

Transect	Order	Spp. Start	Spp. Final	Top- Down Area (cm^2) 5.29.18	6.5.18	6.26.18	% Loss	% Loss per Day
Channel East	1	M	M	14454.2		8944.2	38.1	1.4
	2	P	-	6859.1		0.0	100.0	3.6
	3	M	M	5349.6		4382.8	18.1	0.6
	4	M	M	7545.6		3041.3	59.7	2.1
	5	M	-	10016.7		0.0	100.0	3.6
	6	P	P	3733.4		2286.4	38.8	1.4
	7	M	M	8247.9		2899.5	64.8	2.3
Channel West	1	M	M	6761.8		7778.1	0.0	0.0
	2	M	M	16236.6		8279.5	49.0	1.8
	3	P	P	8266.7		7828.9	5.3	0.2
	4	M	M		5320.8	5395.6	0.0	0.0
	6	P	-	7532.9		0.0	100.0	3.6
	7	M	M	6891.6		2455.3	64.4	2.3
Witches Brew East	1	M	M	13928.8		6250.0	55.1	2.0
	2	P	P	6148.2		3950.4	35.7	1.3
	3	M	M	8554.2		8901.1	0.0	0.0
	4	M	M	10227.7		9635.9	5.8	0.2
	5	M	M	6374.9		5631.1	11.7	0.4
	6	P	P	4276.9		7773.0	0.0	0.0
	7	M	M	5804.1		7039.7	0.0	0.0
Witches Brew West	1	M	M	13594.5		13048.5	4.0	0.1
	2	P	P	7404.9		4683.5	36.8	1.3
	3	M	M	10362.5		5978.9	42.3	1.5
	4	M	M	4790.0		5118.9	0.0	0.0
	5	M	M	4418.0		4814.5	0.0	0.0
	6	P	P	7506.4		6173.7	17.8	0.6
	7	M	M	4451.4		4036.2	9.3	0.3
Offshore	1	M	M		72285.6	72207.5	0.1	0.0
	2	P	P		11002.6	12154.2	0.0	0.0
	3	M	M		12198.5	5564.0	54.4	2.6
	4	M	M		8356.2	9943.3	0.0	0.0
	5	M	M		7128.8	9400.3	0.0	0.0

Table 4. October coral skeleton measurements taken before and after placement in the field for 30 days. Measurements were acquired using ImageJ software from top-down photographs (orange: larger area after experimental period (due to algae overgrowth, yellow: % loss data).

Transect	Order	Survival	Top-Down Area (cm^2)			Days in Field	% Loss	% Loss per Day
			10.2.18	10.30.18	11.1.18			
Backdoors East	1	1	10289.9	7708.2		29	25.1	0.90
	2	1	11482.1	6477.5		29	43.6	1.50
	3	0	8457.8	0.0		29	100.0	3.45
	4	1	13560.5	10078.5		29	25.7	0.89
	5	1	9179.4	7238.7		29	21.1	0.73
	6	1	13289.1	7911.6		29	40.5	1.40
	7	1	13258.8	10684.9		29	19.4	0.67
Backdoors West	1	1	17668.4	13894.2		29	21.4	0.74
	2	1	11903.1	8004.3		29	32.8	1.13
	3	1	15705.0	8624.2		29	45.1	1.55
	4	1	10444.8	3696.0		29	64.6	2.23
	5	1	9011.7	6416.8		29	28.8	0.99
	6	1	7701.2	7036.1		29	8.6	0.30
	7	0	5323.3	0.0		29	100.0	3.45
Keyhole East	1	1	13472.1	6945.7		29	48.4	1.67
	2	1	8424.5	6649.3		29	21.1	0.73
	3	0	7401.5	0.0		29	100.0	3.45
	4	0	7829.2	0.0		29	100.0	3.45
	5	0	7164.1	0.0		29	100.0	3.45
	6	1	6729.1	5195.0		29	22.8	0.79
	7	0	18572.7	0.0		29	100.0	3.45
Keyhole West	1	1	8640.5	3033.2		29	64.9	2.24
	2	0	24614.9	0.0		29	100.0	3.45
	3	0	5999.6	0.0		29	100.0	3.45
	4	1	9655.1	7085.1		29	26.6	0.92
	5	1	12684.8	2255.5		29	82.2	2.84
	6	0	4693.9	0.0		29	100.0	3.45
	7	1	7921.4	5989.5		29	24.4	0.84
Channel East	1	1	5993.1	4719.7		29	21.2	0.73
	2	1	3689.8	2963.9		29	19.7	0.68
	3	1	6781.0	4477.4		29	34.0	1.17
	4	0	11739.3	0.0		29	100.0	3.45
	5	1	6153.4	3615.6		29	41.2	1.42
	6	1	5074.6	2140.9		29	57.8	1.99
	7	1	12727.6	15248.2		29	0.0	0.00

Table 4 cont. (2/2)

Transect	Order	Survival	Top-Down Area (cm^2) 10.2.18	10.30.18	11.1.18	Days in Field	% Loss	% Loss per Day
Channel West	1	1	6491.6	4900.6		29	24.5	0.85
	2	1	3252.5	1948.4		29	40.1	1.38
	3	1	14969.7	5774.9		29	61.4	2.12
	4	1	8190.4	8129.0		29	0.7	0.03
	5	1	3812.9	4370.7		29	0.0	0.00
	6	0	4040.1	0.0		29	100.0	3.45
	7	1	12620.5	8181.7		29	35.2	1.21
Witches Brew East	1	1	8869.6	9538.3		29	0.0	0.00
	2	1	14742.4	12365.5		29	16.1	0.56
	3	1	7334.4	5752.4		29	21.6	0.74
	4	1	10082.2	11107.8		29	0.0	0.00
	5	0	5520.0	0.0		29	100.0	3.45
	6	1	3835.1	3533.1		29	7.9	0.27
	7	1	8857.4	2962.0		29	66.6	2.30
Witches Brew West	1	1	26721.6	10488.8		29	60.7	2.09
	2	1	16541.1	17959.7		29	0.0	0.00
	3	1	11671.9	7786.8		29	33.3	1.15
	4	1	5493.3	4148.0		29	24.5	0.84
	5	1	10802.0	11024.4		29	0.0	0.00
	6	1	5329.9	3341.9		29	37.3	1.29
	7	1	4579.5	6582.4		29	0.0	0.00
Offshore East	1	1	20170.1		5843.0	31	71.0	2.29
	2	1	9662.2		8571.9	31	11.3	0.36
	3	1	7606.5		6047.5	31	20.5	0.66
	4	1	9945.8		12879.1	31	0.0	0.00
	5	1	10818.3		8540.5	31	21.1	0.68
	6	1	8064.3		7598.2	31	5.8	0.19
	7	1	16536.3		7289.7	31	55.9	1.80
Offshore West	1	1	3047.2		3347.6	31	0.0	0.00
	2	1	4305.1		2075.6	31	51.8	1.67
	3	1	5267.9		6393.4	31	0.0	0.00
	4	1	5620.3		3654.3	31	35.0	1.13
	5	1	7416.7		12053.1	31	0.0	0.00
	6	1	7146.3		7929.8	31	0.0	0.00
	7	1	8794.5		8691.8	31	1.2	0.04

Appendix D. Secchi Data. Table 1. June water clarity measurements (Secchi data). Grey shading: open to the public, no shading: closed to the public.

DATE:		Backdoor		Keyhole		Channel		Witches Brew			
		East	West	East	West	East	West	East	West		
6/1/18	Time	12:02	12:11	12:23	12:30	12:46	12:52	1:08	1:16	Obs1:	TD
	Cloud Cover (%)	90	90	50	20	30	30	5	5	Obs2:	RA
	Observation:	partial sun	partial sun	sun	sun	sun	sun	sun	sun		
	Obs1:Secchi distance away (m)	5.2	6.7	6.5	10.4	8.6	5.8	6.5	5		
	Obs1:Secchi distance toward (m)	4.9	5.4	5.6	11	8.2	5.2	6.3	4.5		
	Obs2:Secchi distance away (m)	5	9	7.4	7.8	7.7	7.3	7.6	5.9		
	Obs2:Secchi distance toward (m)	4	4.9	3.2	5	5.4	4.3	4.3	3.1		
6/5/18	Time	8:40	8:50	9:08	9:24	10:32	10:46	11:18	11:38	Obs1:	AM
	Cloud Cover (%)	0	5	40	50	60	50	40	40	Obs2:	AF
	Observation:	sun	sun	sun	sun on 1st	cloud cover	sun	sun	sun		
	Obs1:Secchi distance away (m)	10.6	8.9	7.4	11.2	9.8	10.4	8.05	7.34		
	Obs1:Secchi distance toward (m)	9.9	8.65	6.7	10.4	9.7	8.9	7.3	6.8		
	Obs2:Secchi distance away (m)	9.7	8.4	7.2	10.5	8.7	8.5	8.8	6.7		
	Obs2:Secchi distance toward (m)	8.9	7.6	6.3	8.8	8.1	7.4	7.1	5.9		
6/6/18	Time	12:17	12:30	12:00	12:50	1:26	1:20	1:42	1:48	Obs1:	SS
	Cloud Cover (%)	30	30	30	30	40	40	50	50	Obs2:	TD
	Observation:	sun	sun	partial sun	partial sun	partial sun	partial sun	partial sun	partial sun		
	Obs1:Secchi distance away (m)	7.3	8.4	8.4	10	9.1	6.4	6.9	6.2		
	Obs1:Secchi distance toward (m)	6.4	9.7	8.2	8.4	9.1	6	5.7	5.6		
	Obs2:Secchi distance away (m)	8.2	7.8	6.7	8.3	6.8	3.1	4.9	5.7		
	Obs2:Secchi distance toward (m)	8	8.5	6	8.2	7	5	4.2	5.4		
6/7/18	Time		12:40		12:24		12:06		11:51	Obs1:	SS
	Cloud Cover (%)	10	10	20	20	80	80	80	80	Obs2:	AR
	Observation:	sun	sun	sun	sun	partial sun	partial sun	sun	sun		
	Obs1:Secchi distance away (m)	8.4	9.2	7.1	6	7.7	7.8	6.6	5.1		
	Obs1:Secchi distance toward (m)	8.6	9	7.3	5.7	6.9	7	5.4	4.8		
	Obs2:Secchi distance away (m)	8.4	9.2	7	5.9	6.3	5.8	5.6	5.2		
	Obs2:Secchi distance toward (m)	7.6	9.6	7.2	5.6	6.6	5.6	5.1	4.8		

Table 1 cont. (2/3)

DATE:		Backdoor		Keyhole		Channel		Witches Brew			
		East	West	East	West	East	West	East	West		
6/8/18	Time	12:08		12:30	12:46	1:10	1:26	1:41	1:52	Obs1:	SS
	Cloud Cover (%)	50	50	50	50	75	75	75	75	Obs2:	RA
	Observation:	partial sun	partial sun	partial sun	partial sun	partial cloud	partial cloud	partial cloud	partial cloud		
	Obs1:Secchi distance away (m)	5.1	6.1	3.4	5.1	5	4.6	3.9	3.7		
	Obs1:Secchi distance toward (m)	4.6	5.9	2.9	4.9	4.8	4.5	3.7	3		
	Obs2:Secchi distance away (m)	4.6	5.4	3.3	4.9	5	5.3	3.8	3.4		
	Obs2:Secchi distance toward (m)	4.6	6.1	2.4	4.9	5.1	4.6	3.2	2.1		
6/10/18	Time	10:45	10:58	11:07	11:15	11:58	11:54	11:39	11:29	Obs1:	SS
	Cloud Cover (%)	20	10	10	10	10	10	10	10	Obs2:	SD
	Observation:	sun	sun	sun	sun	sun	sun	sun	sun		
	Obs1:Secchi distance away (m)	5.2	5.5	4.8	5.1	5.9	4.6	3.7	4.1		
	Obs1:Secchi distance toward (m)	5.2	5.3	4.7	5	5.3	3.7	3.2	3.9		
	Obs2:Secchi distance away (m)	5	6.1	5.1	5	4	4.7	3.2	3.1		
	Obs2:Secchi distance toward (m)	4.6	4.9	4.3	4.8	4.2	4.1	3.1	2.9		
6/12/18	Time			11:40		12:30	1:00	2:00		Obs1:	TD
	Cloud Cover (%)	20	20	20	20	80	90	90	90	Obs2:	HR
	Observation:	sun	sun								
	Obs1:Secchi distance away (m)	5.7	5.8	5.4	5.9	4.2	4.8	3.9	2.1		
	Obs1:Secchi distance toward (m)	4.9	5.2	4.3	5.5	3.8	4.7	2.9	2.2		
	Obs2:Secchi distance away (m)	5.2	5.2	5.1	5.9	5.7	6.2	3.8	3		
	Obs2:Secchi distance toward (m)	5.3	5.4	3.8	5.7	5.3	5.8	3.5	2.6		
6/16/18	Time	1:32	1:23	1:16	1:07	12:07	12:27	12:38		Obs1:	SS
	Cloud Cover (%)	20	20	20	20	40	50	50	50	Obs2:	AR
	Observation:	sun	sun	sun	sun	hazy	cloud	sun	sun		
	Obs1:Secchi distance away (m)	6.3	6.5	6	6.4	7.4	6.3	9	6.5		
	Obs1:Secchi distance toward (m)	5.5	6.2	5.6	5.7	6.9	6.3	8.5	6.4		
	Obs2:Secchi distance away (m)	5.6	6.6	5.3	5.9	6.7	5.3	8.2	6.6		
		5.4	6.1	5.2	6	6.8	5.6	7.2	7.5		

Table 1 cont. (3/3)

DATE:		Backdoor	Keyhole	Channel	Witches Brew

		East	West	East	West	East	West	East	West		
6/17/18	**Time**	8:53	9:00	9:10	9:18	9:33	9:42	9:54	10:15	**Obs1:**	**SS**
	Cloud Cover (%)	10	10	10	10	30	75	50	50	**Obs2:**	**DS**
	Observation:	sun	sun	sun	cloud	cloud cover	cloud	sun	cloud		
	Obs1:Secchi distance away (m)	11	13.8	13.6	10.6	8.6	10.5	10.9	9.8		
	Obs1:Secchi distance toward (m)	10.6	13.2	13.1	9.9	8.6	10.1	10.6	9.6		
	Obs2:Secchi distance away (m)	11.5	13.4	12	12.1	9.4	8.9	9.8	8.9		
	Obs2:Secchi distance toward (m)	10.8	13.2	12.2	10.8	9.4	7.6	10	8.9		
6/19/18	**Time**	9:31	9:24	9:15	9:05	9:58	10:05	10:21	10:28	**Obs1:**	**AF**
	Cloud Cover (%)									**Obs2:**	**SF**
	Observation:	sun	sun	sun	sun	sun	sun	sun	sun		
	Obs1:Secchi distance away (m)	13.8	18.6	15.7	16.9	15.3	14.4	11.9	10.1		
	Obs1:Secchi distance toward (m)	14.1	19.5	15.8	17.1	15.1	14.6	10.9	9.8		
	Obs2:Secchi distance away (m)	16.25	17.9	16.1	16.5	14.19	14.3	12.2	11.2		
	Obs2:Secchi distance toward (m)	17.1	16.7	15.9	16.2	14.25	15.5	10.7	8.9		
6/20/18	**Time**	12:10	12:15	12:20	12:24	12:37	12:42	12:50	12:55	**Obs1:**	**SS**
	Cloud Cover (%)	20	20	20	20	20	20	20	20	**Obs2:**	**RA**
	Observation:	sun	sun	sun	sun	sun	sun	sun	sun		
	Obs1:Secchi distance away (m)	9.5	11.7	8.2	3.5	5.5	4.9	7.2	5.9		
	Obs1:Secchi distance toward (m)	8.5	11.5	8.3	3.3	5.1	5.1	6.7	5.8		
	Obs2:Secchi distance away (m)	7.9	10.8	7	2.4	6	4.5	6	5.1		
	Obs2:Secchi distance toward (m)	7.5	8.5	5.8	2.1	4.4	3.9	4.4	4.2		
6/28/18	**Time**	11:47		12:00PM	12:05	12:15	12:20	12:30	12:36	**Obs1:**	**SS**
	Cloud Cover (%)	100	100	100	100	100	100	100	100	**Obs2:**	**AR**
	Observation:										
	Obs1:Secchi distance away (m)	6.9	6.4	5.5	6.4	7	6.5	5.2	4.7		
	Obs1:Secchi distance toward (m)	6	6.1	5.1	6.8	6.6	6.1	5.8	4.3		
	Obs2:Secchi distance away (m)	7.9	7.2	5.3	6.4	5.5	5.1	5	4.1		
	Obs2:Secchi distance toward (m)	7.1	7.4	5.1	5.4	4.9	5.2	4.7	3.9		

Table 2. October water clarity measurements (Secchi data). Grey shading: open to the public, no shading: closed to the public.

Date:		Backdoor		Keyhole		Channel		Witches Brew		Offshore		
		East	West	East	West	East	West	East	West	East	West	
10/5/18	Time	12:09	12:22		12:45	12:57	1:08		1:30			Obs1:SS
	Cloud Cover	0	0	10	0	0	0	0	0			Obs2:AR
	Observation:			cloud	sun	sun	sun	sun	sun			
	Obs1:Secchi distance away (m)	6.9	8	5.5	6.7	10.8	5.3	3.2	2.7			
	Obs1:Secchi distance toward (m)	7.2	7.8	5.8	5.6	10.7	4.3	2.8	1.9			
	Obs2:Secchi distance away (m)	5.3	7.4	6.9	5.4	9.2	4.1	3.5	2.3			
	Obs2:Secchi distance toward (m)	5.7	7.4	5.8	4.9	8.5	3.4	3.2	1.8			
10/8/18	Time	11:42	11:47	11:55	12:05	12:17	12:30	12:47	1:02			Obs1:SS
	Cloud Cover	10	10	50	50	50	50	50	50			Obs2:AR
	Observation:	sun	sun	cloud	cloud	sun/cloud	cloud	cloud	cloud/sun			
	Obs1:Secchi distance away (m)	7.9	10.1	7.6	6.4	6.3	6.4	5.2	4.2			
	Obs1:Secchi distance toward (m)	7.4	9.6	7	6.6	6	5.3	3.9	3.5			
	Obs2:Secchi distance away (m)	7.7	8.8	7	5.3	5.2	4.9	4.6	4.4			
	Obs2:Secchi distance toward (m)	7.4	8.5	5.8	5.9	6.1	4.7	3.8	3.5			
10/9/18	Time	10:57	11:01	11:28	11:35	12:15	12:20	12:44	12:49	10:18	10:30	Obs1:SS
	Cloud Cover	30	30	50	75	95	50	20	20	50	50	Obs2:HG
	Observation:	sun	sun	sun	sun	cloud	sun	sun	sun	cloud	cloud	
	Obs1:Secchi distance away (m)	11.5	11.8	10.1	9.4	7.5	8.8	6.1	5.1	9.1	8.7	
	Obs1:Secchi distance toward (m)	11.2	11.7	9.7	8.9	7	8.2	5.8	5.8	9.3	8.3	
	Obs2:Secchi distance away (m)	11.8	11.4	10.5	8.3	9.6	8.3	6.2	5.8	9.3	8.7	
	Obs2:Secchi distance toward (m)	11.6	11.1	10.1	8.1	9.3	8.1	5.9	5.5	8.9	8.3	
10/10/18	Time	11:42	11:47	11:55	12:01	12:13	12:21	12:35	12:43			Obs1:SS
	Cloud Cover	60	50	50	50	75	75	50	50			Obs2:AR
	Observation:	cloud	sun	sun	cloud	cloud/sun	cloud	sun	sun			
	Obs1:Secchi distance away (m)	8.5	8.7	7.8	7.7	7.6	6.1	4.7	5.3			
	Obs1:Secchi distance toward (m)	7.9	7.4	7.9	7.8	7.9	6.1	5.1	5.1			
	Obs2:Secchi distance away (m)	8.2	8.9	8	9.2	8.4	6.7	5.1	4.7			
	Obs2:Secchi distance toward (m)	6.7	7.9	7	6.2	6.1	4.5	5.1	4.3			

Table 2 cont. (2/3)

Date:		Backdoor		Keyhole		Channel		Witches Brew		Offshore		
		East	West	East	West	East	West	East	West	East	West	
10/11/18	**Time**	11:35	11:54	12:04	12:11	12:27	12:35	12:47	12:57			**Obs1:SS**
	Cloud Cover	15	15	15	15	25	40	40	40			**Obs2:HG**
	Observation:	sun	sun	sun	sun	sun	sun	sun	sun			
	Obs1:Secchi distance away (m)	9.3	10.6	7.8	6.9	7.6	8.1	5.8	4.4			
	Obs1:Secchi distance toward (m)	8.6	11.2	7.3	5.8	7.1	7.5	5.7	4.3			
	Obs2:Secchi distance away (m)	8.8	10	9.5	7.6	8.3	8.1	6.3	4.1			
	Obs2:Secchi distance toward (m)	8.5	9.7	8.9	7.1	7.1	7.7	5.8	3.9			
10/12/18	**Time**	11:34	11:42	11:51	11:59	12:14	12:22	12:39	12:47			**Obs1:SS**
	Cloud Cover	50	50	50	50	50	75	75	100			**Obs2:AR**
	Observation:	cloud	cloud	sun	sun	cloud	cloud	cloud	cloud			
	Obs1:Secchi distance away (m)	10.1	10.4	9.3	9.5	10.5	7.1	5.7	4.8			
	Obs1:Secchi distance toward (m)	10.5	10.4	8.5	10.1	10.3	7.5	4.9	4.1			
	Obs2:Secchi distance away (m)	8.7	11.1	8.6	10.3	8.4	6.9	5.1	3.9			
	Obs2:Secchi distance toward (m)	9.3	10.3	8.6	10.4	7.5	6.5	5.1	4.6			
10/14/18	**Time**	11:59	12:05	12:13	12:22	1:01	1:11	1:20	1:34	12:30	12:51	**Obs1:SS**
	Cloud Cover	10	20	20	20	10	10	20	20	10	10	**Obs2:AT**
	Observation:	sun	sun	sun	sun	sun	sun	sun	sun	sun	sun	
	Obs1:Secchi distance away (m)	11.1	13.6	10.5	9.4	8.5	5.7	4.1	3.6	11.1	13.5	
	Obs1:Secchi distance toward (m)	10.5	12.6	9.8	8	8.1	5.6	3.9	2.5	11.5	13.7	
	Obs2:Secchi distance away (m)	8.15	11.6	10.9	9.2	6.9	5.2	3.5	3	11.9	13	
	Obs2:Secchi distance toward (m)	8.1	12	10.9	9.5	6.9	5.2	3.5	2.9	12.4	12.9	
10/16/18	**Time**	8:48	8:45	9:03	9:19	9:52	9:54	10:07	10:10	8:04	8:00	**Obs1:AR**
	Cloud Cover	20	20	10	10	10	10	20	20	20	20	**Obs2:HG**
	Observation:	sun	sun	sun	sun	sun/cloud	sun	sun	sun	sun	sun	
	Obs1:Secchi distance away (m)	12.2	12.4	8.5	10.1	10.9	9.3	7.1	4.2	24.1	27.3	
	Obs1:Secchi distance toward (m)	12.7	12.2	7	9.4	10.5	8.5	6.6	4.1	24.1	27.5	
	Obs2:Secchi distance away (m)	13.4	12.7	10.4	9.6	12.4	9.9	7.1	4.8	24.3	27.6	
	Obs2:Secchi distance toward (m)	13.2	12.4	10.7	9.4	12.3	9.6	6.8	4.5	24.1	27.2	

Table 2 cont. (3/3)

Date:		Backdoor		Keyhole		Channel		Witches Brew		Offshore		
		East	West	East	West	East	West	East	West	East	West	
10/20/18	**Time**	11:33	11:39	11:46	11:53	12:05	12:12	12:21	12:33			**Obs1:SS**
	Cloud Cover	20	20	30	20	20	20	50	50			**Obs2:AF**
	Observation:	sun	sun	sun	sun	sun	sun	cloud	cloud			
	Obs1:Secchi distance away (m)	7.5	10	7.8	7.1	10.5	6.4	6.1	4.6			
	Obs1:Secchi distance toward (m)	7.1	9.2	7.9	7.1	9.3	5.7	4.9	4.5			
	Obs2:Secchi distance away (m)	7.5	8.2	7.5	7.8	9.8	7.6	5	5.2			
	Obs2:Secchi distance toward (m)	7.2	7	6.6	5.9	8.5	6.5	4.2	3.5			
10/21/18	**Time**	11:56	12:03	12:10	12:16	12:26	12:33	12:42	12:48			**Obs1:SS**
	Cloud Cover	95	95	80	70	50	50	50	50			**Obs2:AT**
	Observation:	Cloud	Cloud	cloud	cloud	sun	sun	sun	sun			
	Obs1:Secchi distance away (m)	6.7	6.5	4.9	4.6	7.1	4.4	3.9	4.2			
	Obs1:Secchi distance toward (m)	6.9	6.1	4.6	4.1	7.5	5.4	3.3	3.8			
	Obs2:Secchi distance away (m)	7.4	7.2	6.1	5.1	7.1	5.5	3.4	4			
	Obs2:Secchi distance toward (m)	7.5	7.3	5.8	5.2	7.1	5.5	3.5	3.6			
10/23/18	**Time**	10:41	10:30	10:19	10:27	9:25	9:34	9:50	9:57	9:02	9:22	**Obs1:HG**
	Cloud Cover	20	20	20	25	50	60	85	85	70	70	**Obs2:RK**
	Observation:	sun	sun	sun	sun	sun	sun	cloud/sun	cloud/sun	sun/cloud	cloud	
	Obs1:Secchi distance away (m)	11.5	10.5	10.8	12.2	12.2	11.6	11.1	8.4	13.2	11.5	
	Obs1:Secchi distance toward (m)	11.3	10.4	10.6	12.1	11.8	11.5	10.8	8.2	12.11	11.2	
	Obs2:Secchi distance away (m)	11.4	11.3	11.2	13.2	12.4	15.6	11.3	9.4	13.6	17.9	
	Obs2:Secchi distance toward (m)	11	11	10	12.8	11.8	15.2	11.1	9.2	13.4	16.8	
10/24/18	**Time**	11:37	11:44	11:51	11:58	12:10	12:19	12:30	12:37			**Obs1:SS**
	Cloud Cover	25	25	80	20	10	10	10	20			**Obs2:AR**
	Observation:	sun	sun	sun	sun	sun	sun	sun	sun			
	Obs1:Secchi distance away (m)	11.3	9.9	8.9	8.6	7.9	6.4	4.8	3.9			
	Obs1:Secchi distance toward (m)	11	10.1	8.7	8.9	7.8	6.1	4.8	4			
	Obs2:Secchi distance away (m)	10.3	9.2	7.2	8.9	8.6	7.3	4.6	4.2			
	Obs2:Secchi distance toward (m)	9.9	9.8	6.4	9.05	8.1	5.1	4.3	3.6			

Appendix E. Sediment accumulation data.
Table 1. Sediment accumulation within sediment traps during June 2018.

Location	Location Along Transect	Days in Field	Sediment Weight (g) Day #1	Day #2	Day #3	Average	SD	Sediment accumulation per day
Backdoors East	0 m	29	3.73	3.71	3.71	3.72	0.009	0.13
	15 m	19	36.14	36.09	36.09	36.10	0.030	2.01
Backdoors West	0 m	29	57.60	59.64	57.55	58.26	1.189	2.43
	15 m	26	37.72	39.75	37.68	38.38	1.182	5.69
Keyhole East	0 m	29	69.74	71.78	69.68	70.40	1.193	0.93
	15 m	29	60.68	62.75	60.65	61.36	1.205	2.60
Keyhole West	0 m	29	164.38	166.38	164.30	165.02	1.177	2.01
	15 m	29	59.36	61.40	59.32	60.02	1.189	1.65
Channel East	0 m	29	27.11	27.09	27.10	27.10	0.010	1.77
	15 m	29	50.31	50.26	50.27	50.28	0.028	1.90
Channel West	0 m	29	75.40	75.37	75.12	75.30	0.153	1.48
	15 m	29	44.95	44.93	44.93	44.93	0.011	2.12
Witches Brew East	0 m	29	58.30	58.28	58.28	58.29	0.013	2.07
Witches Brew West	0 m	29	47.89	47.86	47.87	47.87	0.015	1.73
	15 m	29	53.27	53.24	53.25	53.25	0.017	1.55
Offshore East	0 m	15	26.63	26.62	26.62	26.62	0.008	1.84
	15 m	15	11.54	11.53	11.53	11.53	0.006	0.77

Table 2. Sediment accumulation within sediment traps during October 2018.

Transect	Location Along Transect	Days in Field	Sediment Weight (g) Day #1	Day #2	Day #3	Average	SD	Sediment accumulation per day
Backdoors East	0 m	29	61.23	61.15	61.24	61.20	0.051	2.11
	15 m	29	137.26	137.15	137.28	137.23	0.069	4.73
Backdoors West	0 m	29	70.55	70.48	70.55	70.52	0.038	2.43
	15 m	29	64.06	64.01	64.06	64.04	0.032	2.21
Keyhole East	0 m	29	162.51	162.38	162.48	162.46	0.065	5.60
	15 m	29	85.84	85.73	85.76	85.78	0.056	2.96
Keyhole West	0 m	29	403.38	402.79	403.26	403.14	0.308	13.90
	15 m	29	87.31	87.23	87.31	87.28	0.047	3.01
Channel East	0 m	15	19.72	19.69	19.72	19.71	0.016	1.31
	15 m	29	18.84	18.82	18.84	18.83	0.015	0.65
Channel West	0 m	29	83.72	83.64	83.70	83.69	0.042	2.89
	15 m	29	36.75	36.71	36.74	36.73	0.020	1.27
Witches Brew East	0 m	29	81.89	81.79	81.87	81.85	0.050	2.82
	15 m	29	94.91	94.82	94.91	94.88	0.054	3.27
Witches Brew West	0 m	29	77.95	77.87	77.94	77.92	0.043	2.69
	15 m	29	29.50	29.47	29.51	29.49	0.024	1.02
Offshore East	0 m	31	96.97	96.88	96.95	96.93	0.049	3.13
	15 m	31	152.28	152.14	152.27	152.23	0.079	4.91
Offshore West	0 m	31	37.12	37.08	37.12	37.10	0.024	1.20
	15 m	31	46.63	46.58	46.64	46.62	0.032	1.50

Appendix F. Adult Coral Surveys

Table 1. October coral visual surveys of transects within Hanauma Bay.

Observer:	**Sarah Severino**				**12/4/2018**
Transect	**Distance along Transect (m)**	**Common Name**	**Spp.**	**Diameter (cm)**	**Growth on vertical surface? (Yes)**
Backdoors East	0	Brown Lobe	PE	15	
	0	Ocellated	CO	5	
	0	Cauliflower	PM	5	
	5.2	Brown Lobe	PE	100	
	5.2	Cauliflower	PM	5	
	5.2	Cauliflower	PM	5	
	11.5	Sandpaper	PN	50	
	12.6	Rubbery Zoanthid	PT	50	
	15	Rubbery Zoanthid	PT	100	
	15	Rubbery Zoanthid	PT	30	
	13	Cauliflower	PM	30	
	9.6	Rubbery Zoanthid	PT	30	
	9.6	Porkchop	PD	10	
	9.6	Porkchop	PD	5	
	9.6	Porkchop	PD	5	
	9.6	Porkchop	PD	5	
	9.6	Porkchop	PD	10	
	8.3	Cauliflower	PM	5	
	7	Brown Lobe	PE	40	
	7	Brown Lobe	PE	20	
	7	Brown Lobe	PE	20	
	7	Brown Lobe	PE	5	
	7	Brown Lobe	PE	5	
	7	Brown Lobe	PE	10	
	4.2	Corrugated	PV	5	
	4.2	Corrugated	PV	5	
	0.9	Brown Lobe	PE	20	
	0	Brown Lobe	PE	30	
Backdoors West	0	Cauliflower	PM	30	
	2	Sandpaper	PN	100	
	2	Sandpaper	PN	10	
	8.7	Cauliflower	PM	20	
	3	Cauliflower	PM	10	

Table 2 cont. (2/6)

Transect	Distance along Transect (m)	Common Name	Spp.	Diameter (cm)	Growth on vertical surface? (Yes)
Keyhole East	0	Cauliflower	PM	30	
	6.7	Lobe	PL	5	
	7.8	Lobe	PL	5	
	8	Brown Lobe	PE	20	
	11.6	Ocellated	CO	5	
	12.4	Corrugated	PV	5	
	13.6	Cauliflower	PM	5	
	13.6	Cauliflower	PM	30	
	15	Lobe	PL	10	
	15	Sandpaper	PN	100	
	12.5	Lobe	PL	10	
Keyhole West	2.5	Rice	MC	20	
	1.5	Lobe	PL	5	
	13.1	Cauliflower	PM	50	
	8.3	Cauliflower	PM	20	Y
	0	Cauliflower	PM	30	Y
Channel East	15	Lobe	PL	10	Y
	13.4	Rice	MC	100	Y
	12.5	Rice	MC	200	Y
	11.4	Ocellated	CO	5	
	10.4	Cauliflower	PM	5	
	7.7	Brigham's	PB	5	
	6.8	Sandpaper	PN	100	Y
	6.5	Ringed Rice	MP	50	Y
	4.7	Sandpaper	PN	50	
	4.1	Ocellated	CO	5	
	0	Rice	MC	250	Y
	2	Cauliflower	PM	5	
	2	Cauliflower	PM	5	
	3.3	Cauliflower	PM	10	
	5.3	Lobe	PL	100	Y
	6.3	Ocellated	CO	5	
	6.5	Brigham's	PB	5	Y
	7	Lobe	PL	5	
	13	Lobe	PL	10	Y
	13	Sandpaper	PN	20	Y
	13.3	Ocellated	CO	5	
	13.6	Sandpaper	PN	20	

Table 2 cont. (3/6)

Transect	Distance along Transect (m)	Common Name	Spp.	Diameter (cm)	Growth on vertical surface? (Yes)
Channel West	15	Rice	MC	20	Y
	12.4	Ocellated	CO	5	
	11.4	Ocellated	CO	5	
	9	Ocellated	CO	5	Y
	8.9	Cauliflower	PM	5	
	8	Rice	MC	100	Y
	6.9	Rice	MC	50	Y
	5.3	Cauliflower	PM	10	
	3.3	Rice	MC	100	Y
	7.9	Rice	MC	300	Y
	9.3	Ringed Rice	MP	400	Y
	10.9	Cauliflower	PM	5	
Witches Brew East	15	Cauliflower	PM	5	
	15	Rice	MC	100	Y
	14.1	Cauliflower	PM	7	
	13.9	Cauliflower	PM	5	
	11.5	Brigham's	PB	5	
	11.2	Brown Lobe	PE	100	
	8.4	Brown Lobe	PE	100	
	6.1	Brown Lobe	PE	50	
	3.6	Brown Lobe	PE	300	
	0	Brown Lobe	PE	10	
	0	Brown Lobe	PE	20	
	3.7	Corrugated	PV	10	
	9.2	Brown Lobe	PE	5	Y
	11.5	Cauliflower	PM	5	
	11.5	Cauliflower	PM	5	
	12.4	Cauliflower	PM	5	
	12.4	Cauliflower	PM	5	
	12.6	Brown Lobe	PE	20	
	12.6	Brown Lobe	PE	10	
	13.3	Rice	MC	100	

Table 2 cont. (4/6)

Transect	Distance along Transect (m)	Common Name	Spp.	Diameter (cm)	Growth on vertical surface? (Yes)
Witches Brew West	15	Brown Lobe	PE	20	
	15	Brown Lobe	PE	20	
	13.9	Brown Lobe	PE	20	
	13.9	Brown Lobe	PE	20	
	13.9	Brown Lobe	PE	20	
	13.9	Brown Lobe	PE	20	
	12.6	Brown Lobe	PE	20	
	12	Brown Lobe	PE	5	
	12	Brown Lobe	PE	5	
	12	Brown Lobe	PE	5	
	12	Sandpaper	PN	10	
	11.6	Brown Lobe	PE	10	
	11.6	Brown Lobe	PE	5	
	11.6	Brown Lobe	PE	5	
	11.6	Cauliflower	PM	5	
	11.1	Brown Lobe	PE	5	
	11.1	Brown Lobe	PE	5	
	11.1	Brown Lobe	PE	5	
	11.1	Brown Lobe	PE	5	
	11.1	Brown Lobe	PE	10	
	9.9	Brown Lobe	PE	10	
	9.9	Brown Lobe	PE	5	
	9.9	Brown Lobe	PE	5	
	9.9	Brown Lobe	PE	5	
	9.9	Brown Lobe	PE	5	
	9.9	Brown Lobe	PE	10	
	8.8	Brown Lobe	PE	10	
	8.8	Brown Lobe	PE	5	
	8.8	Brown Lobe	PE	5	
	8.8	Brown Lobe	PE	20	
	7.2	Brown Lobe	PE	20	
	7.2	Brown Lobe	PE	20	
	7.2	Brown Lobe	PE	5	
	7.2	Brown Lobe	PE	5	
	7.2	Brown Lobe	PE	20	

Table 2 cont. (5/6)

Transect	Distance along Transect (m)	Common Name	Spp.	Diameter (cm)	Growth on vertical surface? (Yes)
Witches Brew West Cont.	7.2	Brown Lobe	PE	30	
	7.2	Brown Lobe	PE	20	
	7.2	Brown Lobe	PE	20	
	6	Brown Lobe	PE	30	
	6	Stellar	PS	5	
	6	Lobe	PL	5	
	6	Sandpaper	PN	5	
	5.1	Brown Lobe	PE	20	
	4	Brown Lobe	PE	100	
	3.7	Brown Lobe	PE	5	
	0	Brown Lobe	PE	5	
	0	Brown Lobe	PE	5	
	0	Brown Lobe	PE	5	
	0	Brown Lobe	PE	5	
	0	Brown Lobe	PE	5	
	0	Brown Lobe	PE	10	
	0	Cauliflower	PM	10	
	2	Ocellated	CO	7	
	2.6	Brown Lobe	PE	5	
	2.6	Brown Lobe	PE	5	
	2.6	Brown Lobe	PE	5	
	2.6	Brown Lobe	PE	5	
	2.6	Brown Lobe	PE	5	
	2.6	Brown Lobe	PE	10	
	2.6	Brown Lobe	PE	10	
	4.1	Sandpaper	PN	10	
	4.1	Sandpaper	PN	10	
	4.1	Sandpaper	PN	10	
	4.1	Sandpaper	PN	10	
	4.1	Sandpaper	PN	10	
	4.1	Stellar	PS	5	
	4.1	Cauliflower	PM	5	
	4.7	Sandpaper	PN	10	
	4.7	Sandpaper	PN	10	
	4.7	Sandpaper	PN	10	

Table 2 cont. (6/6)

Transect	Distance along Transect (m)	Common Name	Spp.	Diameter (cm)	Growth on vertical surface? (Yes)
Witches Brew West Cont.	4.7	Sandpaper	PN	5	
	7.2	Brown Lobe	PE	20	
	7.2	Brown Lobe	PE	10	
	7.2	Brown Lobe	PE	5	
	7.2	Sandpaper	PN	10	
	8	Brown Lobe	PE	10	
	10.9	Brown Lobe	PE	5	
	10.9	Brown Lobe	PE	5	
	10.9	Brown Lobe	PE	20	
	10.9	Brown Lobe	PE	5	
	10.9	Brown Lobe	PE	5	
	10.9	Brown Lobe	PE	5	
	10.9	Brown Lobe	PE	5	
	10.9	Brown Lobe	PE	5	
	10.9	Brown Lobe	PE	5	
	10.9	Brown Lobe	PE	5	
	12	Brown Lobe	PE	20	
	13.4	Brown Lobe	PE	10	
	14.1	Brown Lobe	PE	20	
	14.1	Brown Lobe	PE	10	
	14.1	Brown Lobe	PE	10	
	14.1	Brown Lobe	PE	10	
	14.1	Brown Lobe	PE	10	
	14.1	Brown Lobe	PE	10	
	14.1	Brown Lobe	PE	10	

Species Code	Species
CO	*Cyphastrea ocellina*
MC	*Montipora capitata*
MF	*Montipora flabelata*
MP	*Montipora patula*
PB	*Porites brighami*
PD	*Pavona duerdeni*
PE	*Porites evermanni*
PL	*Porites lobata*
PM	*Pocillopora meandrina*
PN	*Psammocora nierstraszi*
PS	*Psammocora stellata*
PT	*Palythoa tuberculosa*
PV	*Pavona varians*

Appendix G. CRAMP Data.

Table 1. Hanauma Bay CRAMP percent coral cover from 1999 to 2018.

Site	Transect	Survey Year						
		1999	2000	2002	2009	2012	2017	2018
OaHan03	**1**	17.75%	20.89%	24.93%	6.55%	9.54%	18.00%	13.40%
OaHan03	**2**	27.62%	36.73%	32.53%	10.91%	8.33%	18.74%	26.00%
OaHan03	**3**	29.37%	32.60%	22.67%	19.50%	15.00%	20.80%	14.80%
OaHan03	**4**	16.62%	22.00%	15.60%	5.82%	9.67%	8.00%	8.73%
OaHan03	**5**	42.56%	42.00%	25.73%	18.40%	14.72%	17.52%	20.40%
OaHan03	**6**	21.76%	26.18%	22.67%	10.00%	7.00%	8.94%	7.50%
OaHan03	**7**	32.21%	0.00%	28.53%	13.45%	8.36%	17.52%	24.00%
OaHan03	**8**	14.80%	19.00%	12.13%	5.09%	7.67%	7.43%	14.20%
OaHan03	**9**	14.82%	13.83%	12.13%	12.44%	4.92%	7.82%	2.60%
OaHan03	**10**	18.63%	18.73%	20.93%	15.60%	10.33%	16.95%	15.81%
OaHan10	**1**	22.35%	29.78%	26.63%	-	35.33%	40.38%	29.52%
OaHan10	**2**	28.93%	25.17%	19.20%	-	13.25%	3.20%	9.91%
OaHan10	**3**	36.32%	28.50%	22.00%	-	36.33%	24.76%	22.18%
OaHan10	**4**	33.56%	24.57%	24.53%	-	49.85%	27.40%	26.20%
OaHan10	**5**	28.00%	26.73%	19.87%	-	5.33%	4.95%	3.80%
OaHan10	**6**	25.44%	37.40%	26.40%	-	23.00%	3.62%	23.67%
OaHan10	**7**	22.84%	24.36%	21.33%	-	44.00%	12.38%	22.48%
OaHan10	**8**	24.74%	22.36%	17.60%	-	52.53%	14.67%	17.91%
OaHan10	**9**	22.35%	21.27%	22.40%	-	10.74%	7.27%	9.40%
OaHan10	**10**	22.82%	29.78%	22.40%	-	29.67%	17.14%	-

Appendix H. Temperature Data.

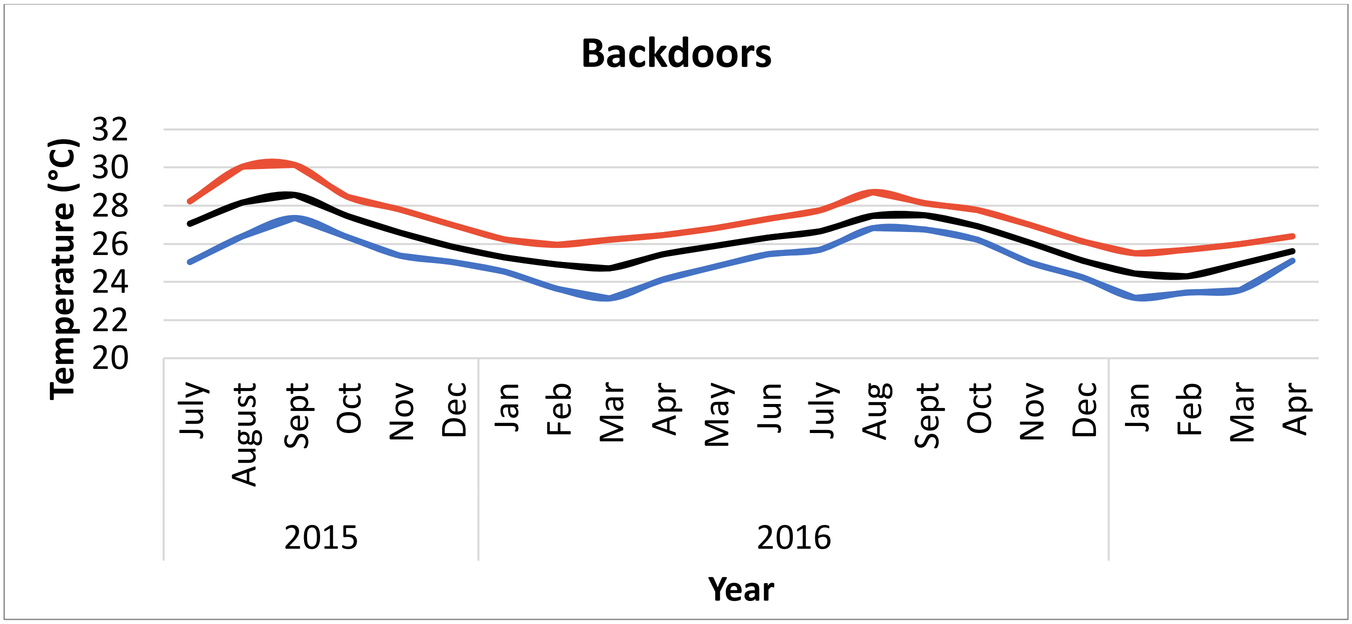

Figure 1. Temperature graph with calculations for average temperature (black line), maximum temperature (red line) and minimum temperature (blue line) received by the HOBO data logger placed in Backdoors sector from July 2015 till April 2017.

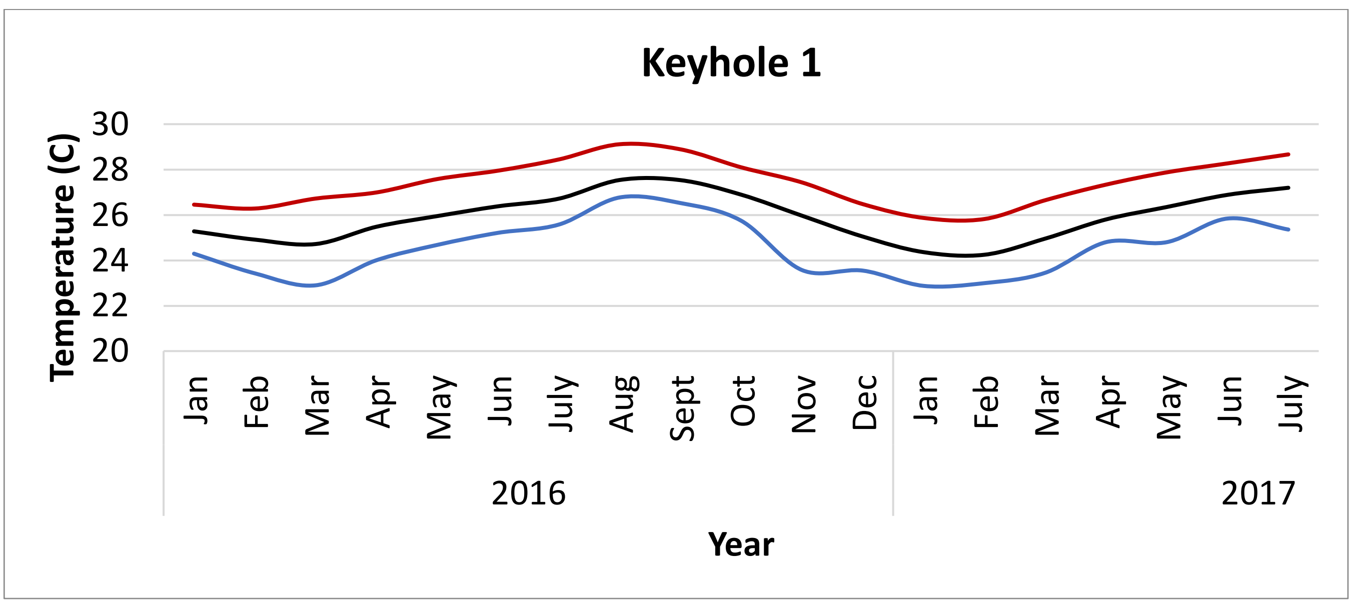

Figure 2. Temperature graph with calculations for average temperature (black line), maximum temperature (red line) and minimum temperature (blue line) received by the one of the two HOBO data loggers placed in Keyhole sector from January 2016 till July 2017.

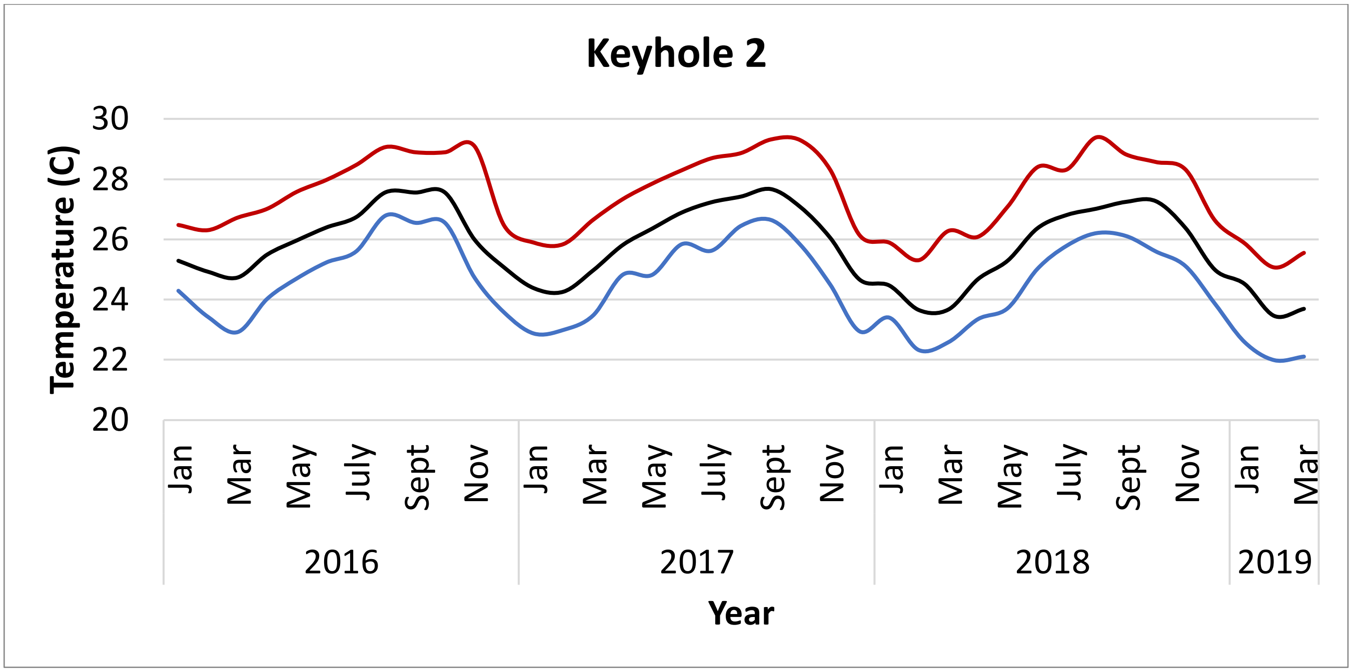

Figure 3. Temperature graph with calculations for average temperature (black line), maximum temperature (red line) and minimum temperature (blue line) received by the one of the two HOBO data loggers placed in Keyhole sector from January 2016 till March 2019.

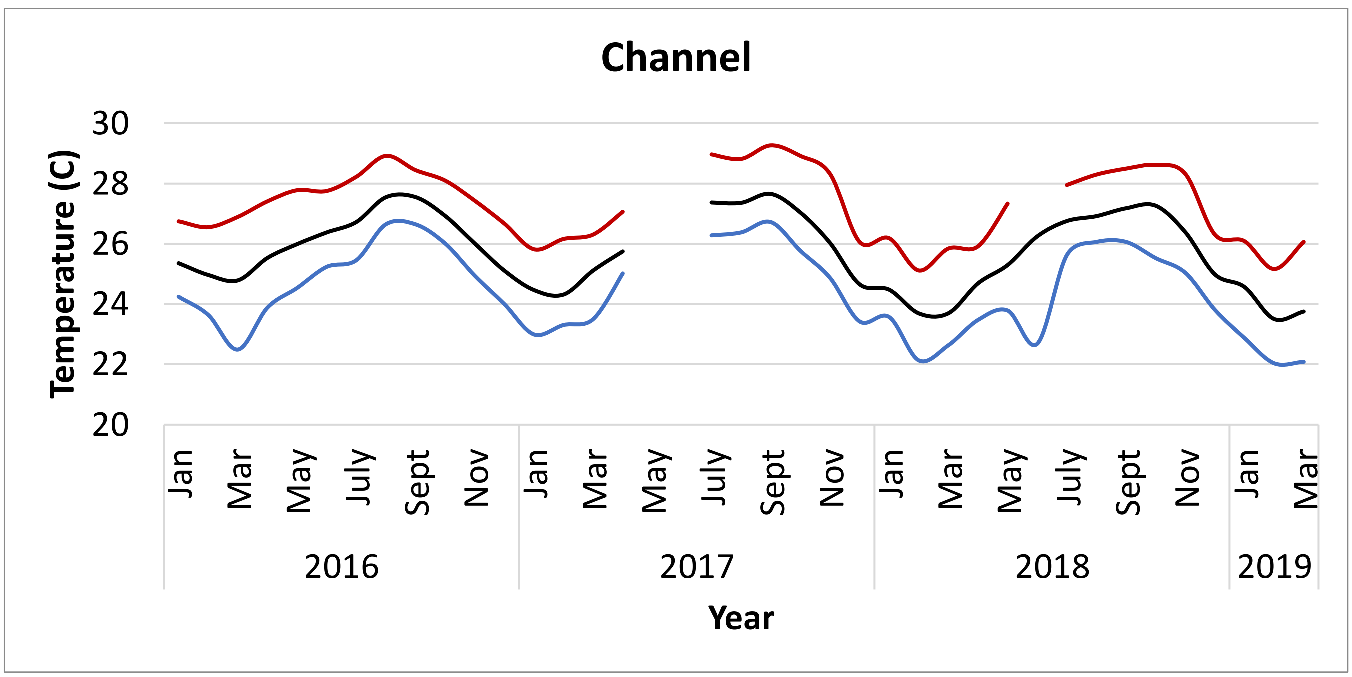

Figure 4. Temperature graph with calculations for average temperature (black line), maximum temperature (red line) and minimum temperature (blue line) received by the HOBO data logger placed in Channel sector from January 2016 till March 2019.

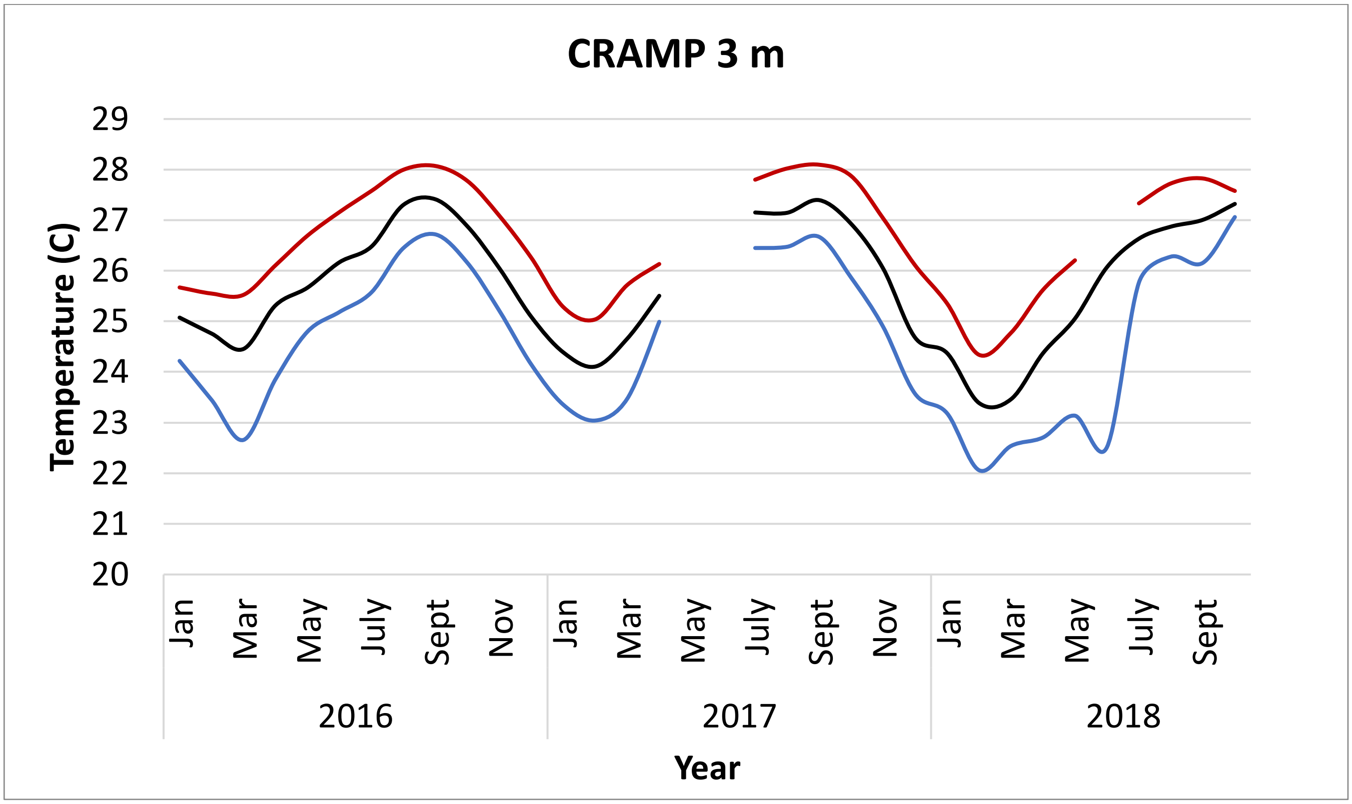

Figure 5. Temperature graph with calculations for average temperature (black line), maximum temperature (red line) and minimum temperature (blue line) received by the HOBO data logger placed at the 3 m (9 ft.) deep Coral Reef Assessment and Monitoring (CRAMP) site from January 2016 till October 2019.

Table 1. Summary of temperature data taken in 4 locations within Hanauma Bay.

Year	Month	Backdoors					Keyhole 1					Keyhole 2					Channel					CRAMP 3 m				
			Temperature (°C)					Temperature (°C)					Temperature (°C)					Temperature (°C)					Temperature (°C)			
		N	Ave.	SD	Max	Min	N	Ave.	SD	Max	Min	N	Ave.	SD	Max	Min	N	Ave.	SD	Max	Min	N	Ave.	SD	Max	Min
2015	July	2976	27.05	0.97	28.22	25.04																				
	Aug	2976	28.16	1.19	30.04	26.40																				
	Sept	2880	28.57	0.80	30.14	27.36																				
	Oct	2976	27.46	0.76	28.47	26.35																				
	Nov	2880	26.59	0.81	27.80	25.38																				
	Dec	2976	25.84	0.64	26.99	25.04																				
2016	Jan	1863	25.29	0.33	26.23	24.53	1863	25.28	0.46	26.45	24.29	1863	25.29	0.46	26.48	24.29	1865	25.36	0.55	26.74	24.24	1867	25.08	0.25	25.67	24.22
	Feb	2784	24.92	0.44	25.94	23.64	2784	24.91	0.55	26.28	23.42	2784	24.92	0.55	26.30	23.42	2784	24.96	0.63	26.55	23.64	2784	24.76	0.36	25.55	23.45
	Mar	2976	24.72	0.57	26.21	23.14	2976	24.72	0.71	26.72	22.90	2976	24.73	0.71	26.72	22.92	2976	24.78	0.83	26.89	22.49	2976	24.46	0.41	25.53	22.66
	Apr	2880	25.44	0.37	26.45	24.12	2880	25.48	0.49	26.99	24.00	2880	25.50	0.49	27.01	24.03	2880	25.53	0.60	27.41	23.88	2880	25.32	0.37	26.11	23.86
	May	2976	25.89	0.46	26.82	24.80	2976	25.95	0.59	27.58	24.68	2976	25.96	0.59	27.58	24.70	2976	25.99	0.67	27.78	24.53	2976	25.67	0.43	26.70	24.80
	Jun	2880	26.32	0.35	27.31	25.45	2880	26.38	0.51	27.95	25.21	2880	26.40	0.51	27.97	25.23	2880	26.38	0.53	27.75	25.23	2880	26.17	0.39	27.16	25.19
	July	2976	26.66	0.44	27.75	25.70	2976	26.72	0.55	28.44	25.57	2976	26.74	0.55	28.47	25.60	2976	26.72	0.54	28.22	25.45	2976	26.48	0.42	27.58	25.57
	Aug	2976	27.47	0.30	28.72	26.82	2976	27.54	0.45	29.12	26.77	2976	27.56	0.44	29.07	26.79	2976	27.54	0.43	28.92	26.65	2976	27.30	0.29	28.00	26.45
	Sept	2880	27.50	0.28	28.12	26.74	2880	27.53	0.43	28.89	26.52	2880	27.55	0.43	28.89	26.55	2880	27.55	0.35	28.44	26.65	2880	27.41	0.29	28.07	26.72
	Oct	2976	26.92	0.33	27.78	26.21	2976	26.89	0.47	28.10	25.74	2880	27.55	0.43	28.89	26.55	2976	26.93	0.44	28.10	26.01	2976	26.88	0.34	27.78	26.16
	Nov	2880	26.06	0.49	26.99	25.02	2878	25.96	0.57	27.43	23.57	2878	25.99	0.57	29.09	24.73	2880	26.01	0.56	27.43	24.94	2880	26.05	0.44	27.09	25.21
	Dec	2976	25.13	0.44	26.13	24.24	2976	25.05	0.53	26.48	23.55	2976	25.06	0.53	26.45	23.57	2976	25.11	0.51	26.67	24.00	2976	25.09	0.42	26.26	24.15
2017	Jan	2976	24.43	0.41	25.50	23.16	2976	24.36	0.53	25.87	22.87	2976	24.38	0.53	25.89	22.87	2976	24.47	0.55	25.82	22.99	2976	24.39	0.34	25.28	23.35
	Feb	2688	24.29	0.44	25.70	23.45	2688	24.24	0.60	25.82	22.99	2688	24.26	0.60	25.84	22.99	2688	24.31	0.54	26.16	23.30	2688	24.11	0.33	25.04	23.04
	Mar	2976	24.93	0.50	25.99	23.57	2976	24.95	0.65	26.65	23.45	2976	24.97	0.65	26.65	23.47	2976	25.11	0.64	26.30	23.50	2976	24.66	0.50	25.72	23.47
	Apr	775	25.61	0.25	26.40	25.11	2880	25.80	0.51	27.33	24.80	2880	25.81	0.51	27.33	24.82	775	25.75	0.43	27.06	25.02	775	25.51	0.28	26.13	24.99
	May						2976	26.35	0.56	27.88	24.80	2976	26.36	0.56	27.85	24.82										
	Jun						2880	26.88	0.49	28.27	25.84	2880	26.89	0.49	28.30	25.84										
	July						1672	27.20	0.51	28.67	25.36	1998	27.23	0.51	28.69	25.62	652	27.37	0.51	28.97	26.28	1300	27.15	0.29	27.80	26.45
	Aug											744	27.42	0.50	28.87	26.45	1488	27.36	0.46	28.82	26.38	2976	27.15	0.28	28.02	26.48
	Sept											720	27.67	0.51	29.32	26.65	1440	27.65	0.54	29.27	26.72	2880	27.40	0.27	28.10	26.67
	Oct											759	27.07	0.63	29.29	25.82	1494	27.04	0.65	28.92	25.77	2955	26.93	0.47	27.88	25.87

	Nov		1440	26.06	0.72	28.32	24.51	1440	26.03	0.69	28.32	24.87	1440	26.05	0.50	27.04	24.90
	Dec		1488	24.66	0.57	26.13	22.94	1488	24.66	0.56	26.06	23.42	1488	24.68	0.47	26.11	23.57
2018	Jan		1488	24.47	0.42	25.89	23.40	1488	24.48	0.47	26.18	23.57	1488	24.37	0.34	25.36	23.18
	Feb		1344	23.65	0.52	25.31	22.32	1344	23.69	0.58	25.11	22.13	1344	23.39	0.35	24.34	22.06
	Mar		1488	23.67	0.59	26.28	22.59	1488	23.69	0.62	25.84	22.63	1488	23.46	0.35	24.77	22.54
	Apr		1440	24.68	0.51	26.09	23.35	1440	24.69	0.51	25.91	23.47	1440	24.37	0.54	25.62	22.71
	May		1488	25.29	0.63	27.09	23.71	1488	25.29	0.67	27.33	23.79	1488	25.06	0.54	26.21	23.14
	Jun		1440	26.36	0.70	28.39	25.02	1544	26.24	1.09		22.68	1544	26.07	1.01		22.51
	July		1488	26.81	0.46	28.32	25.79	1488	26.75	0.51	27.95	25.62	1488	26.64	0.31	27.33	25.77
	Aug		1488	27.02	0.49	29.39	26.21	1488	26.92	0.47	28.30	26.06	1488	26.87	0.31	27.73	26.28
	Sept		1440	27.25	0.55	28.82	26.11	1440	27.18	0.55	28.49	26.06	1440	27.01	0.33	27.83	26.16
	Oct		781	27.27	0.52	28.57	25.60	1488	27.26	0.54	28.62	25.53	66	27.32	0.16	27.58	27.06
	Nov		720	26.38	0.67	28.32	25.11	1440	26.39	0.71	28.32	25.04					
	Dec		744	24.99	0.44	26.62	23.86	1488	24.98	0.49	26.30	23.81					
2019	Jan		744	24.52	0.61	25.87	22.59	1488	24.56	0.64	26.09	22.87					
	Feb		672	23.46	0.61	25.07	21.99	1344	23.50	0.66	25.16	22.03					
	Mar		611	23.69	0.66	25.55	22.11	1221	23.75	0.74	26.06	22.08					