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Technical Report 190

Baseline assessment of the coral reef habitat in Kaloko-Honokōhau National Historical Park adjacent to the Shores at Kohanaiki development, 2006-2007

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ABSTRACT

This study provides current-condition baseline data and long-term monitoring methodology for coral reef habitats within the northern portion of Kaloko-Honokōhau National Historical Park for 2006-2007. The Park contains approximately 596 acres of coral reefs, state-designated pristine coastal waters, and unique coastal aquatic ecosystems such as Hawaiian fishponds and anchialine pools. The Park is located on the rapidly urbanizing Kona Coast on the west side of Hawaiʻi Island and will be surrounded by large-scale developments that include a golf course; commercial, light industrial, and residential developments; and a possible harbor expansion resort complex. Coastal development in the Kailua-Kona area will also impact the Park's reefs through increases in fishing, anchoring, and recreational use. Worldwide, coastal development has had profound impacts on coral benthic communities, and is implicated in shifts from coral dominance to algal dominance with resulting loss of habitat for reef organisms. In response to the construction of the "Shores at Kohanaiki" development adjacent to the Park's north boundary, this study was initiated to establish a current baseline and to identify changes in percent coral cover, algal cover, and coral survival over time at two habitat zones within Kohanaiki Reef compared to two reference sites. In Spring 2006, Fall 2006, and Summer 2007, pre-development baseline data were collected on (1) randomly selected photo transects, (2) individual corals, and (3) macroinvertebrate densities to monitor coral reef health. Benthic cover at all three sites was primarily composed of coral, turf algae, and crustose coralline algae. Mean coral cover at Kohanaiki Reef as a whole remained stable throughout the 17-month study period, varying from 30.7 to 34.3%. Macroalgae were a minor component, comprising less than 1% cover at all sites on all survey dates except at Kohanaiki Reef vertical-wall sites where macroalgae were approximately 4.5% of benthic cover. Grazing urchin populations were present at all sites, averaging 6.0 urchins/m^2 ± SD 2.8. *Acanthaster planci* were present, but uncommon. *Porites* Tissue-Loss Disease was encountered on several *Porites lutea* colonies at the Kaloko Reference Site in the summer of 2006, and *Porites* Trematodiasis was observed throughout the study at all sites. Partial bleaching was widespread on *Pocillopora meandrina* heads at Kohanaiki Reef in October of 2005, but corals had recovered or died by the time of our surveys. Results indicate that the study design and survey methods are robust and have a good probability of correctly identifying $\geq$10% absolute change in coral cover over time.

INTRODUCTION

Coral reef ecosystems provide ecological, cultural, and economic benefits. Comparison isoften made to tropical rainforests because of high species diversity and complex interactions (Connell 1978). Coral reefs are essential to the traditional lifestyle and cultures of many traditional coastal peoples including the Hawaiians. Worldwide, coral reefs protect shorelines from storm damage and erosion, provide medically valuable substances, and are essential for commercial activities such as fishing and tourism (Waddell 2005). Hawaiʻi's coral reefs make up more than 70% of the total reef in the United States (Pew Oceans Commission 2003, Cesar and Beukering 2004). The annual net-benefits from Hawaiian coral reefs alone have been estimated at $360 million per year for the state's economy, and the overall asset value for the 410,000 acres of reef in the main Hawaiian Islands is estimated at nearly $10 billion (Cesar and Beukering 2004). Together with the intrinsic and ecological value of reefs, it is apparent that they are valuable and worth conserving.

Corals are sensitive to various sources of environmental threats and cumulative degradation. They are therefore, a good indicator of tropical nearshore marine ecosystem health or condition, and have been selected by the National Park Service Inventory and Monitoring Program as a high-priority “Vital Sign” for long-term monitoring in the Pacific Island Network (PACN-I&M) (Brown et al. 2006). Furthermore, the National Park Service is mandated under the 1998 Executive Order 13089, Coral Reef Protection, and the Coral Reef Conservation Act of 2000 to research, monitor, manage, and restore coral reefs within parks, including, but not limited to, measures reducing impacts from pollution, sedimentation, and fishing. Executive Order 13089 established the U.S. Coral Reef Task Force and directed the Secretaries of Commerce and Interior to improve understanding, preservation, and restoration of coral reef ecosystems while promoting wise management and sustainable use of these valuable marine resources.

Stressors to Coral Reef Habitats

Human activity is commonly identified as a major contributor to the observed global decline of coral reef ecosystem health. The loss of live coral cover, decline of species diversity, and increase in coral diseases are reported in many areas (Bruckner et al. 2005). Some scientists project that, worldwide, 70% of coral reefs may disappear in 40 years (PEW 2003). Stressors that affect coral reefs include global climate change and bleaching, disease, coastal development and resulting population pressures, overfishing, sedimentation, elevated nutrients, contaminants, storms and other physical disturbances, alien species, and outbreaks of coral predators (e.g., *Acanthaster planci*) (Waddell and Clarke 2008, Waddell 2005, Wilkinson 2004).

In the past two decades, a rapid emergence of coral diseases worldwide has been linked to environmental stressors including degrading water quality and climate change (Buckner et al. 2005). In some geographic hotspots such as the Caribbean, epidemic disease outbreaks have resulted in high coral mortality (Waddell and Clarke 2008). For example, in the US Virgin Islands following a 2005 bleaching event, a widespread disease outbreak resulted in the loss of over 50% live coral cover (Miller et al. 2006). Coral populations in the Hawaiian Archipelago continue to be spared from such epidemics, however rapid increases in coastal development and global climate change necessitate close monitoring (Friedlander et al. 2005, Friedlander et al. 2008).

Since 1998, coral bleaching has become a common phenomenon around the world with severe bleaching occurring in every region (Marshall and Schuttenberg 2006). Bleaching is characterized by the loss of zooxanthellae (symbiotic micro-algae) from coral tissues causing corals to appear white. Many local stressors can cause bleaching but the primary cause of regional bleaching events appears to be increased water temperature. Sea surface temperature changes as little as 1-2°C above the long term average are all that is needed for mass bleaching events to occur (Marshall and Schuttenberg 2006). Bleached corals may survive and regain zooxanthellae unless stressors, such as elevated water temperatures, continue and ultimately cause mortality. Bleaching events correlate with elevated SST that in many cases is hypothesized to be the result of global climate change. Although Hawaiian waters are cooler than equatorial regions where many of the massive bleaching mortality events have occurred, large-scale bleaching events did occur in late summer of 1996 and 2002. These events correlated with summer SST maximums that were 1°C warmer than average. Most corals recovered after several months (Jokiel and Brown 2004).

One of the most significant threats to coral reefs worldwide is runoff-associated issues (e.g., sediments, nutrients, contaminants, and freshwater inputs) (Birkeland 1997, Fabricius 2005). Poor water quality can cause widespread adult coral mortality, with a resulting decrease in coral species diversity, and increase reef bio-erosion. More significantly, coral reproduction and recruitment are far more sensitive to water quality than are adult corals, and these functions are highly dependent on clean water and low sedimentation (Fabricius 2005). Even minor pollution can therefore have a strong impact on a reef's resilience and its ability to regenerate after natural or anthropogenic disturbance. It is possible for a reef to appear healthy, however it may be unable to reproduce and sustain itself (Richmond 1997).

Degradation of coral reefs often involves a "phase shift" from abundant coral to abundant macroalgae (Done 1992, McCook 1999). On healthy reefs, turf and coralline algae are major contributors to primary productivity, nitrogen fixation, and reef building, and may occupy large portions of space (McCook 1999). However, in the presence of high nutrients and decreased grazing pressures, macroalgae can come to dominate coral reef ecosystems causing death to corals and a fundamental change in ecosystem structure (Littler and Littler 1984, Smith et al. 2001). Once mass coral mortality and invasion by macroalgae occurs, increased erosion diminishes the reef's ability to protect adjacent shorelines and to provide habitat for reef fishes. Fish numbers will significantly decrease, and the reef loses its aesthetic appeal (Done 1992). Numerous examples of this type of phase shift from coral-dominant reefs to algal-dominant reefs are documented (Smith et al. 1981, Done 1992, Lapointe 1997, Smith et al. 2005, Williams et al. 2007a). Although there has been some discussion over the relative importance of grazing pressures versus elevated nutrients (Hughes et al 1999, Lapointe 1999), numerous studies and reviews describe the importance of synergistic effects and the influence of both (McCook et al. 2001, Thacker et al. 2001, Smith et al. 2005, Williams et al. 2007b).

Documented Phase Shift on Hawaiian Reefs

One example of a phase shift that has occurred on Hawaiian reefs is off West Maui, where invasive algae blooms are creating aesthetic, economic, and ecological problems. On many shallow reefs in Maui, coral cover, fishery stocks, and species diversity have significantly declined with coral cover decreasing as much as 75% over a 13-yr period (Williams et al. 2007a). In the North Kihei area alone, algal proliferation costs Maui County over $20 million per year due to lost revenue and remediation expenses (Van Beukering and Cesar 2004). Research in the Kihei area, one of two major resort developments on Maui, shows that shallow reefs where blooms are occurring are highly enriched in dissolved nutrients (nitrogen and phosphorus), low in salinity, and have isotopic signals in algal tissues indicating substantial input of sewage derived nutrients (Smith and Smith 2006). These results strongly suggest that groundwater enriched by anthropogenic nutrients is seeping onto nearshore reefs and is driving the harmful algal blooms. Onshore groundwater testing shows that groundwater fluxing to Kihei's marine environment is highly enriched in anthropogenic nutrients, especially downstream from the local sewage treatment injection well (Hunt 2006).

The West Coast of Hawaiʻi Island has a similar climate and geology to West Maui including characteristic leeward-slope precipitation patterns with upslope groundwater recharge, a dry coastal zone, extensive groundwater seepage into nearshore waters (Oki et al 1999, Hunt 2006), and historically healthy coral reefs. Although West Hawaiʻi has a steep, narrow shelf with better mixing than the extensive shallow shelf on Maui, this study was prompted by concerns that rapid coastal development in West Hawaiʻi will adversely affect groundwater and Park coral reef ecosystems, mirroring what has occurred in West Maui.

Submarine Groundwater Discharge

Marine waters on coral reefs are typically low in nutrients, and groundwater is a source of new nutrients to reefs. Submarine groundwater discharge is also the primary conduit for additional nutrients and contaminants from land-based activities to be released into the Kaloko-Honokōhau National Historical Park marine environment. Thermal infrared images in 1992 (Wilkins 1992) and 2005 (Johnson et al. 2008) show that Honokohau Harbor, Kaloko Fishpond, and “Kaloko Cut” (an area south of Kaloko Fishpond where two intertidal lava-protrusions form a narrow “cut” in the shoreline) are prominent groundwater discharge areas in the Park. Some points of lesser discharge exist along the Kohanaiki shoreline. With increasing upslope water-source development (USGS 2014), groundwater flow through the Park is expected to decrease whereas nutrient and contaminant loads in groundwater from upslope commercial and residential areas will increase (Oki et al. 1999). The quantity and fate of this brackish discharge is therefore of interest to be able to predict potential effects of these anthropogenic inputs on the coral reef ecosystem.

Measurements of nearshore water temperature, salinity, Ra-isotopes, nutrients, waves, and tidal currents between Dec 2003 and April 2006 show the discharge of cool, nutrient-rich groundwater into Park waters, patterns of transport, and its fate as it mixed with marine waters (Presto et al. 2007, Street et al. 2007, Knee et al. 2008). Knee et al. (2008) measured fluxes of submarine groundwater discharge to the Park’s coastal waters ranging from 1–22 m^3/d per meter of shoreline. This study also found that groundwater composed a significant proportion (8– 47% volume) of coastal-ocean water with high spatial variability. Other recent studies show net northward currents move nutrient-rich groundwater across the Park from Honokohau Harbor while large wave events caused mixing to at least 10-15 m depths (Grossman et al. 2010).

Grazer Populations on Coral Reefs

Healthy populations of sea turtles, herbivorous fish, and sea urchins keep algal growth in check and are therefore important for coral reef integrity. Throughout Hawaiʻi, reefs with large stocks of herbivorous fishes tend to have much less macroalgae than reefs with low stocks of grazing fishes (Williams et al. 2007a). In the Park, the herbivore community appears to be adequate to maintain reef communities in coral-dominated states, however research indicates the decline of some fish populations (see Discussion for more detail). Since protection in 1978 under the US Endangered Species Act, the Hawaiian green sea turtle population has had a substantial long-term increase in abundance after serious depletion (Balazs and Chaloupka 2004). Ongoing monitoring by NPS Staff shows that green sea turtles are commonly seen foraging on turf and macro algae in intertidal and nearshore reefs at Kaloko-Honokōhau. Few data exist regarding urchin densities in Park waters; therefore urchin are examined in this study.

Development-Related Threats to Reefs in Kaloko-Honokōhau National Historical Park

Kaloko-Honokōhau National Historical Park is located on the arid west coast of Hawaiʻi Island, three miles north of the town of Kailua-Kona (Lat: 19.67° Long: -156.033°, Figure 1). The Park contains 596 acres of coral reefs in class AA coastal waters. Class AA marine waters are designated by the State of Hawaiʻi "with the objective that these waters remain in their natural pristine state as nearly as possible with an absolute minimum of pollution or alteration of water quality from any human-caused source or actions. To the extent practicable, the wilderness character of these areas shall be protected." (HAR §11-54-3).

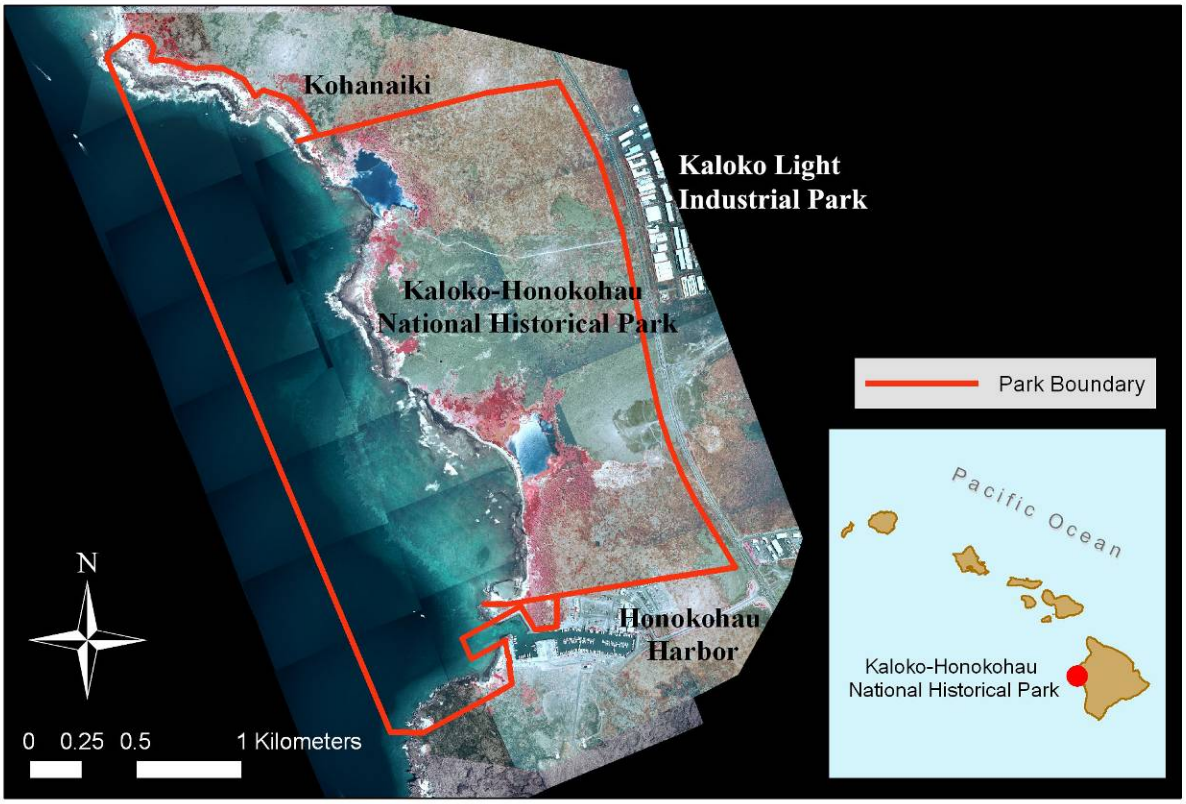


Figure 1. Kaloko-Honokōhau National Historical Park.

The National Park will ultimately be surrounded by large-scale developments that include a golf course, light industrial parks, and residential areas. A marina resort and Honokohau Harbor expansion was proposed in 2006. Semi-treated irrigation water, fertilizers, injection wells, septic systems, and storm runoff from constructed impervious surfaces will have a significant cumulative impact on groundwater nutrient and toxin loads in the Park's water resources. Coastal development growth in the Kailua-Kona area will also increase impacts to coral reefs from fishing, anchoring, and recreational use.

In 2003, the County of Hawaiʻi approved a Special Management Area (SMA) permit for a coastal shoreline development "The Shores at Kohanaiki" (herein referred to as Kohanaiki). Kohanaiki contains 18 acres of private shoreline property situated within the northernmost authorized boundary of Kaloko-Honokōhau National Historical Park. The development adjoins the Park's northern boundary (Figure 2). The development plans include 500 residences, an 18-hole golf course, which in some sections is less than 60 m from the shoreline, and a residents' beach facility. Additionally, eight brackish water wells are proposed to pump 1.8 million gallons per day of water from the basal aquifer for golf course irrigation. Because of the potential for this development to alter coastal hydrology, water quality, and nearshore ecosystems, this project was initiated to collect statistically meaningful pre-construction baseline data on coral condition, coral cover, and the density and distribution of benthic species on Kohanaiki Reef. The baseline surveys reported herein are the beginning of long-term monitoring of Kohanaiki and other reefs adjacent to or within the National Park boundaries.

Study Objective

The objective of this project was to develop a "current-condition" baseline data set and long-term monitoring methodology for coral reef habitats within Kaloko-Honokōhau NHP boundaries. The essential questions the monitoring program attempts to answer are: a) Do total percent coral cover, algal cover, and coral condition/survival change over time at two habitat zones within Kohanaiki Reef? b) Are there differences in total percent coral cover, algal cover, or coral condition/survival over time at Kohanaiki versus reference sites? c) What are the changes over time in urchin and *Acanthaster planci* populations at Kohanaiki and reference sites? Randomly selected photo transects, individual corals, and macro-invertebrate surveys were used to monitor coral reef conditions. Driven by a proposed harbor expansion development, three additional Park reef sites offshore of Honokohau Harbor were sampled in 2006/2007 using the same methodology (Wijerman et al. 2014, Appendix V).

This study will be complimented by the NPS Inventory and Monitoring Program (I&M) that began long-term monitoring of coral reefs, fish, and water quality within the Pacific Region in 2008 (NPS 2014a, 2014b). Although this study was designed to specifically track changes on the Park's reefs as they relate to adjacent development, the data will be comparable to those of the I&M program that will provide within and among park comparisons.

METHODS

Study Area Description

Study areas were selected within the Kohanaiki Reef as well as at two appropriate reference sites, one north of Kaloko Point and one offshore of Puʻuhonua o Hōnaunau National Historical Park (Figures 2 and 4). Habitat, groundwater discharge, and diver use were taken into consideration when sites were selected.

Benthic Habitat

The coral reef off of the Kohanaiki development is a narrow band that drops quickly along a steeply sloping face to about 40 m (Figures 2, 3). Kohanaiki Reef zonations are typical of Hawaiʻi's west coast (Dollar 1982), include a shallow boulder zone in which the corals *Pocillopora meandrina* and *Porites lobata* dominate; a boulder and deep pavement zone that gently slopes from 7-15 m, dominated by *P. lobata*, *P. meandrina,* and *Porites compressa* (15-35% coral cover); and a zone that steeply drops from 18-38 m comprised almost entirely of live and dead *P. compressa*. At the base of the deep *P. compressa* zone there is an abrupt shift to a deep sandy zone. Shoreward, the reef is bounded by lava benches that plunge into the subtidal zone creating cliffs of near vertical, fractured basalt full of crevices and caves. The cliff base is at 3 – 9 m. Turbulence from ocean swell and waves is often pronounced at these cliffs. Groundwater intrusion is moderate to heavy along parts of the cliff habitat and is easily detected by cold temperatures and reduced visibility (Parrish et al. 1990, Gibbs et al. 2007). Kohanaiki Reef sites include vertical cliff walls (4.5-8 m depths) and the boulder/pavement zone (10-m depth) (Figure 3a).

The Kohanaiki Reef community is relatively unique within Kaloko-Honokōhau NHP therefore it was difficult to find identical "control," or more appropriately, "reference" sites within the Park. One reference site, located just north of Kaloko Point, has a section of reef with estimated 50-90% *P. meandrina*, *P. lobata* and some *P. compressa* cover at 5 to 12-m depths (Gibbs et al. 2007, Figure 2 & 3b). Large *Porities lutea* colonies are prominent in this area. However, this area is not "impact free". Kaloko Light Industrial Park is upslope of the Park (Figure 1) at this latitude, and the reef is less than 0.5 km from Kaloko Fishpond. This section of reef is currently appears to be in good condition and is in the path of high quantities of freshwater flowing out of Kaloko Cut (Figure 2). The second reference site is an area offshore of Puʻuhonua o Hōnaunau National Historical Park, (hereafter referred to as PUHO), where *P. meandrina*-encrusted boulder habitats and aggregate *Porites* coral communities exist (Figure 4). The more wave-exposed northern and southern sections of the PUHO site consist of volcanic pavement and boulder substrate with an estimated 10-50% coral cover (transects P6, P7, P11, P12, P21, P19) and the central portion of the site is predominantly aggregate reef with an estimated 50-90% coral cover (Cochran et al. 2007, Figure 4). A small area with vertical walls is located in the central portion of the PUHO site. Three vertical-wall transects at 3-7 m depths off Puʻuhonua o Hōnaunau are included for comparison to the Kohanaiki vertical wall communities. Although no large developments exist inland of the Puʻuhonua o Hōnaunau reef tract, rural agricultural farms are present. High quantities of freshwater are also evident at this reef.

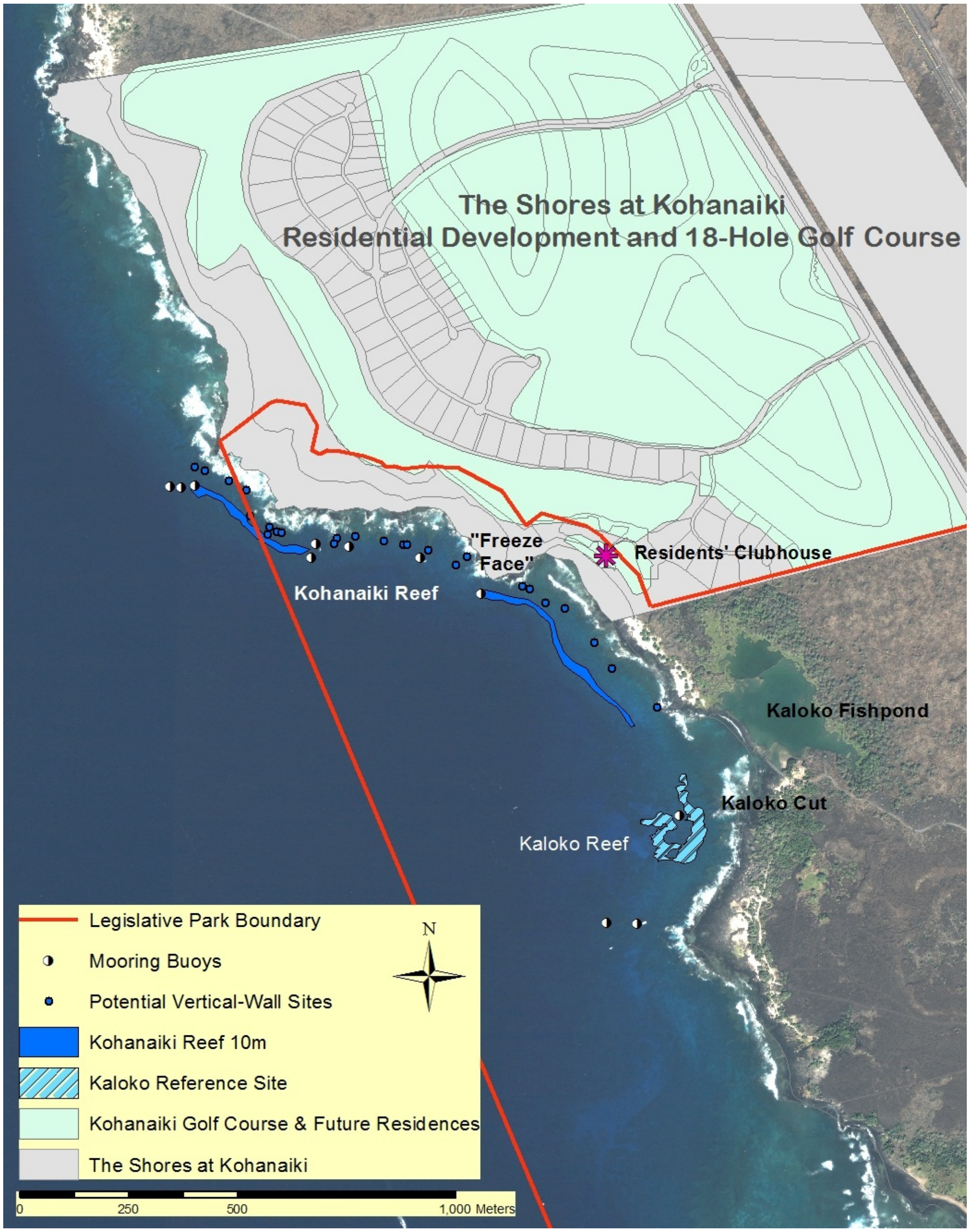


Figure 2. Location of Kohanaiki Reef and the Kaloko Reference Site within Kaloko-Honokōhau National Historical Park in relation to The Shores at Kohanaiki Development (the planned Residents' Clubhouse location is approximate). Ten shallow and ten 10-m transects were randomly selected from each study site.

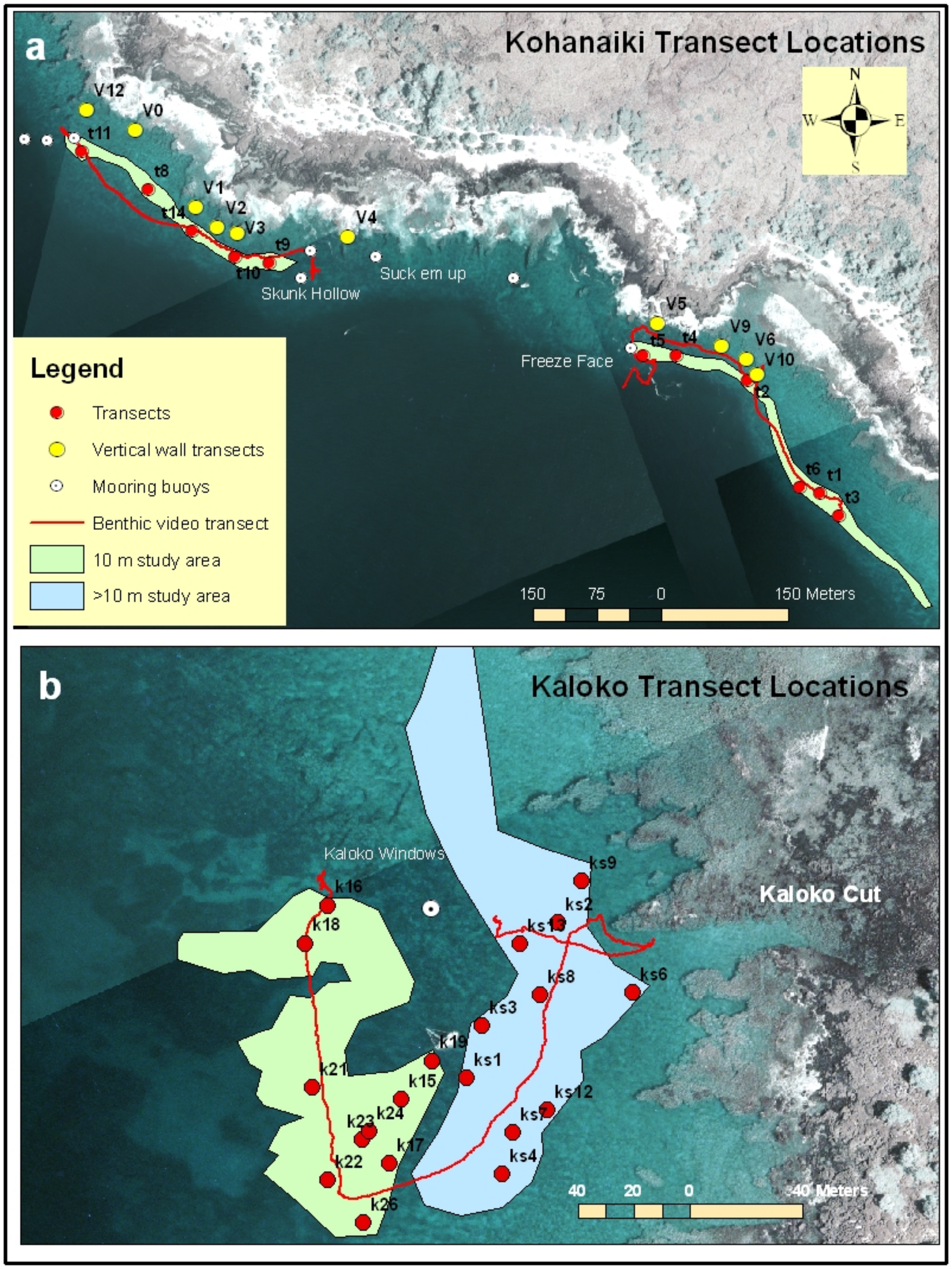


Figure 3. Transect locations at Kohanaiki (a) and Kaloko sites (b). At Kohanaiki, transect names “t#” indicate 10-m depths (n =11) and “V#” indicate vertical walls (n =10). At Kaloko, transect names “k#” indicate 10-m depths (n =10) and “ks#” indicate shallow sites (n =10). Transect start points are shown on map. Video transects are for qualitative record of reef condition in area.

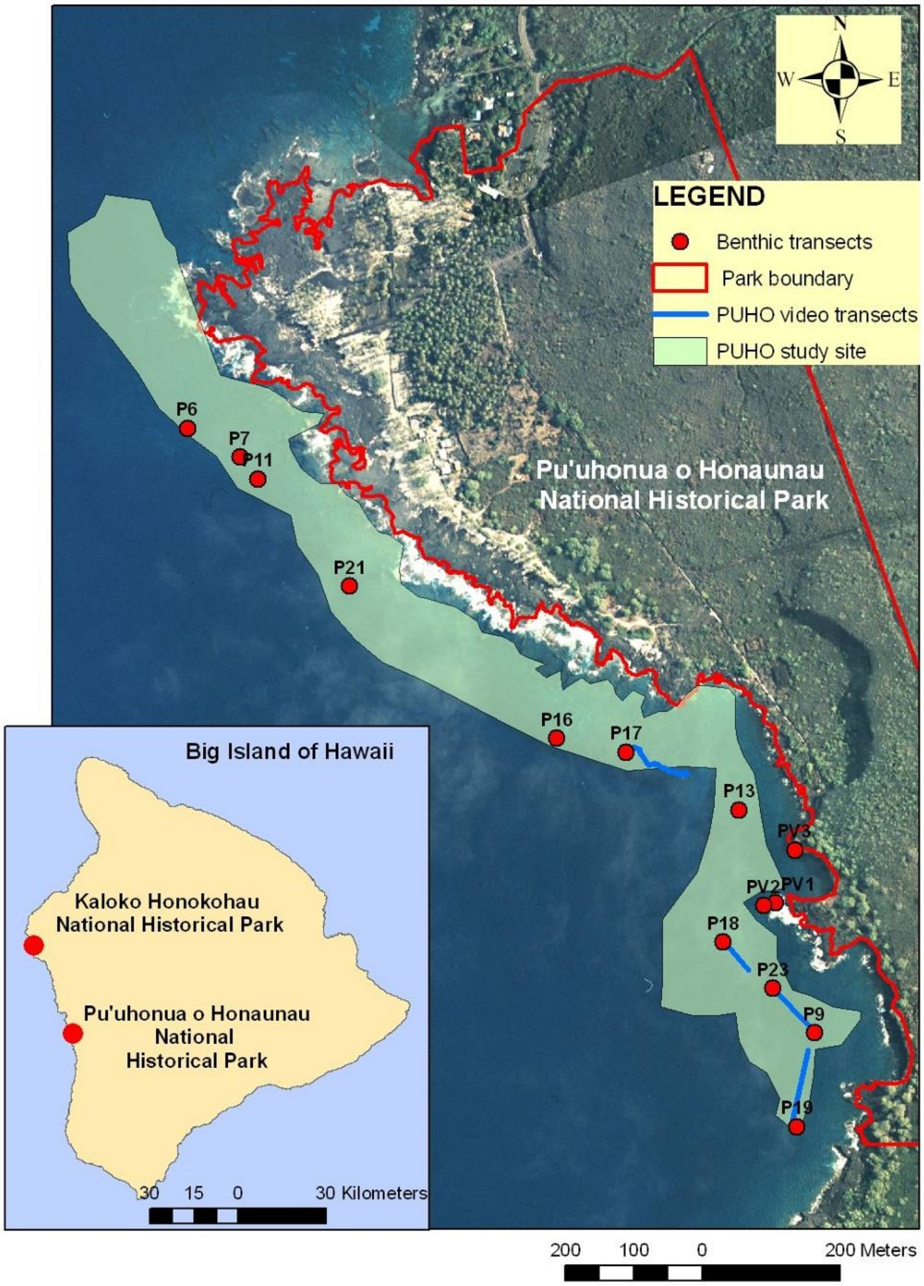


Figure 4. Reference Site sampled off of Pu‘uhonua o Hōnaunau National Historical Park (PUHO). Eleven 10-m transects (P#) were randomly selected from the study site. Three shallow vertical wall transects (PV#) were added for comparison with Kohanaiki vertical wall sites. Transect start points are shown on map. Video transects are for qualitative record of reef condition in area.

Groundwater discharge

At the Kohanaiki site, groundwater is known to discharge from a lava tube locally known by divers as “Freeze Face Cave” and the cove just south of the cave near the planned golf clubhouse (Brock 2006, Johnson et al. 2008, Knee et al. 2008). The coastline north of Freeze Face dive site up to the Park’s north legislated boundary do not appear to have obvious points of groundwater discharge (Wilkins 1992, Brock 2006).

US Geological Survey (USGS) studies (Presto et al. 2007; Storlazzi and Presto 2005) show that Kaloko Cut is a strong point source for groundwater discharge with clear pulses of discharge after rain events. Groundwater in the Kaloko area is primarily transported along-shore with the seasonal currents. During periods with consistent southwest tradewinds (spring and early summer), current flowed predominantly northeast. Southwest offshore flow was observed during swell events while currents in the winter months (low wind) moved predominantly alongshore in a southern direction. Daily tidal changes to alongshore currents were also observed. Infrequent low-salinity pulses were measured at 13-m depths and correlated with offshore flow. Although mixing was not examined at this site, wave action undoubtedly acts to bring groundwater components to the Kaloko reef habitat.

Groundwater studies similar to those described for Kaloko-Honokōhau have not been done at Puʻuhonua o Hōnaunau. However, points of high discharge do exist because freshwater was evident on the surface throughout the Hōnaunau study site during several visits in 2006 (Marrack, personal obs).

Diver Impacts

Within the Kohanaiki and Kaloko reefs, nine mooring buoys, regularly used by commercial dive operators, are anchored in approximately 10-m depths (Figure 3). During a large northwest swell, especially in winter months, there is high use of some of these buoys because they are protected from wave action. When there is no northwest swell, the mooring use is low to medium. One long-term dive operator estimates that high use is 28-42 divers (from all dive operators combined) per mooring per day while low use would be 0-7 divers per mooring per day. The three buoys in the center of Kohanaiki Reef, known as “Skunk Hollow,” or “Aquarium” (two buoys), and “Suck Em’ Up” (one buoy), are the most frequently used on Kohanaki Reef.

Study Area Selection

Transects were chosen randomly from within study areas that are defined by reef zonation, groundwater intrusion, and diver use. Randomly selected transects within a defined study area enables the data to be interpreted as representative of the entire study area. To examine groundwater intrusion within Kohanaiki Reef and control areas, outflow points were identified based on existing thermal infrared video (Wilkins 1992, Johnson et al. 2008), USGS studies (Presto et al., 2007, Storlazzi and Presto 2005), and initial surveys by NPS staff. To confirm known seepage points and to search for additional ones at Kohanaiki Reef, salinity, temperature, and depth were measured with a Hydrolab Quanta multi-probe sonde suspended from a two-man kayak throughout the Kohanaiki study site. Salinity was examined at the surface, mid-water column, and near the bottom along the entire shoreline of the project. When groundwater was detected nearshore, salinity and temperature were measured at points along a transect perpendicular to shore to determine how quickly freshwater was diffusing in the area. An additional transect along the 20-m depth contour was examined to look for evidence of deep water seepage. All data points were marked using a GPS, resulting in a GIS shapefile of depth, temperature and salinity.

Homogeneous areas representative of reef zones on the Kohanaiki Reef and in reference sites were first mapped by snorkeling with a waterproof GPS unit (Trimble GeoExplorer XT 2003 in a dry bag) attached to a surface float. Detailed aerial photographs (NPS 2002) and USGS benthic habitat maps (Gibbs et al. 2007, Cochran et al. 2007) aided in the selection of study sites. The zones of interest at Kohanaiki Reef include the shallowest reef on vertical cliff walls (4-8 m) and the boulder/pavement zone (9–12 m). The 9- to 12-m depth zone will be called the 10-m habitat in this study. Transects at 20 m were eliminated from the study because the bottom at this depth at Kohanaiki Reef is predominantly coral rubble rather than live coral. Identical methods were used at the reef off of Kaloko Cut just north of Kaloko Point and at Puʻuhonua o Hōnaunau NHP.

Diver-use areas were determined by proximity to popular mooring buoys and interviews with dive boat operators. Study areas were selected to exclude high diver-use areas so that change due to development impacts is minimally confounded by diver impacts. For analysis purposes, a semi-quantitative use rating was determined for each transect based on proximity to mooring buoys and interviews with dive companies. To determine diver-use areas, maps of study areas were shown to staff members from 11 dive companies using the area. Dive staffers were asked to show area use based on a scale from 1 to 3, 1 representing light use, 2 moderate use, and 3 heavy use. We used this information to determine an average diver-use level for each transect.

Once study area boundaries were determined, representative polygons were created within the GIS program ArcMap 9.1 (Table 1). Transect start points were randomly selected within these pre-defined areas using the NPS-developed extension AlaskaPak Toolkit (Sarwas 2011). Random transect start points were uploaded into the GPS.

Table 1. Study area descriptions including depths, dimensions, and number of transects.

Site	Depth (m)	Area (hectares)	Length of Coastline(km)	# of transects
Kohanaiki-10m	9-12	0.89	0.81	11
Kohanaiki-Walls	4-8	n/a	1.1	10
Kaloko-10m	9-12	0.75	0.12	10
Kaloko-Shallow	6-9	0.27	0.22	10
PUHO	9-12	20.6	1.8	11
PUHO-Walls	3-6	n/a	0.27	3

Benthic Transects

The primary method for examining benthic cover and coral condition off of Kohanaiki and at reference sites was 10-m long permanent photo transects. Divers used the Park’s 22-ft vessel or shoreline entrances to access study sites. To locate transects, a GPS unit (Trimble GeoXT) was placed in a dry bag on a dive float and was used to navigate on the surface of the water. Once divers were over the transect start point, they descended to the bottom. If there was no coral in the immediate area because of rubble or sand channels, divers swam to the closest area with coral. If the area was not within the correct depth zone, divers moved up or down the reef slope to the appropriate depth. Once at the correct depth, divers located a crack or dead coral head to fasten the starting pin. The transect was then laid out as tight and straight as possible and an end pin location was found. Semi-permanent start and end pins made of stainless steel all-thread or small stainless steel eye-bolts were installed with a small sledge hammer and affixed with small amounts of marine epoxy. Cable ties were attached to pins for easier visual relocation. Damage to live coral during the placement of stakes was avoided by using existing cracks within the basalt base rock or dead coral heads. Transects at Kohanaiki Reef were laid out parallel to shore along the depth contour. At Kaloko and Puʻuhonua o Hōnaunau reefs, transects were laid out parallel to shore when possible, but in many areas transects were placed perpendicular to shore within the 9–12-m contour to avoid shoreward-running sand and rubble channels. Depth of transect start and end pins, compass bearing, the side of the transect photographed (i.e., up or downslope), and notes on recognizable features in the area were recorded. Landscape photos of the reef at oblique angles and of recognizable features around transect pins were taken and used to create laminated photo-identification sheets to help relocate transects and for a qualitative record of overall reef condition. Video transects at each site were also conducted to gather qualitative record of present reef condition. Divers swam 1-5 m above the 10-m depth contours with a Sony DCR PC110 video camera in a Light and Motion MAKO housing on the wide angle setting. Divers towed a GeoXT GPS unit on a float at the surface to gather the track lines of video surveys.

Digital still photographs were taken perpendicular to the substrate with an Olympus C7070 camera in an Olympus underwater housing. A 6-mm diameter “mono-pod” rod attached to the housing kept the camera 0.62 m from the substrate for each photograph. The length of the rod was a distance that created a 0.5-m x 0.43-m photoquadrat when the camera was in the wide-angle setting. Before transect photos were taken, the camera’s white-balance was reset at the transect depth, and the transect number was inscribed on a magnetic slate and photographed. As photos were taken along the 10-m transect, the foot of the metal rod was placed on the transect tape at 0.5 m intervals starting with 0 m. Twenty-one 0.5-m x 0.43-m photoquadrats were collected on each 10-m transect.

Pilot studies were used to determine the minimum number of transects per habitat, frames per transect, and points within a frame needed to accurately portray total percent coral cover and detect a statistically significant change in coral cover of 10% absolute (Appendix I). We considered 10% to be a reasonable biologically meaningful value of change, as changes less than that could be indicative of measurement and observer error (Brown et al. 2004). Therefore, for the purposes of this study, absolute change in coral cover ≥10 % was defined as biologically relevant if the change was statistically significant. To summarize Appendix I, ten transects per habitat appeared to be an acceptable minimum sample size due to reasonably low standard error. Based on the results for transects with varying coral cover, 11 frames appeared to be an acceptable minimum subsample size. Therefore, every other frame starting with 0 m was analyzed so that errors of overlapping quadrats did not occur. Finally, 40 points within a frame were shown to be adequate. In the lab, a unique plot of 40 computer generated random points was overlain on each digital photo image using the National Coral Reef Initiative (NCRI) software CPCe (Kohler and Gill, 2006). Photoquadrats were then analyzed for percent coral cover, percent algal cover, coral diseases, and other substrate details.

Appendix II gives a complete list of all parameters identified in photoquadrats. Turf, macroalgae and crustose coralline algae (CCA) are ecologically significant algal groups in terms of their likely response to changes in nutrient availability and grazing pressures, and were therefore categorized separately for analysis. Percent cover was tabulated for the following benthic categories: coral, turf algae, fleshy macroalgae, CCA, sand, available substrate for colonization (rubble and bare rock), and invertebrates. Mobile and sessile invertebrates were identified to major groups including urchins, crown-of-thorns sea star (*Acanthaster planci)*, zoanthids, tunicates, sponges, octocoral, and bryozoans. Coral disease and bleaching were noted if encountered in photoquadrats. The identification of specific coral diseases requires specialized expertise that goes beyond the scope of this study.

Observers underwent training to reduce observer error on photo analysis. When observers could not distinguish if benthic cover was turf or CCA, they defaulted to turf. Octocoral was probably underestimated as it often appeared blurry with even minor water motion. It would have been mistaken as turf. When in doubt between *Porites lobata* and *P. lutea*, *P. lobata* was the default. Measurements of observer error are in Results section.

Sampling error was measured for other aspects of methodology (see Results). To measure sampling variability associated with placement of the transect line, five transects were re-sampled within a week of each other. Assuming coral cover did not change in this short time period, the difference between transects was used as a representation of measurement error. Because new random points are automatically generated for each frame during photo analysis, these results included variability due to transect-line placement and random point placement. To isolate variability associated with random point placement on frames, 32 frames were each analyzed with two different sets of 40 random points, and differences in percent coral cover due to point placement was calculated.

Initial reconnaissance and pilot study work occurred from October 2005 to February 2006. Baseline sampling occurred during the Spring of 2006 (4/7/06 to 5/11/06), Fall of 2006 (10/25/06 to 12/15/06), and Summer of 2007 (6/6/2007 to 8/9/07).

Macroinvertebrate Survey

Urchins (*Echinothrix* sp., *Heterocentrotus mamillatus*, *Tripnuestes gratilla*, and *Diadema paucispinum*) and Crown-of-thorns (*Acanthaster planci)* were counted in a 1.75-m belt centered along each transect so that an equal area was examined on each side of the tape. Recruits and sizes were noted if present. The density of boring urchins, *Echinometra mathaei*, was roughly estimated by counting all individuals in a one m^2 area and multiplied to get an estimate of the total density in the 17.5-m^2 transect survey area. If density of *E. mathaei* was not relatively uniform along the transect due to substrate differences, estimates within each sub-habitat were used to calculate total density.

Coral Mortality Study

Along 82% of permanent transects, individual *P. meandrina* colonies with basal diameters greater than 2 to 3 cm were selected for monitoring coral condition. Coral growth and survival are indicative of coral reef health and water quality, providing a time-integrated measure of the condition of these factors (Brown et al. 2006). At Kohanaiki, Kaloko, and Puʻuhonua o Hōnaunau (PUHO) reefs, approximately 30 colonies of *P. meandrina* per site, were selected for monitoring prior to and after construction. On each transect, divers identified the first three *P. meandrina* encountered within 0.5 m of either side of the permanent transect line. Once a colony was located, its position was recorded as the distance down the transect and the distance and direction perpendicular to the transect. Measurements of colony height, width, and length as well as information on coral condition were recorded. The length was the longest length of a coral colony; the width was the widest part perpendicular to the length axis. Each colony was photographed with an Olympus C7070 camera in an Olympus underwater housing; categorized as live, partially dead, or dead; and examined for disease, bleaching, or other irregularities. Measuring of coral colonies was done with care to ensure that the colonies were not damaged. Because colony measurements are only accurate within ± 1 cm, this study is not meant to be a growth study.

Data Analysis and Management

All maps, photoquadrats, video transects, and data were computer and CD archived. A Microsoft Access database was created to store data from the photoquadrats, macroinvertebrate surveys, and the colony mortality study. Graphical plots were generated for three benthic functional groups (coral cover, turf algae, and coralline algae) at each location and depth for the three sampling periods. Percent cover data for total coral were arcsine square-root transformed prior to statistical analysis to approximate normal distributions (Zar 1996). Repeated measures ANOVA and Tukey's Honest Significant Difference (HSD) tests determined whether significant changes in coral cover occurred over the three sampling periods at each location. Coral cover was the dependent variable with location and depth as independent factors. Two separate analyses were conducted due to the unbalanced design of the entire model. The first excluded PUHO from the model due to the lack of observations in the spring of 2006 at the PUHO shallow site. The second analysis included PUHO by pooling coral cover at the two depths within each location. Statistical analyses were performed with JMP 5.0 software (SAS Institute Inc, 2000) and Statistica 8.0 (StatSoft). Diver impact levels and depth were not examined as covariates at this time but could be examined in future data.

RESULTS

Groundwater

During the October 13-15, 2005 surveys, the only evidence for groundwater discharge in Kohanaiki Reef was along the nearshore cliffs and in the cove off the golf clubhouse site (Figure 2). Salinities in the cove were 33 psu (practical salinity units) as compared to salinities in the 34-35 psu range throughout the rest of the reef. No groundwater appeared to be flowing out of Freeze Face Cave, which is known for large amounts of cold fresh water outflow. On October 13, 2005, other groundwater sources were confirmed at the south end of Kaloko Fishpond (19.1 psu) and at Kaloko Cut. When working at the Kaloko Reference Site, divers usually entered the area from Kaloko Cut shore access and on all occasions noticeably cold brackish water was present. Cold, freshwater was also present throughout the Puʻuhonua o Hōnaunau (PUHO) study area on several occasions during this study.

Diver Use

Diver use at PUHO and Kohanaiki Wall transect sites are low while diver use at Kaloko is moderate (Table 2). Most dive companies from Kailua-Kona do not visit Hōnaunau and NPS staff confirm light use of the entire area. Kohanaiki Reef 10-m transects experience light to moderate diver use with one transect (t5) near Freeze Face mooring buoy ranked as heavily used. Transects ranked as moderately used are all near mooring buoys as well. Three dive companies take an average of 4-6 divers/week, three companies take an average of 12-14 divers/week, two companies take an average of 24-36 divers/week, and three only take divers out occasionally. The companies interviewed represent most of the companies utilizing park waters.

Table 2. Number of transects at study sites with ranking of diver use. PUHO = Puʻuhonua o Hōnaunau.

	Light (1)	**Moderate (2)**	**Heavy (3)**	**Average Use Score**
Kohanaiki-10m	5	5	1	1.6
Kohanaiki-Walls	10			1
Kaloko-10m		10		2
Kaloko-Shallow		11		2
PUHO-10m	11			1
PUHO	3			1

Benthic Cover

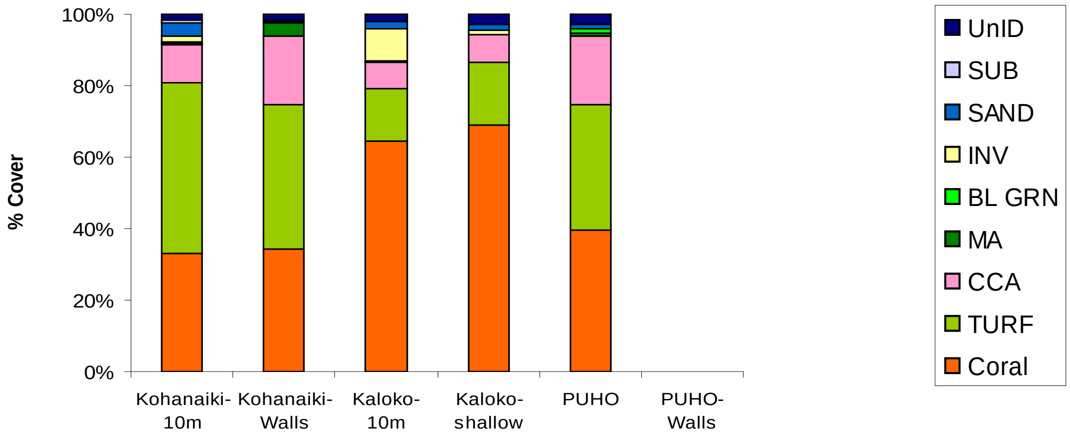
Measurement Error

Variability in coral cover associated with placement of the transect line, placement of random points on photo-transects within the lab, and observer error were estimated. When five transects were sampled within a week of each other there was an average 3.5% ± SD 2.1 difference in coral cover. Assuming there was no actual change in coral cover, this difference represents the measurement error associated with line placement in the field as well as random point placement during lab analysis. Variability in coral cover associated with random point placement alone was 5.5% ± SD 3.5 per frame (n = 32), but when frames were combined to represent a transect (the sampling unit), difference in coral cover due to point placement was 0.26 to 0.45% (n = 2). Observer error during substrate identification in photoquadrats was lowest for coral cover. Out of six transects (66 frames) observer variability after training averaged 2.1% ± SD 1.3 (< 1 point per frame) for coral cover while it averaged 7.5% ± SD 2.9 for turf, octocoral, and CCA. Measurement errors for turf algae, coralline crust algae, and octocoral were higher due to lack of image clarity.

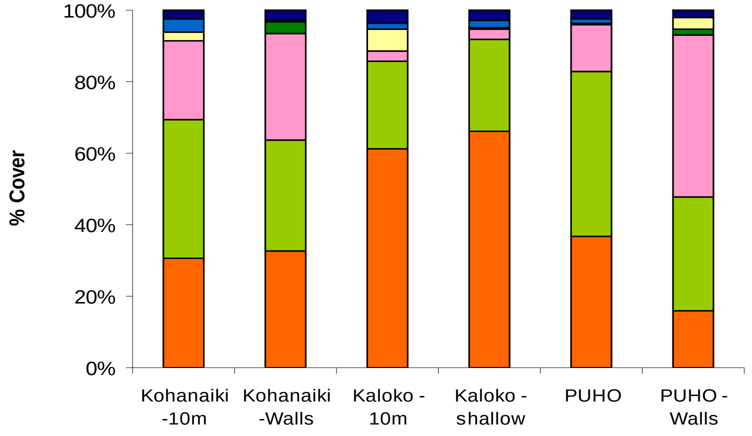
Benthic Cover Sampling

Coral, turf algae and crustose coralline algae (CCA) were the dominant benthic cover at all sites during all three sampling dates (Figure 5, Table 3). Within Kaloko-Honokōhau NHP (KAHO), mean percent coral cover was significantly lower ($F_{1,35} = 90.14$, $p < 0.0001$) at the reef adjacent to the Kohanaiki development site compared to the Kaloko Reference Site (Figure 5, Table 4A). This pattern was identical at both the shallow and deep depths ($F_{1,35} = 0.20$, $p = 0.66$). There was a significant difference ($F_{2,70} = 7.95$, $p = 0.001$) in mean percent coral cover among the three sampling periods with a slight decrease in coral cover of 2.3% from Spring 2006 to Fall 2006 and a slight increase of 2.9% from Fall 2006 to Spring 2007. The greatest percentage change in coral cover occurred at the Kaloko – 10-m transects where there was a decrease of 2.9% between Spring 2006 and Fall 2006 and a subsequent increase of 5.1% in Spring 2007. Changes in coral cover at Kohanaiki mirrored this decline and subsequent increase but were not as pronounced (Figure 6, Table 4A). However, because these changes were within the 10% measurement and observer error, they indicated that the coral communities were fairly stable during this time period.

a) Spring - 2006



b) Fall - 2006



c). Summer - 2007

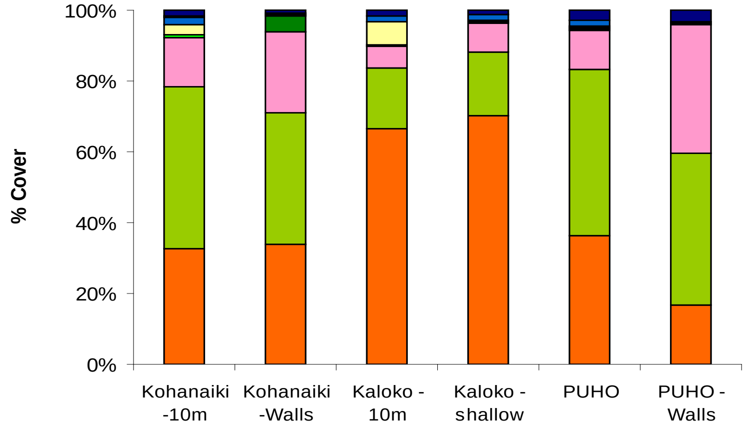


Figure 5. Comparison of mean benthic cover for three sampling periods in two depths at Kohanaiki, Kaloko, and Puʻuhonoua o Hōnaunau (PUHO) Reef sites. UnID = unidentified, SUB=substrate, SAND=Sand, INV=invertebrates, BL GRN=Blue Green, MA = macroalgae, CCA = Crustose Coralline Algae, TURF = Turf algae, Coral = Coral .

Table 3. Average percent cover ± SD of benthic components at three sites and two depth habitats for Spring 2006, Fall 2006, and Summer 2007. Total algae includes turf, crustose coralline algae (CCA), and macroalgae.

Spring-2006

	Coral	Turf	CCA	Macro algae	Total Algae	Blue Green	Inverts	Sand	Substrate	UnID
Kohanaiki-10m	**33.20**	**47.42**	**10.99**	**0.06**	**58.47**	**0.41**	**1.71**	**3.72**	**0.74**	**1.74**
(n=11)	±10.72	±9.85	±9.62	±0.15	±19.62	±0.56	±2.71	±2.40	±1.20	±0.86
Kohanaiki-Walls	**34.26**	**40.33**	**19.44**	**3.66**	**63.43**	**0.02**	**0.43**	**0.04**	**0.04**	**1.78**
(n=10)	±10.54	±12.37	±13.59	±6.00	±31.96	±0.07	±0.97	±0.14	±0.09	±1.04
Kaloko-10m	**64.32**	**15.05**	**7.34**	**0.23**	**22.61**	**0.11**	**8.75**	**2.00**	**0.09**	**2.11**
(n=10)	±13.31	±11.51	±6.25	±0.43	±18.18	±0.25	±6.44	±2.74	±0.29	±1.21
Kaloko-Shallow	**68.99**	**17.35**	**7.92**	**0.02**	**25.30**	**0.07**	**1.08**	**1.83**	**0.02**	**2.71**
(n=10)	±7.64	±4.95	±3.77	±0.07	±8.78	±0.11	±0.95	±1.75	±0.07	±1.76
	39.50	**35.02**	**19.55**	**0.74**	**55.31**	**1.20**	**0.10**	**1.05**	**0.04**	**2.79**
PUHO(n=11)	±9.90	±10.07	±7.39	±1.05	±18.51	±1.19	±0.19	±1.56	±0.14	±1.72
PUHO-Walls										
(n=3)	**N/A**									

Fall-2006

	Coral	Turf	CCA	Macro algae	Total Algae	Blue Green	Inverts	Sand	Substrate	UnID
Kohanaiki-10m	**30.70**	**38.53**	**22.02**	**0.04**	**60.60**	**0.08**	**2.44**	**3.57**	**0.27**	**2.33**
(n=11)	±8.13	±7.34	±8.37	±0.09	±15.81	±0.15	±5.07	±1.84	±0.65	±1.04
Kohanaiki-Walls	**32.70**	**31.00**	**29.89**	**3.18**	**64.07**		**0.36**	**0.05**	**0.02**	**2.80**
(n=10)	±11.51	±7.96	±11.68	±3.11	±22.75	**0.00**	±0.47	±0.14	±0.07	±1.34
Kaloko-10m	**61.38**	**24.42**	**2.64**	**0.02**	**27.08**	**0.07**	**6.03**	**1.89**		**3.56**
(n=10)	±13.56	±13.16	±1.73	±0.07	±14.95	±0.11	±5.45	±2.99	**0.00**	±2.02
Kaloko-Shallow	**66.16**	**25.86**	**2.86**	**0.00**	**28.73**	**0.16**	**0.25**	**2.00**		**2.70**
(n=10)	±8.83	±6.55	±2.06		±8.61	±0.30	±0.79	±1.95	**0.00**	±0.79
	36.90	**45.85**	**12.98**	**0.45**	**59.28**	**0.12**	**0.10**	**1.24**		**2.36**
PUHO(n=11)	±8.10	±11.72	±5.36	±0.85	±17.93	±0.19	±0.16	±1.45	**0.00**	±1.23
PUHO-Walls	**16.06**	**31.59**	**45.53**	**1.52**	**78.64**	**0.08**	**3.18**			**2.05**
(n=3)	±0.35	±16.82	±15.76	±0.86	±33.44	±0.13	±2.53	**0.00**	**0.00**	±0.60

Summer-2007

	Coral	Turf	CCA	Macro algae	Total Algae	Blue Green	Inverts	Sand	Substrate	UnID
Kohanaiki-10m	**32.53**	**45.76**	**13.89**	**0.09**	**59.74**	**0.60**	**2.92**	**2.11**	**0.55**	**1.56**
(n=11)	±10.41	±14.54	±6.16	±0.16	±20.86	±0.36	±5.58	±1.38	±0.66	±0.90
Kohanaiki-Walls	**33.77**	**37.11**	**23.00**	**4.59**	**64.70**	**0.05**	**0.36**	**0.05**	**0.36**	**0.70**
(n=10)	±11.59	±6.74	±9.93	±4.43	±21.10	±0.14	±0.59	±0.14	±0.61	±0.41
Kaloko-10m	**66.43**	**17.20**	**6.30**		**23.50**	**0.25**	**6.45**	**1.86**		**1.50**
(n=10)	±12.40	±10.62	±5.04	**0.00**	±15.67	±0.36	±5.52	±2.70	**0.00**	±0.85
Kaloko-Shallow	**70.10**	**18.16**	**8.21**		**26.36**	**0.08**	**0.71**	**1.52**	**0.08**	**1.16**
(n=10)	±6.64	±5.21	±3.18	**0.00**	±8.40	±0.11	±0.72	±1.15	±0.11	±0.57
	36.24	**47.21**	**11.01**	**0.23**	**58.45**	**0.60**	**0.14**	**1.61**	**0.02**	**2.93**
PUHO(n=11)	±8.09	±12.91	±6.15	±0.25	±19.31	±0.94	±0.41	±1.37	±0.07	±1.49
PUHO-Walls	**16.92**	**42.85**	**36.07**	**0.30**	**79.22**		**0.53**			**3.33**
(n=3)	±2.95	±3.63	±7.47	±0.52	±11.62	**0.00**	±0.26	**0.00**	**0.00**	±1.25

Including the Puʻuhonua o Hōnaunau NHP (PUHO) sites into the model showed that percent coral cover at the three locations was still significantly different ($F_{2,47} = 55.88$, $p < 0.0001$) among locations. The PUHO site was similar to the Kohanaiki Reef area adjacent to the development but had lower coral cover than the Kaloko Reference Site (Table 4B, Figure 5). There was a small but statistically significant difference ($F_{2,94} = 6.82$, $p = 0.002$) in mean percent coral cover among the three sampling periods with a slight decrease in Fall 2006 from Spring 2006. The PUHO sites, however, did not show a subsequent increase in coral cover in Spring 2007 as observed at the Kaloko-Honokōhau sites ($F_{4,94} = 3.15$, $p = 0.018$, Table 4B). In contrast, mean coral cover at the PUHO sites stayed statistically constant at 36% (Figure 6).

Table 4. A Repeated Measures ANOVA comparing changes in percent coral cover across the sampling periods at KAHO (Kohanaiki and Kaloko Reefs) with depths separated (A) and KAHO and Puʻuhonua o Hōnaunau (PUHO) sites with depths pooled (B). Statistically significant results at $\alpha < 0.05$ are in bold.

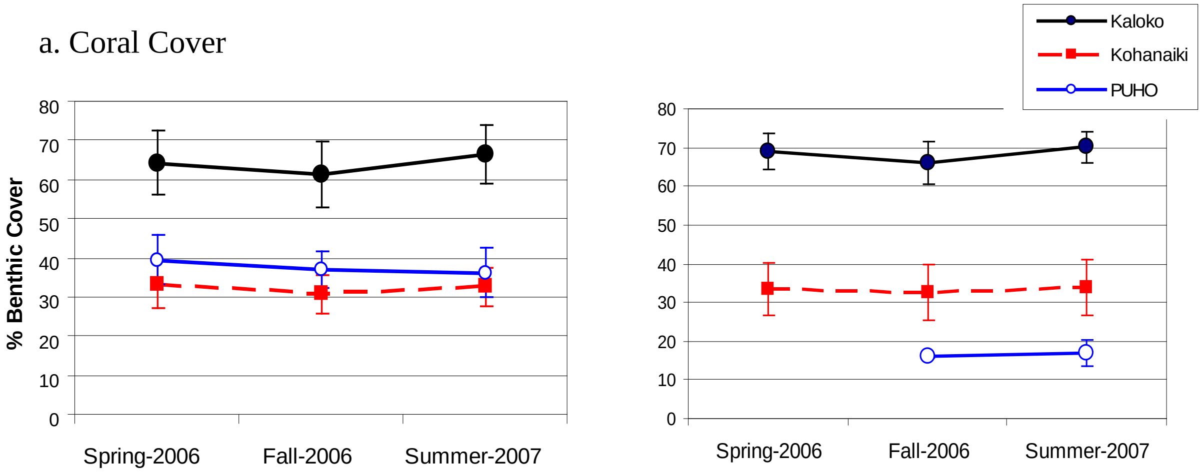
A. Model One: KAHO sites at both depths.

	SS	**DF**	**MS**	**F**	**p**
Intercept	71.018	1	71.018	1802.279	0.000
Location	3.552	1	3.552	90.136	**0.000**
Depth	0.020	1	0.020	0.512	0.479
Location*Depth	0.008	1	0.008	0.199	0.658
Error	1.379	35	0.039		
TIME	0.021	2	0.010	7.950	**0.001**
TIME*Location	0.006	2	0.003	2.359	0.102
TIME*Depth	0.000	2	0.000	0.144	0.866
TIME*Location*Depth	0.001	2	0.000	0.206	0.815
Error	0.091	70	0.001		

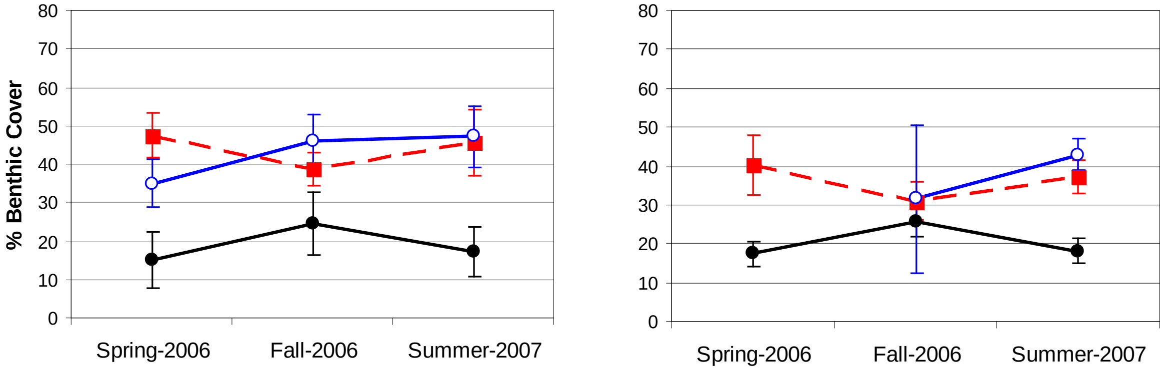
B. Model Two: KAHO and PUHO sites with depths pooled.

	SS	**DF**	**MS**	**F**	**p**
Intercept	76.149	1	76.149	2189.366	0.000
Location	3.887	2	1.944	55.878	**0.000**
Error	1.635	47	0.035		
TIME	0.016	2	0.008	6.815	**0.002**
TIME*Location	0.015	4	0.004	3.152	**0.018**
Error	0.109	94	0.001		

a. Coral Cover



b. Turf Cover



c. CCA Cover

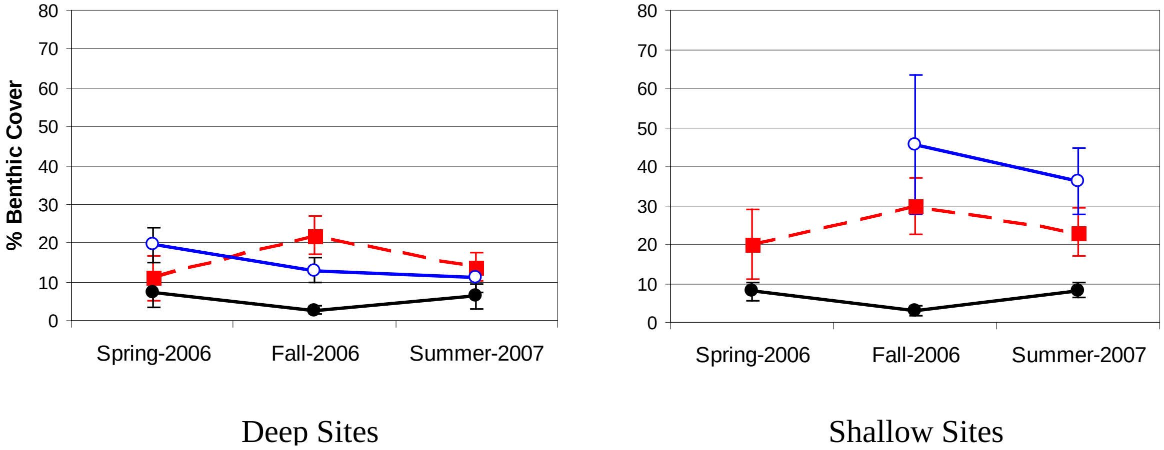


Figure 6. Comparison of mean percent coral, turf and CCA cover over three sampling periods (Spring-2006, Fall-2006, and Summer-2007) at three sampling locations. Within each location benthic cover is pooled from two depths. Error bars denote ± 95% confidence intervals.

Mean percent turf cover was significantly different among study sites ($F_{4,45} = 17.59$ $p < 0.0001$). Turf accounted for the largest benthic component at both Kohanaiki 10 m and Wall sites (averaging 31.0 to 47.4%) and Hōnaunau sites (averaging 31.6 to 47.2%). Kaloko sites had the lowest turf cover (averaging 15.1 to 25.9%) (Figure 5, Table 3).

Mean percent crustose coralline algae cover (CCA) was also significantly different between study sites ($F_{4,45} = 15.2067$, $p < 0.0001$). CCA cover was highest on vertical walls at Hōnaunau (averaging 36.1 to 45.5%) and Kohanaiki Reef (averaging 19.4 to 29.9%). CCA was lowest at Kaloko sites (averaging 2.6 to 8.2 %) (Figure 5, Table 3).

There was a significant difference ($F_{2,44} = 3.23$, $p = 0.049$) in mean percent turf algae cover among the three sampling periods but CCA cover was not significantly different ($F_{2,44} = 0.01$, $p = 0.9892$). Levels of both algal groups changed the most in the Fall of 2006, dropping in some sites and increasing in others, but by the Summer 2007, CCA and turf cover returned to levels similar to those in Spring 2006 at all locations except Hōnaunau where turf cover increased and CCA decreased (Figure 6). However, because the degree of change in CCA and turf cover was small relative to degrees of measurement and observer error for those variables, we cannot conclude that the change detected is biologically meaningful.

Throughout the study, macroalgae was a minor component of benthic cover. It represented less than 1% of benthic cover at all sites on all dates except at PUHO Walls in the summer of 2007 (1.5% ± SD 0.9%) and at Kohanaiki Vertical Walls where macroalgae cover ranged from 4.6% ± SD 4.4% to 3.2% ± SD 3.1% at different sampling times (Figure 7). An encrusting algae (probably *Peyssonnelia* sp.) was the most prevalent macroalgae observed at these wall sites. It was also present in other sites, typically in crevices and on undersides of coral heads and was not visible in quadrat photos. Other algae included *Asparagopsis taxiformis*, *Caulerpa serrulata*, *Dictyota* spp., *Liagora* sp., *Sargassum* sp., *Turbinaria ornata*, red gelatinous algae, and geniculate corallines. Macro-algae were more dominant in reef crevices inaccessible to herbivores and not visible in photoquadrat images. More detailed algal inventories of these sites are available (Appendix III and IV). Available substrate in the form of bare rock without visible turf or CCA was low at all sites, comprising less than 0.75 % of the benthos.

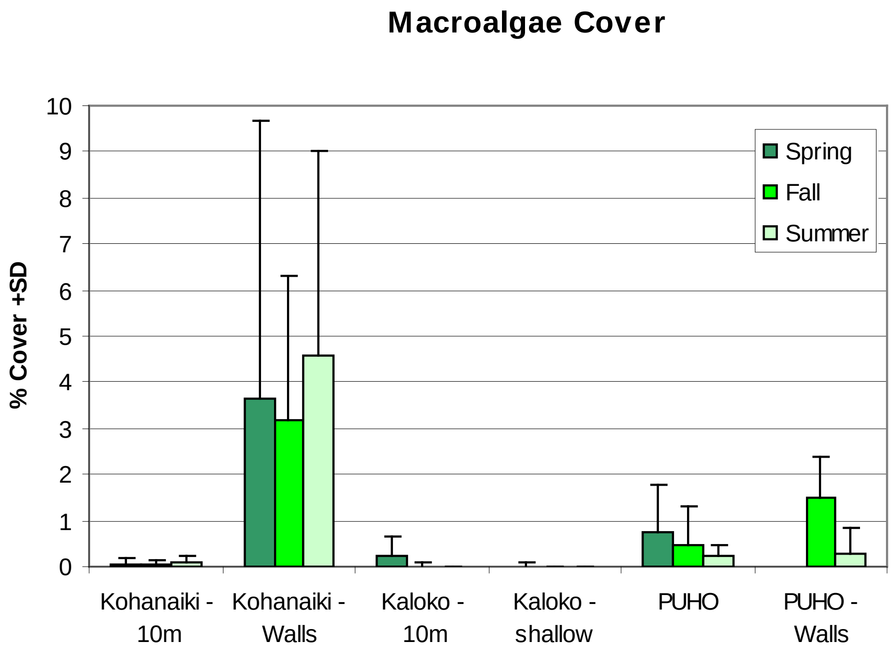


Figure 7. Macroalgae mean percent cover + SD at all study sites across time. PUHO = Pu‘uhonoua o Hōnaunau NHP.

Coral Community Structure

Porites lobata was the dominant coral species at all sites. However, there were differences in coral community structure among surveyed locations. *Pocillopora meandrina* was prevalent at all Kohanaiki Reef transects and at PUHO Walls, but was less common at other locations. *Porites compressa* was dominant in 10-m depths at Kaloko Reef and Hōnaunau Reef locations. Large colonies of *P. lutea* were important members of the coral community at Kaloko transects but were infrequently seen elsewhere (Table 5). *Montipora capitata* was found throughout study sites, but it, along with *M. patula*, was most prevalent on Kohanaiki Walls.

Recorded *P. lutea* levels varied among the three sampling periods, however this variance was presumably due to observer difficulty distinguishing *P. lutea* from *P. lobata* in photoquadrats in the lab rather than changes in the benthic community. When *P. lutea* and *P. lobata* are combined and analyzed as “Massive *Porites*,” very little change in taxonomic composition occurs over the sampling periods (Figure 8). *Fungia* sp. were observed on some transects during field work but not captured in photoquadrat analysis.

Table 5. Species composition of coral community at study sites during Summer 2007 (% of total coral cover ± SD). Dominant species are shown as percent of total coral (100%). Other species observed are listed.

STUDY SITES	***P.lobata***	***P. compressa***	***P. lutea***	***P. meandrina***	***M. capitata***	***M. patula***	**Other (< 3% cover)**	**Other Species**
Kohanaiki-10m	**64.3** ±17.8	**2.9** ±3.4	**1.5** ±2.5	**28.2** ±18.8	**1.7** ±1.5	**0.4** ±0.6	**1.0** ±2.5	*Leptastrea bewickensis, Pavona duerdeni, Pocillopora eydouxi*
Kohanaiki-Walls	**57** ±18.8	**0.1** ±0.2	**0.7** ±1.9	**28.3** ±13.1	**6.8** ±5.5	**4.4** ±4.4	**2.8** ±4.2	*L. bewickensis, P.duerdeni, Pavona varians*
Kaloko-10m	**62.1** ±18.6	**18** ±10.7	**19.1** ±20.6	**0.9** ±1.4	**0.1** ±0.2	**0.0**	**0.0**	
Kaloko-Shallow	**61.8** ±9.7	**5.7** ±4.6	**31.1** ±11.2	**1.1** ±2.0	**0.2** ±0.4	**0.0**	**0.1** ±0.2	*P. eydouxi,* *P. varians*
PUHO - 10m	**66.9** ±13.2	**19.9** ±19.9	**2.4** ±4.9	**9.1** ±14.6	**1.6** ±2.0	**0.0**	**0.1** ±0.3	
PUHO-Walls	**73.2** ±6.2	**0.0**	**0.0**	**25.0** ±6.5	**1.7** ±0.4	**0.0**	**0.0**	

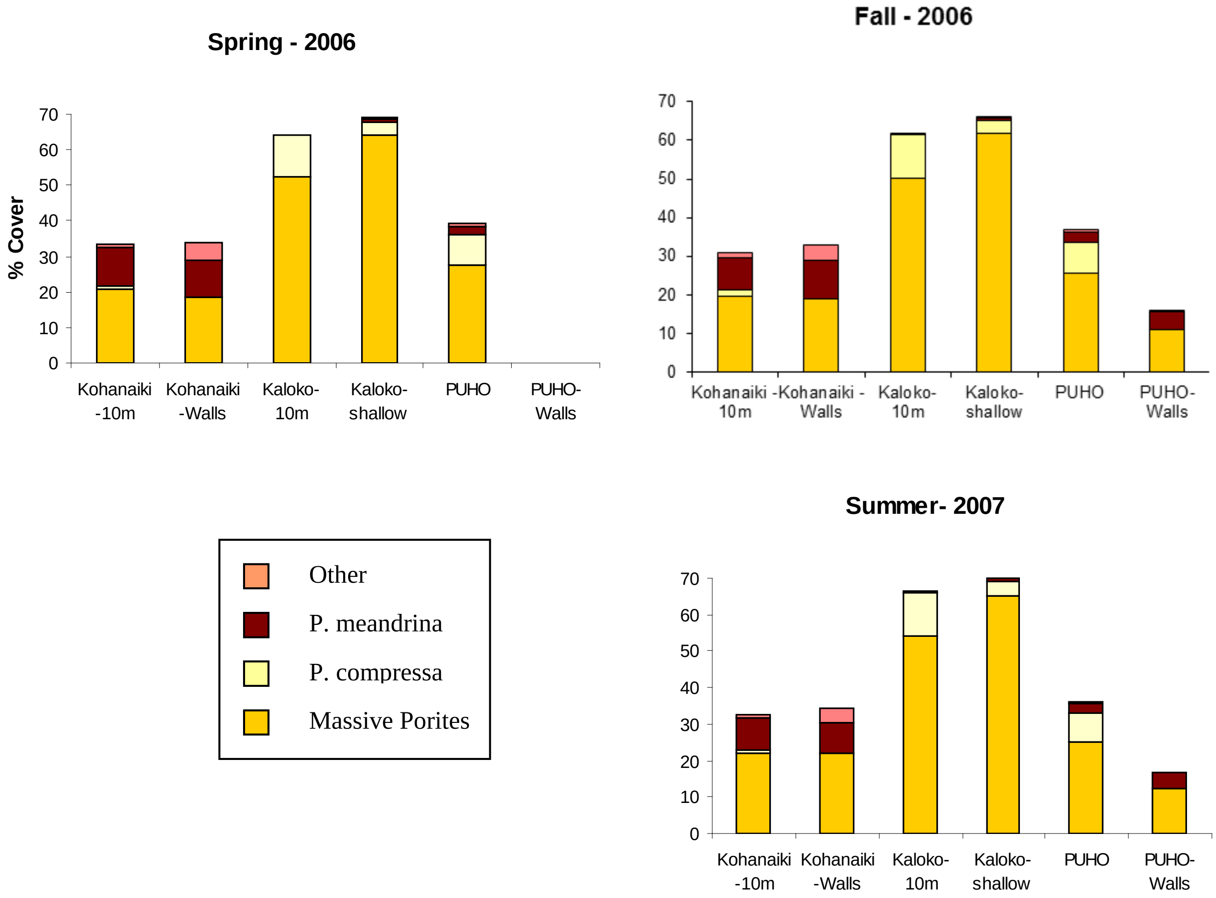


Figure 8. Coral species composition per site as a mean percent of total benthic cover.

Invertebrate Species Diversity

Urchins were common at all study sites during this study (Table 6). Banded and blue-black urchins (*Echinothrix* sp.) and collector urchins (*Tripnuetes gratilla*) were found at all locations. Pencil urchins (*Heterocentrus mamillatus*) were found at all locations but PUHO Walls (Figure 9). *Echinometra mathaei*, the small boring urchin, was present in higher numbers at all sites except at PUHO vertical walls. Densities were highest at Kaloko Shallow (144 individuals/ 17.5 m^2 ± SD 48.3) and PUHO 10-m sites (158.6 individuals/ 17.5 m^2 ± SD 59.8) in the fall of 2006 (Figure 10). Comparison of *E. mathaei* densities at all locations over the two sampling periods show a significant difference between sampling dates ($F_{1,47} = 21.26$, $P < 0.0001$). *E. mathaei* densities were lower at all sites in the summer of 2007 compared to the fall of 2006. The crown-of-thorns sea star, *Acanthaster planci*, was occasionally seen in the study sites. In total, four were counted on all transects in fall of 2006 and one was observed on transects in the summer of 2007. No recruitment was observed except in 4-m depths at Kaloko Cut in 2006 where *T. gratilla* ranging from 2-5 cm numbered in the hundreds.

Table 6. Abundance of urchin species at study sites during Fall 2006 and Summer 2007 (n/17.5m^2 ± SD). Total counts of *A. planci* per study area are also included.

Fall 2006

	Echinothrix sp	*Heterocentrus mamillatus*	*Tripnuestes gratilla*	*Echinometra mathaei*	*Acanthaster planci*-**total**
Kohanaiki-10m	**6.9** ±4.8	**0.6** ±0.9	**4.7** ±6.6	**97.3** ±30.1	**0**
Kohanaiki-Walls	**8.7** ±5.4	**0.3** ±0.5	**2.4** ±6	**73.0** ±37.1	**0**
Kaloko-10m	**3.7** ±3.7	**4.1** ±4.1	**5.5** ±8.5	**100** ±31.2	**1**
Kaloko-Shallow	**2.8** ±2.3	**7.0** ±3.3	**7.8** ±11.4	**144.0** ±48.3	**1**
PUHO-10m	**1.6** ±1.8	**0.8** ±1	**6.7** ±5.8	**158.6** ±59.8	**1**
PUHO-Walls	**6.7** ±2.1	**0.0**	**0.3** ±0.6	**6.7** ±7.6	**1**

Summer 2007

	Echinothrix sp	*H. mamillatus*	*T. gratilla*	*E.mathaei*	*Acanthaster planci*-**total**
Kohanaiki-10m	**6.0** ±3.9	**1.4** ±1.9	**1.8** ±1.7	**68.5** ±26.6	**1**
Kohanaiki-Walls	**5.7** ±2.7	**0.1** ±0.2	**0.7** ±1.9	**60.6** ±37.6	**0**
Kaloko-10m	**3.4** ±6.3	**5.2** ±6.0	**3.5** ±3	**77.7** ±43.2	**0**
Kaloko-shallow	**0.9** ±0.9	**5.9** ±4.6	**7.3** ±11.2	**91.1** ±39.0	**0**
PUHO - 10m	**3.9** ±3.4	**0.2** ±4.7	**0.50** ±12.1	**50.0** ±36.1	**0**
PUHO-Walls	**8.0** ±0.0	**0.0**	**3.0** ±4.4	**2.7** ±4.6	**0**

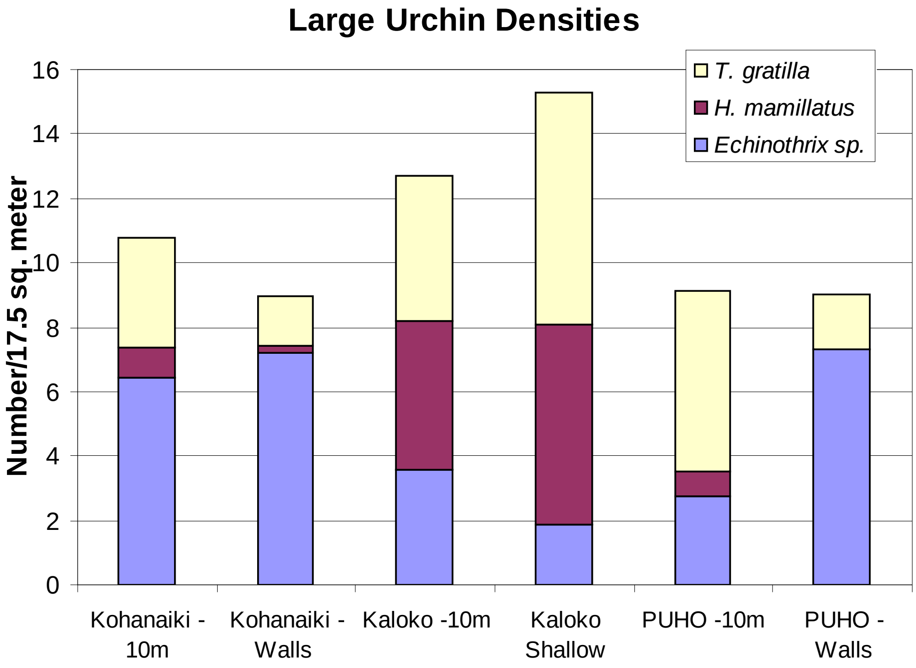


Figure 9. Large urchin abundance (n/17.5m^2) along transects at all sites. Data are averaged from the two macro-invertebrate sampling periods (Fall – 2006, Summer – 2007).

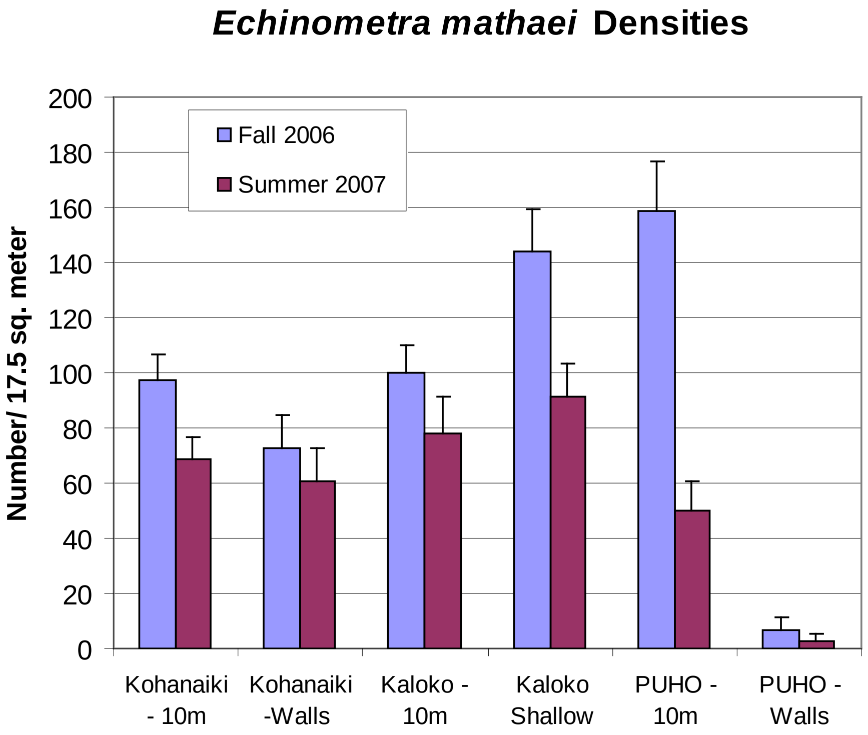


Figure 10. *Echinometra mathaei* abundance (n/17.5m^2) along transects at all sites for two sampling periods.

Comparison of octocoral (*Sarcothelia edmondsoni*) cover at all locations over three sampling periods revealed no statistically significant difference detected between sampling dates ($F_{2,44}$ = 0.6849, P< 0.5094). Pooling data from the three time periods shows a clear difference in octocoral cover among sites (Table 7). Mean octocoral cover varied from 0.1 to 7.1% at study sites. Octocoral cover was highest at Kaloko 10-m and Kohanaiki 10-m sites (7.1% and 2.3% respectively). These estimates are conservative because, as we describe above, octocoral tend to be underestimated when there is even slight water motion

In photoquadrats, sessile and mobile invertebrates other than octocoral, urchins, and coral were infrequently recorded. Other sessile invertebrates made up less than 0.7% ± SD 0.75 of the benthic cover at all sites. Other mobile invertebrates made up less than 0.08% ± SD 0.13 of the benthic cover at all sites. Organisms such as sponges, tunicates, zoanthids, mollusks, holothuroides, and crustaceans were seen on the reefs during field work but were usually hidden, and therefore were not observed in photoquadrats.

Table 7. Summary of benthic cover of invertebrates other than corals (% cover ± SD). Data are averages from three sampling periods of photo-transects.

	Octocoral	**Urchins**	**Other Sessile**	**Other Mobile**
Kohanaiki-10m	**2.3** ± 4.3	**0.7** ± 0.6	0.0	**0.03** ± 0.1
Kohanaiki-Walls	**0.3** ± 0.7	**0.7** ± 0.5	**0.08** ± 0.1	**0.04** ± 0.04
Kaloko-10m	**7.1** ± 5.0	**0.4** ± 0.2	**0.01** ± 0.2	**0.02** ± 0.03
Kaloko-Shallow	**0.7** ± 0.7	**0.8** ± 3.3	0.0	**0.03** ± 0.1
PUHO - 10m	**0.1** ± 0.2	**0.6** ± 0.5	**0.03** ± 0.1	0.0
PUHO-Walls	**1.2** ± 0.6	**0.9** ± 0.3	**0.7** ± 0.7	**0.1** ± 0.1

Coral Bleaching

In October 2005, *Pocillopora meandrina* tips were bleached throughout the Kohanaiki Reef site from approximately 7 to 15-m depths (Figure 11). By the spring of 2006, bleaching was not evident (Table 8). At all locations during all three sampling periods, bleaching was minimal and occurred primarily on *P. meandrina.* Bleaching occurred most frequently in the fall of 2006, but during the fall period was present in only 23 out of a possible 23,760 random photoquadrat points.

Table 8. Points per study area for which bleaching was observed. “Bleached coral” refers to the entire coral structure while “bleached tips” refers to bleaching only on the top several inches of coral branches. For either type of bleaching to be counted, the coral tissue under a point would be bleached. n= number of random points evaluated within a study site. “Massive Porites” means *P. lutea* and *P. lobata* combined.

	Bleached coral			**Bleached tips**		
	Spr.06	**Fall.06**	**Sum.07**	**Spr.06**	**Fall.06**	**Sum.07**
Kohanaiki-10m (n=4840)	1	11		2	3	
Kohanaiki–Walls (n=4440)	1		6	1	2	
Kaloko–10m (n=4440)					1	
Kaloko–Shallow (n=4440)	2				1	
PUHO-10 m (n=4440)		4			1	
PUHO–Walls (n=1320)			1			
	All *P. meandrina* except 3 massive *Porites* in summer			All *P. meandrina* except 2 *Porites* in fall		

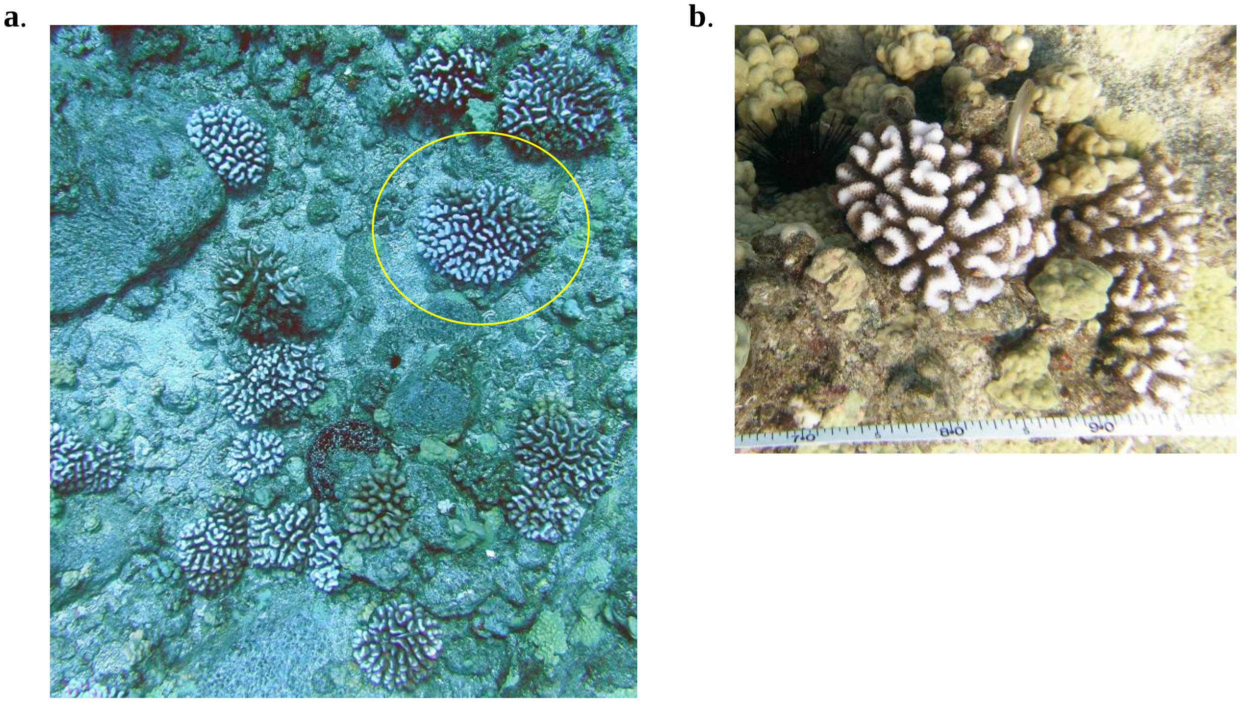


Figure 11. Widespread partial bleaching observed on Kohanaiki Reef in October, 2005. Tips of *P. meandrina* were bleached but not the bottom of branches. By the spring of 2006, bleaching was no longer evident presumably due to coral recovery and/or death.

Coral Disease

Porites Trematodiasis was observed throughout the sites during this study. Other diseases were not observed until the summer of 2007 when the first documented case of coral disease other than Trematodiasis was observed in the Kaloko study site on *P. lutea* (Table 9, Figure 12). Coral disease specialist Dr. Greta Aeby (University of Hawai‘i at Manoa) described this disease as a multi-focal *Porites* Tissue Loss Disease. It appears to be a different condition than another tissue loss disease seen on *P. lutea* and documented at other sites along the west coast of Hawai‘i Island by the State of Hawai‘i Department of Aquatic Resource staff (Steve Cotton, personal communication).

Freidlander et al. (2008) report that two coral diseases of concern for the main Hawaiian Islands are *Montipora* White Syndrome and *Porites* growth anomalies. *Montipora* White Syndrome, which causes acute tissue loss, was first found in Kaneohe Bay in 2004 and has now been documented throughout the main Hawaiian Islands. This disease has not been documented in Kaloko-Honokōhau or off Pu‘uhonua o Hōnaunau. *Porites* growth anomalies are more widespread in the main Hawaiian Islands compared to the reefs of the Northwest Hawaiian Islands (Aeby, 2006; Aeby et al., unpublished data). These growth anomalies were observed within Kaloko-Honokōhau during the summer of 2008 surveys (Figure 12c).

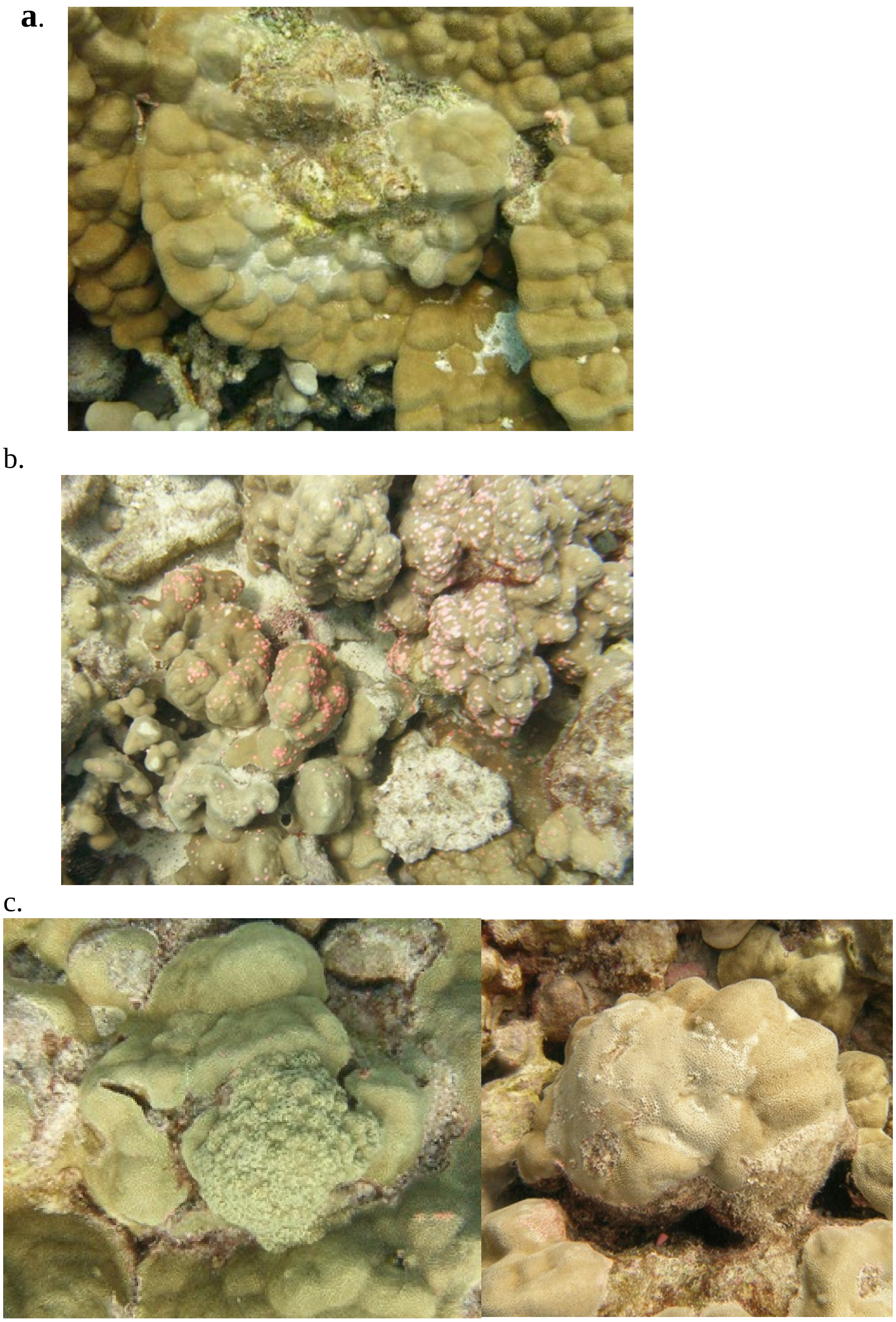


Figure 12. Coral Diseases at Kaloko-Honokōhau National Historical Park: (a) *Porites* Tissue Loss Disease on *P. lutea*. Central portion of photo shows dead coral surrounded by stressed gray tissue; (b) Trematodiasis on *P. lobata* observed at Kaloko Reef study site Summer of 2007; (c) Two frames showing *Porites* growth anomalies on *P. lobata* at Kaloko Reef Summer of 2008.

Table 9. Points per study area for which disease was observed**.** n = number of random points evaluated within a study site.

	Other Disease			**Trematodiasis**		
	Spr.06	**Fall.06**	**Sum.07**	**Spr.06**	**Fall.06**	**Sum.07**
Kohanaiki - 10m (n=4840)					1	
Kohanaiki – Walls (n=4440)					1	
Kaloko – 10m (n=4440)			3		4	
Kaloko – Shallow (n=4440)			14		11	
PUHO - 10 m (n=4440)						
PUHO –Walls (n=1320)						
	All *P.lutea*			All massive *Porites*		

Coral Mortality Study

A total of 148 *Pocillopora meandrina* heads were individually identified across all study sites (Table 10). Colony length averaged 27 ± SD 7.2 cm ranging from 3 to 44 cm. Colony width was 20.0 ± 6.5 cm (mean ± SD), and height was 14.0 ± 4.5 cm. Of the identified colonies, 73% were completely living, 6% were classified as half-alive/half-dead, and 21% were living colonies with partially dead areas that ranged from several dead branch tips to 20% dead tissue.

Table 10. Summary of morphometric data for *Pocillopora meandrina* individual heads for mortality study**.** Size data are averages ± SD.

	Colony Count	**Length (cm)**	**Width (cm)**	**Ht (cm)**	**Min length (cm)**	**Max length (cm)**
Kohanaiki -10m	**33**	**28.1** ±6.4	**22.4** ±5.5	**13.6** ±3.4	14	44
Kohanaiki –Walls	**32**	**26.5** ±6.2	**21.5** ±5.7	**12.7** ±3.3	8	37
Kaloko -10m	**23**	**23.8** ±8.1	**16.4** ±6.5	**12.4** ±3.	3	37
Kaloko –Shallow	**29**	**25.9** ±9.8	**18.2** ±7.9	**15.7** ±7.3	6	43
PUHO	**27**	**27.7** ±5.0	**19.9** ±5.8	**13.3** ±3.3	16	36
PUHO –Walls	**4**	**30.8** ±2.1	**21** ±3.5	**11** ±2.0	28	33
Total	**148**	**27** ±7.2	**20** ±6.5	**14** ±4.5	3	44

DISCUSSION

Benthic Cover

This study establishes a baseline of data from Spring 2006, Fall 2006, and Summer 2007 surveys. Compared with two other national park units in Hawai‘i (Kaulaupapa National Historical Park (NHP) on Moloka‘i and Pu‘ukoholā Heiau National Historical Site (NHS) on Hawai‘i Island) the coastal environments in Kaloko-Honokōhau National Historical Park and offshore of Pu‘uhonoua o Hōnaunau NHP have impressive coral communities interspersed among hard bottom habitats with very low coral cover and low spatial complexity (Beets et al. 2010, Cochran et al. 2007, Gibbs et al. 2007). At Kaloko-Honokōhau NHP, high fish species richness values have been associated with high density coral communities (Beets et al. 2010). Kaloko-Honokōhau reefs are very similar in species composition compared to other well established reefs on the west coast of Hawai‘i (Dollar 1982, DAR unpublished data).

The benthic coral habitat at the Kohanaiki, Kaloko and Puʻuhonoua o Hōnaunau study sites was in relatively stable condition within the three sample periods of this study. Over the 22 months of this study, only small changes occurred in coral species composition and cover of primary benthic components, indicating reefs are stable at those sites. Additionally, macroalgae represented only a very small portion of benthic cover at all sites, and the coral: macroalgae ratio at all sites was very high. Coral disease, although recorded at the Kaloko site on some *P. lutea* colonies, was not widespread. Despite stability of benthic cover over the course of the study, a 3% coral cover change was determined to be statistically significant at several sites. Although not biologically significant, the capacity of survey methods to statistically detect significant change of that magnitude indicates that the study design and survey methods are robust and will provide adequate baseline sampling for comparisons with future surveys.

Groundwater

Submarine groundwater discharge is the primary conduit for nutrients and contaminants from land-based activities to be released into Kaloko-Honokōhau's marine environment (Street et al. 2007). Knowing the quantity, quality, and fate of this brackish discharge is important for predicting the potential effects of the input on the coral reef ecosystem. Future monitoring of groundwater discharge quantity and quality along with mixing fate will be needed so that managers can protect coral reef health. An isotope-tracing effort by the USGS was initiated in 2008 to identify the sources and quality of groundwater entering park waters (Hunt in press). The NPS Inventory & Monitoring Program also initiated its Water Quality Monitoring Protocol during 2008 in all park water resources including coral reef areas (NPS 2014b).

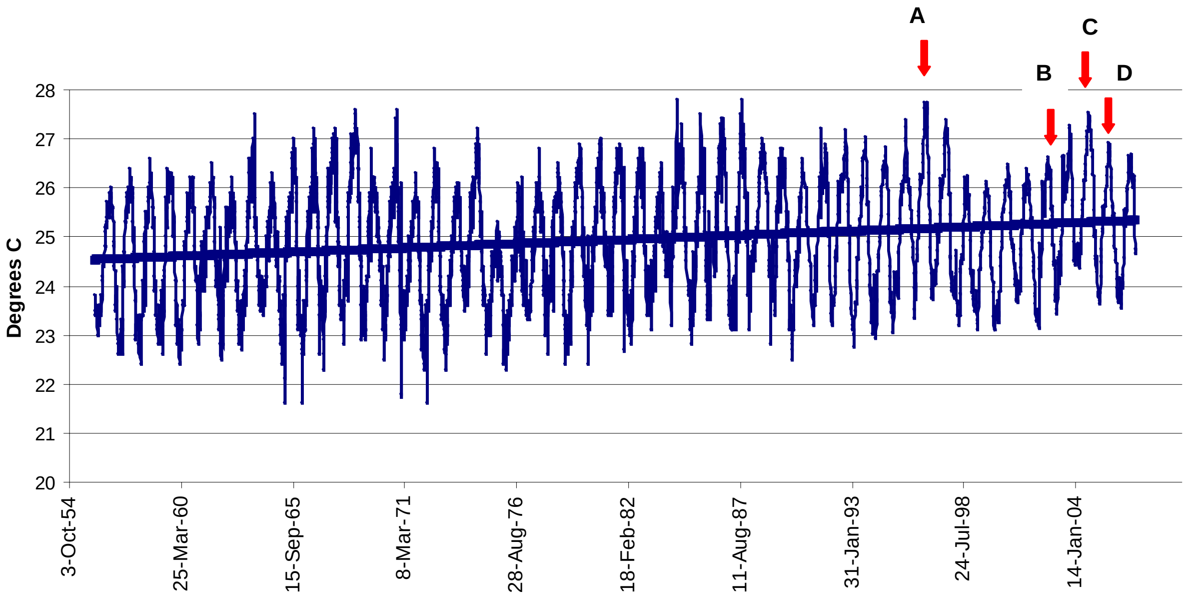
Dive Tourism

High numbers of divers and snorkelers have been associated with more broken and bleached corals, smaller coral colonies, and less overall coral cover in some studies (Hawkins and Roberts 1993, Tissot and Hallacker 2000, Zakai and Chadwick-Furman 2002). In Kealakekua Bay (Hawai'i Island) more broken and bleached coral was found at high diver use-areas compared with a control site (Tissot and Hallacker 2000). Coral breakage is mostly due to standing on coral, dangling gauges, placement of photographic equipment, and bad buoyancy control, and could possibly be improved by diver education. Within Kaloko-Honokōhau NHP, Kaloko and Kohanaiki are moderately popular dive sites. As population along the Kona Coast continues its rapid growth, diving pressures may well increase. Future monitoring and statistical analysis should take into account the diver impact data when comparing coral benthic cover over time between the sites.

Bleaching

Hawaiian waters show a trend of increasing temperature over the past several decades (Figure 13) that are consistent with observations in many coral reef areas of the world (Jokiel and Brown 2004). Although summer water temperatures in 2005 were not as warm as the previous summer, they were warm enough to cause partial bleaching in *P. meandrina* corals throughout Kohanaiki Reef from about 7 to 15-m depths. Bleaching was not observed on corals in shallower depths. Cold groundwater discharging at Kohanaiki Reef and nearby sources such as Kaloko Fishpond mix with surface ocean waters and could potentially keep water temperatures at shallow areas below the bleaching threshold. Any monitoring of ocean temperatures at Kaloko-

Honokōhau should take into account that, due to groundwater intrusion, local sea surface temperatures may be cooler than the deeper water surrounding and immediately effecting corals. Stress due to global warming and ocean acidification is likely to increase in the decades to come (Intergovernmental Panel on Climate Change 2001, Kleypas et al. 2006), resulting in more frequent and severe bleaching events, suppressed coral growth, reduced disease resistance, and ultimately increased coral mortality.



A – Oct 6, 1996 27.8 °C Widespread Hawaiian bleaching event (Jokiel and Brown 2004)
B – Sept 22, 2002 26.6 °C Widespread Hawaiian bleaching event (Jokiel and Brown 2004)
C – Sept 5, 2004 27.5 °C Highest temperature record since 1996.
D – Sept 11, 2005 26.9 °C Widespread bleached tips at Kohanaiki Reef.

Figure 13. Combined sea surface temperature record using National Marine Fisheries Service data for Koko Head, Oahu (1956–1992) and corrected Integrated Global Ocean Services System–National Meteorological Center temperature data (1992–2006). Adapted from Jokiel and Brown 2004. Parameters for the trend line are slope x 10^{-5} = 4.28, intercept = 23.6504, r^2 =0.03144, P<0.0001.

Alien algae

No alien species were found on Kaloko-Honokōhau or Pu‘uhonua o Hōnaunau NHP transects. However, the presence of *Acanthophora spicifera* has been documented on the west coast of Hawai’i at three sites including these two National Parks (Kaloko Fishpond and Honaunau tidepool, C. Squair unpubl. data 2006, Smith et al. 2002). Boats are known vectors for the distribution of marine (alien) species, therefore, special attention should be given in surveys for alien species to establish early detection and prevent invasions.

Octocoral

Octocoral is locally abundant in Kaloko-Honokōhau NHP waters as demonstrated by our study and by others (Cotton 2004, Beets et al. 2010). *Sarcothelia edmondsoni* was most abundant in areas of high submarine groundwater discharge (E. Grossman, personal communication). Little is known about the role this soft coral takes in the reef ecosystem. Studies on the Great Barrier Reef show that octocoral communities can be sensitive to water quality parameters such as nutrients and turbidity (De'ath and Fabricius 2008). It would be worth investigating the ecological role *Sarcothelia edmondsoni* plays in Hawaiian reef communities as it may be a useful indicator species for water quality.

Grazer Populations

Healthy populations of sea turtles, herbivorous fish, and sea urchins keep algal growth in check and are therefore important for coral reef ecosystems. In the Park, the herbivore community appears to be adequate to maintain reef communities in coral dominated states, however research indicates decline of some fish populations. Statewide there is clear evidence of overexploitation of many target food fishes, invertebrates, and key marine aquarium trade species (Freidlander et al. 2005). Data from several studies on fish species, abundance, and biomass in Kaloko-Honokōhau waters suggest that there is evidence of overexploitation. Hawaiʻi Department of Aquatic Resources (DAR) has conducted fish surveys four to six times per year since 1999 at 26 sites in West Hawaiʻi as part of an ongoing monitoring program (DAR unpublished data, 2006). At 14 of those sites, DAR conducts 'resource fish surveys' that focus on fish species targeted by commercial and recreational fishers. Among these 14 sites, the Honokōhau site in the southern part of Park waters has the lowest biomass of 'resource fish' including herbivorous surgeonfish (Acanthurids) and parrotfish (Scarids) (Figure 14). The relatively low fish stocks in the Honokohau Harbor area are perhaps due to accessibility of the area to spear-fishers.

In 2005, the NPS Inventory and Monitoring Program (I&M) compared marine vertebrates at four national park units, Kaloko-Honokōhau NHP, Puʻuhonua o Hōnaunau NHP, Puʻukoholā Heiau NHS, and Kalaupapa NHP on Molokaʻi Island (Beets et al. 2010). Surveys examined marine fish assemblages (density, biomass, species richness, diversity) and habitat utilization. Fish assemblages at Kalaupapa were higher in all measures than Kaloko-Honokōhau and Puʻuhonua o Hōnaunau, most likely due to habitat differences and fishing pressures. Kaloko-Honokōhau and Puʻuhonua o Hōnaunau are easily accessible to shore and boat fisherman while Kalaupapa NHP is on a remote coastline with low visitation. Although impacted, fish assemblages at Kaloko-Honokōhau and Puʻuhonua o Hōnaunau are in much better condition than Puʻukoholā Heiau NHS, a site with multiple anthropogenic impacts such as easy access to shore and boat fishermen, harbor construction, and upland erosion. At Kaloko-Honokōhau and Puʻuhonua o Hōnaunau, the surgeon fish (Acanthuridae) dominated in biomass while damselfish (Pomacentridae) and surgeon fish were the groups with the highest density. In Kaloko-Honokōhau NHP, the introduced ta'ape (*Lutjanus fulvus*) was the dominant species in biomass. Corresponding with the DAR's results, few large piscivores such as jacks were encountered.

In summary, surgeonfish, parrotfish and, to a lesser extent, damselfish are important grazers on macroalgae and though common at Kaloko-Honokōhau, appear to be undergoing noticeable fishing pressure (Beets et al. 2010). The NPS should work with the DAR where possible to facilitate fisheries management. The NPS I&M program began monitoring fish assemblages in October 2007 and those data will assist with the state's future management efforts (NPS 2014a).

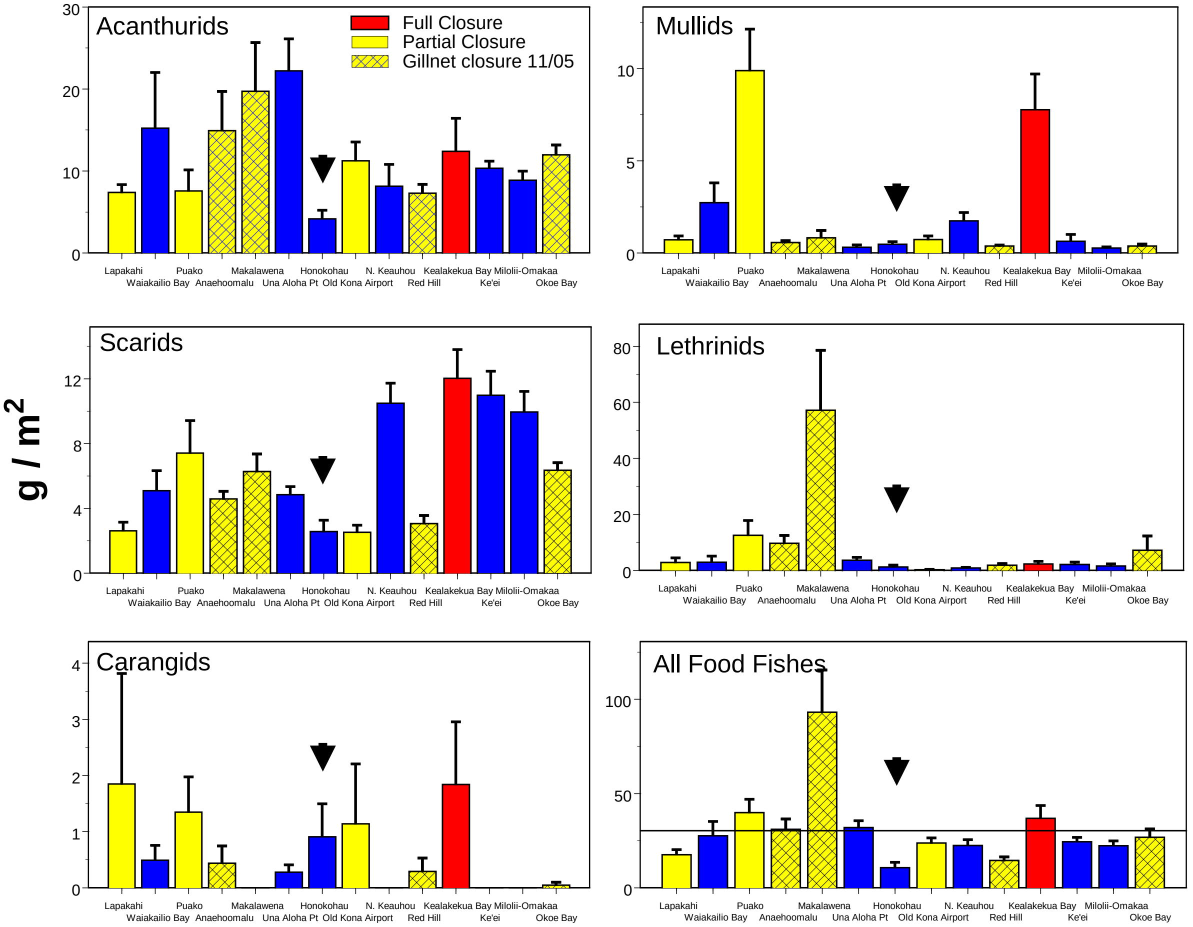


Figure 14. Mean (± SE) biomass (g/m^2) of 'resource fishes' from eight surveys at each of 14 West Hawai'i sites (x-axis) in 2005 - 2006. Data include acanthurids (surgeonfish), mullids (mullets), scarids (parrotfish), lethrinids (emperors), and carangids (jacks). Honokōhau site is 7th from the left. Solid blue bars are open fishing areas. Horizontal line in last figure represents mean biomass of all sites combined. Graph used with permission from Hawai'i Division of Aquatic Resources (DAR West Hawai'i Aquarium Fish Project, B. Walsh, unpublished data).

Urchins were observed throughout study sites and appeared healthy and abundant with an average of 104.5 ± 48.2 individuals/17.5 m^2 (± SD). Because of high juvenile growth rates, low adult mortality, high grazing rates, and preference for invasive red algae, the collector urchin *Tripnuestes gratilla* has been identified as having high biologic potential to control invasive red algae (Carlon 2006). The other species of urchins observed in this study likely play key grazing roles as well. Long-term data from the Caribbean have documented that grazing urchin populations are essential for the health of coral reefs. When *Diadema* populations crashed in the 1980's due to disease, macroalgae overgrew coral causing widespread coral mortality and shifts from coral-dominated to algal-dominated reefs (Hughes 1994). Hawaiʻi Division of Aquatic Resources (DAR) urchin-abundance data from sites along the west coast of Hawaiʻi Island show that *Echinothrix* sp. and *Heterocentrotus mamillatus* have not increased noticeably since 1999 however *Tripnuestes gratilla* numbers have increased dramatically, from approximately 10 per 100 m^2 to 40 per 100 m^2 (DAR unpublished data). It is unclear what this increase means in ecological terms, however, given that pace of change, monitoring of urchin populations will be essential in ongoing management of the Park's reef community.

Summary

The benthic habitats at Kohanaiki Reef, Kaloko Reef and Puʻuhonua o Hōnaunau sites are presently in relatively good condition, and over this 17-month study coral cover was stable. The sampling design of the project enabled statistically significant detection of < 5% change in coral cover over time. Although these results are not biologically significant because they fall within the 10% measurement and observer error, they indicate that the study design is robust.

In addition to The Shores at Kohanaiki development, at the time of this study 10 other large residential and industrial developments are planned in the immediate vicinity of the Park. In response to the proposed Kona Kai Ola Harbor Expansion development, three additional Park reef sites offshore of Honokohau Harbor were sampled in 2006/2007 (Appendix V, Wijerman et al. 2014). Monitoring coral and algal cover, coral condition, and macroinvertebrates at these sites should continue to identify potential future changes to reef health before ecosystem shifts occur.

Water quality, herbivore populations, invasive algae, and diver use are some of the factors that will influence reef condition and should be monitored and managed as well. As Kailua-Kona's human population grows and urban development moves forward, local stressors to coral reef ecosystems will likely increase. Controlling land-use practices and using preventative management practices is a more effective and economical approach to protecting valuable reef resources than attempting the difficult and usually impossible task of re-establishing reefs once they are disrupted.

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this report does not constitute endorsement or recommendation by the National Park Service or the University of Hawai‘i.

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APPENDIX I: Pilot study to determine sampling design.

Determination of the number of transects, number of frames per transect and the number of points per frame to use for the most accurate representation of percent coral cover with the least sampling intensity.

After study sites were mapped at Kohanaiki Reef, twelve, 10-m transects were randomly selected and photographed on October 27 and November 3, 2005 for a pilot study. The start and end points of these transects were temporarily marked with cable ties, logged onto a GPS, and removed at the end of sampling. The questions targeted by the pilot study were: 1) What is the minimum number of 10-m transects needed to accurately describe the total percent coral cover of the 10m habitat at Kohanaiki Reef? 2) What is the minimum number of frames needed to accurately describe the total percent coral cover of a transect within the 10-m habitat at Kohanaiki? 3) What is the minimum number of random points per frame needed to accurately describe the total percent coral cover within an average frame within an average transect at the 10-m habitat at Kohanaiki?

Number of Transects

To determine the minimum number of 10-m transects needed to accurately describe the total percent coral cover of the 10-m habitat at Kohanaiki Reef, every other frame within a transect was analyzed with the point-count method. Twenty five points per frame were randomly placed and identified. This number of points was initially selected to follow Hawaiʻi Division of Aquatic Resources protocols. Based on the results, coral cover varied from 8.4 to 50.9 % at 10 m depths at Kohanaiki study areas (Table 1). Average percent cover was 28.1 ± 169.3 (St Dev).

Table 1. Mean Percent coral cover at 10-m depth at Kohanaiki Study Site. Transects are 10-m long.

Transect #	% coral cover
T1	27.2
T2	43.2
T3	33.3
T4	10.8
T5	19.3
T6	50.9
T7old	8.4
T8	25.8
T9	28.1
T10	29.7
T11	42.6
T14	17.8
Average	28.1

MSExcel with the POPTOOLS feature was used to randomly resample these transects and to calculate the standard error for 1 to 30 transects. We repeated the process 100 times and averaged the resulting standard errors (Figure 1). Based on the results, 10 transects appear to be an acceptable minimum sample size due to reasonably low standard error (Andrew and Mapstone 1987). Due to diver time constraints, sampling many more transects per habitat would be difficult and would not yield a great increase in precision. Because variability of coral cover at Kohanaiki was approximately equal to or greater than other sites (see Results from 2006 to 2007 baseline survey, Table 3, pg. 23) 10 transects was sufficient for sampling each of the sites.

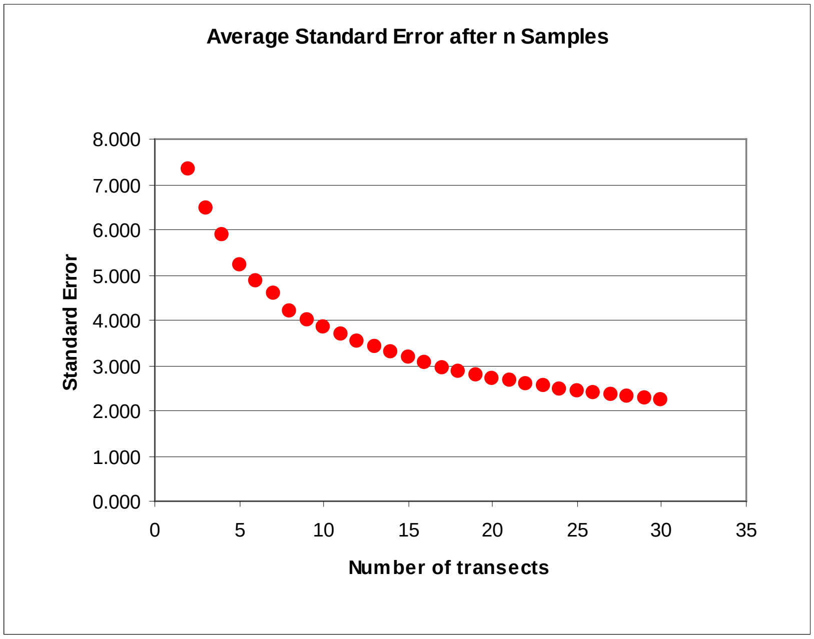

Figure A1. The average standard error for 1 to 30 transects. Calculations are based on 100 resamples of 12 transects sampled in the 10-m zone at Kohanaiki study site.

Intentional Bias

Because the study is focused on coral cover and health, we intentionally avoided sampling areas with less than 10% coral that had sand channels or rubble because we assumed these were not good coral habitat. If a random point fell on such an area, divers moved to the closest area with coral and hard bottom substrate. This bias also limited some of the variability in samples.

Number of frames

To determine the minimum number of 0.5m x 0.43m photoquadrats needed to accurately describe the total percent coral cover of a transect within the 10-m habitat at Kohanaiki Reef, we analyzed every other frame along a transect with the point-count method. Non-contiguous frames were analyzed to ensure independence of samples and to avoid overlapping images. Twenty – five points randomly placed points were identified in each frame. By using MSExcel with the POPTOOLS features, photoquadrats from a transect were randomly re-sampled to calculate standard error for 1 to 30 frames. We repeated this process 100 times and averaged the resulting standard errors (Figure 4). We used this method on four different transects, one with high coral cover (T10), one with low coral cover (T7old), and two with average coral cover (T9 and T6). Based on the results for all four transects, 11 frames appear to be an acceptable minimum sample size due to reasonably low standard error. Therefore, every other frame starting with 0m were analyzed so that errors of overlapping quadrats did not occur.

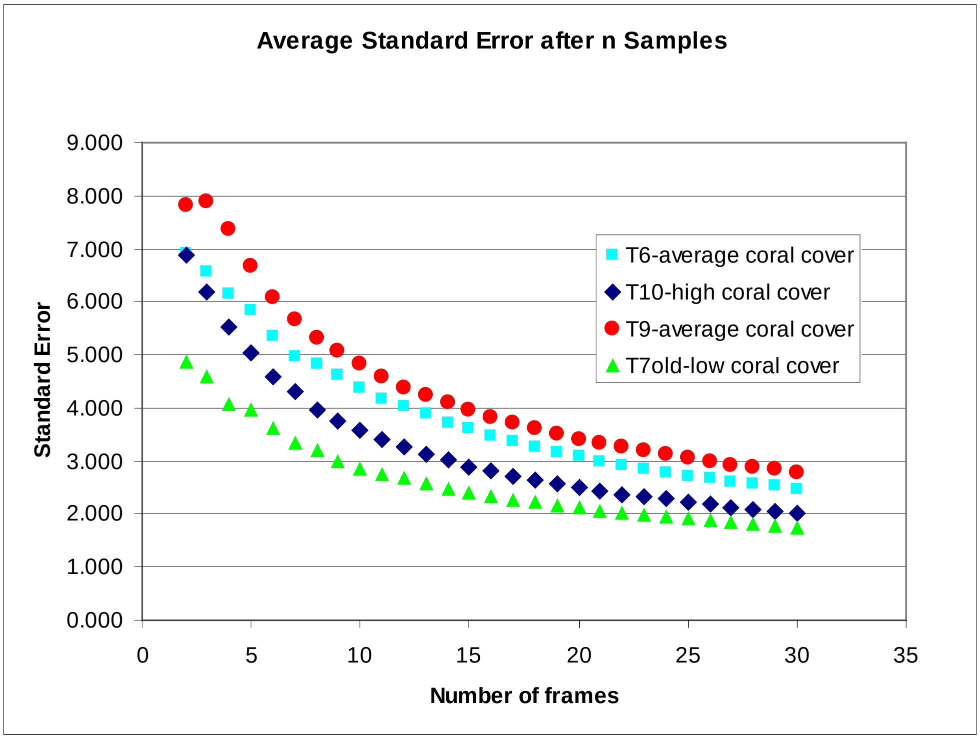

Figure A2. The average standard error for 1 to 30 photoquadrats on transects with varying coral cover. Calculations are based on random resampling of 10 to 14 frames per transect. Transects are representative of the 10m zone at Kohanaiki study site.

<u>Number of points per frame</u>

To determine the minimum number of random points needed to accurately describe the total percent coral cover of a frame within a transect at the 10m habitat, 100 random points were identified within frame # T10-017 ten times. This frame was selected to represent a quadrat with average coral cover (34%) in a transect with average coral cover (27.9%). From each set of 100 random points, average coral cover was calculated for 10, 25, 30, 40, 50, 60, 70, 80, 90, and 100 points. Standard error was then calculated for the 10 replicates from each category (Figure 5). The results show that a 25-point sample has a rather high standard error and with low precision. At 40 points, standard error and variability have dropped enough that much further sampling does not greatly improve precision. Therefore, 40 points were selected for calculation of total percent coral cover.

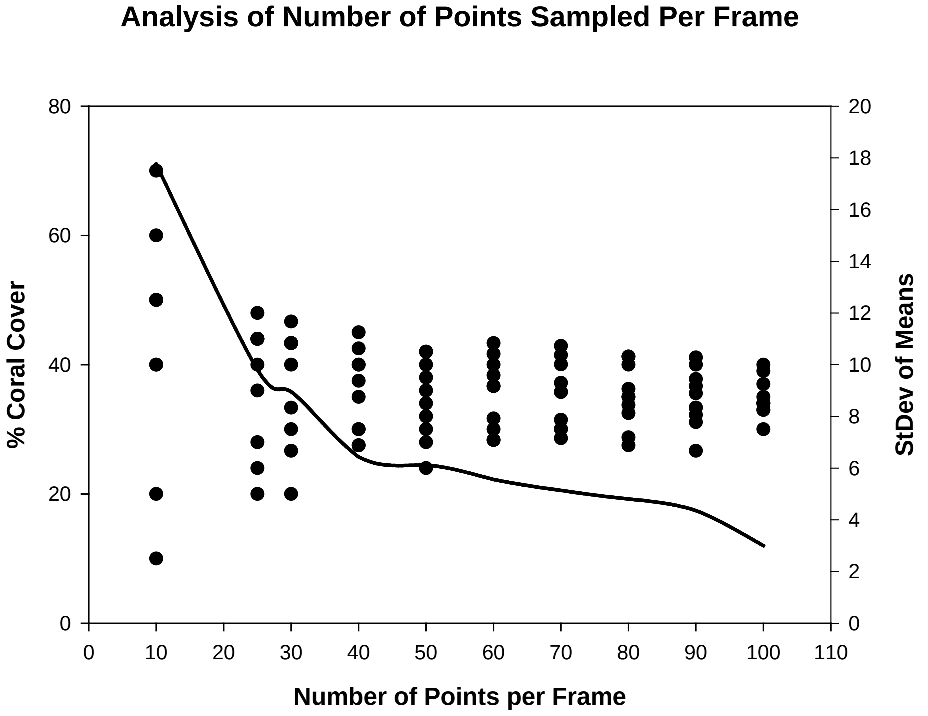

Figure A3. Sampling variability with increasing numbers of random points used to identify percent coral cover in a photoquadrat from a transect at Kohanaiki Reef. Scatter plot shows the percent coral cover resulting from ten analyses of the same frame with the same number of random points. The line plot represents the standard deviation of means from these replicates.

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APPENDIX II: Categorization and codes used in the photoquadrat CPCe analysis.
C = coral; SUB = available substrate for colonization; UNIDENT = unidentified; MA = fleshy frontose macroalgae >1 cm height; CCA = crustose coraline algae; M INV = mobile invertebrate; INV = sessile invertebrate; BL GRN = Blue-green cyanobacteria; TURF = turf algae < 1 cm height; NA = not appropriate.

CPCe Code	Description	Category	Broad Category
NEC	Necrotic Coral	DISEASE	DISEASE
RDC	Recently Dead Coral	DEAD C	SUB
DMEA	Dead Pocillopora meandrina	DEAD C	SUB
TWS	Tape, wand, shadow	TWS	UNIDENT
FSCU	Cyphastrea ocellina	C	C
FSCU	Fungia scutaria	C	C
LBEW	Leptastrea bewickensis	C	C
LPUR	Leptastrea purpurea	C	C
LINC	Leptoseris incrustans	C	C
MCAP	Montipora capitata	C	C
MPAT	Montipora patula	C	C
MFLA	Montipora flabellata	C	C
PBRA	Porites Branching	C	C
PMAS	Porites Massive	C	C
PLOB	Porites lobata	C	C
PCOM	Porites compressa	C	C
PLUT	Porites lutea	C	C
PRUS	Porites rus	C	C
PVAR	Pavona varians	C	C
PDUE	Pavona duerdeni	C	C
PEYE	Pocillopora eydouxi	C	C
PMEA	Pocillopora meandrina	C	C
PDAM	Pocillopora damicornis	C	C
UNCO	Unindentified coral	C	C
HOPU	Halimeda opuntia	MA	MA
NEOM	Neomeris sp	MA	MA
VENT	Ventricaria sp	MA	MA
CODI	Codium sp	MA	MA
CSER	Caulerpa serrulata	MA	MA
CRAC	Caulerpa racemosa	MA	MA
DVER	Dictiosphaeria versluysii	MA	MA
UNGR	Unindentified green	MA	MA
DICT	Dictyota sp	MA	MA
TURB	Turbinaria sp	MA	MA
LOBO	Lobophora sp	MA	MA
LOBOU	Lobophora upright	MA	MA
SARG	Sargassum sp	MA	MA
PADI	Padina sp	MA	MA
STYP	Stypopodium sp	MA	MA
Continuation of Appendix II: Categorization and codes used in the photoquadrat CPCe analysis			

CPCe Code	Description	Category	Broad Category
LIAG	Liagora sp	MA	MA
BRCR	Brown crustose	MA	MA
UBRN	Unindentifed brown	MA	MA
GOOEY	Gelatinous red	MA	MA
GMAR	Galaxaura marginata	MA	MA
ASPA	Asparagopsis sp	MA	MA
JCAL	Jointed calcareous red	MA	MA
CRST	Crustose corralline	CCA	CCA
HALY	Halymenia sp	MA	MA
URED	Unindentified red	MA	MA
ASPI	Acanthophora spicifera	MA	MA
GSAL	Gracillaria salicornia	MA	MA
HMUS	Hypnea musciformis	MA	MA
KAPP	Kappaphycus sp	MA	MA
AVRA	Avrainvillea sp	MA	MA
CSER	Cladophora sericea	MA	MA
DCAV	Dictyosphaeria cavernosa	MA	MA
URCH	Urchin sp	M INV	M INV
ACAN	Acanthaster Planci	M INV	M INV
HOLO	Holothuriidae	M INV	M INV
MINV	Other Mobile Inverts	M INV	M INV
ZOAN	Zoanthid	INV	INV
TUNI	Tunicate	INV	INV
SPNG	Sponge	INV	INV
OCTO	Octocoral	INV	INV
BRYO	Bryozoan	INV	INV
ANEM	Anenome	INV	INV
OSIN	Other sessile inverts	INV	INV
REDC	Dead coral	DEAD C	SUB
SAND	Sand	SAND	SAND
RUBL	Rubble	SUB	SUB
BARR	Bare Rock	SUB	SUB
BHOL	Black Hole	NA	UNIDENT
BLGR	Blue green, Cyano bacteria	BL GRN	BL GRN
TURF	Turf Algae	TURF	TURF
TAPE	Tape	TWS	UNIDENT
WAND	Wand	TWS	UNIDENT
Shadow	Shadow	TWS	UNIDENT
NOTES	NOTES	NOTES	NOTES
OD	Other disease	DISEASE	DISEASE
TREM	Trematodiasis	DISEASE	DISEASE
PBD	Pink Band Disease	DISEASE	DISEASE
BLTP	Part bleaching on tips	BLEACH	BLEACH
BL	Full bleaching	BLEACH	BLEACH

APPENDIX III: Kaloko-Honokōhau NHP Harbor Preliminary Algal Species List.

Algae inventory conducted by Cheryl Squair, University of Hawai'i, Mānoa, in July, 2006. Qualitative and quantitative surveys examined macroalgal species at 10- and 20-m depths.

Functional forms

Filamentous turf
Wiry Turf
Crustose Coralline Algae (Geniculate)
Crustose Coralline Algae (Non-geniculate)
Cyanophyta
Brown crusts

Kaloko-Honokōhau NHP Algal Species List – Preliminary

Chlorophyta

Boodlea sp.
Bryopsis sp.
Caulerpa sp.
Chaetomorpha antennina
Cladophora sp.
Cladophoropsis sp.
Codium edule
Dictyosphaeria cavernosa
Dictyosphaeria versluysii
Enteromorpha sp.
Halimeda discoidea
Halimeda opuntia
Microdictyon sp.
Neomeris sp.
Ulva fasciata
Valonia sp.

Rhodophyta

Acanthophora spicifera
Amansia sp.
Ahnfeltiopsis sp.
Asparagopsis taxiformis
Dasya sp.
Gelids
Gibsmithia sp.
Grateloupia sp.
Halymenia sp.
Jania sp.
Laurencia sp.
Martensia fragilis

Peyssonnelia sp.
Predaea sp.

Phaeophyta
Asteronema breviarticulatum
Chnoospora sp.
Colpomenia sinuosa
Dictyota acutiloba
Dictyota sp.
Lobophora variegata
Padina sp.
Sargassum echinocarpum
Sargassum obtusifolium
Sargassum polyphyllum
Sphacelaria sp.
Stypopodium flabelliforme
Turbinaria ornata

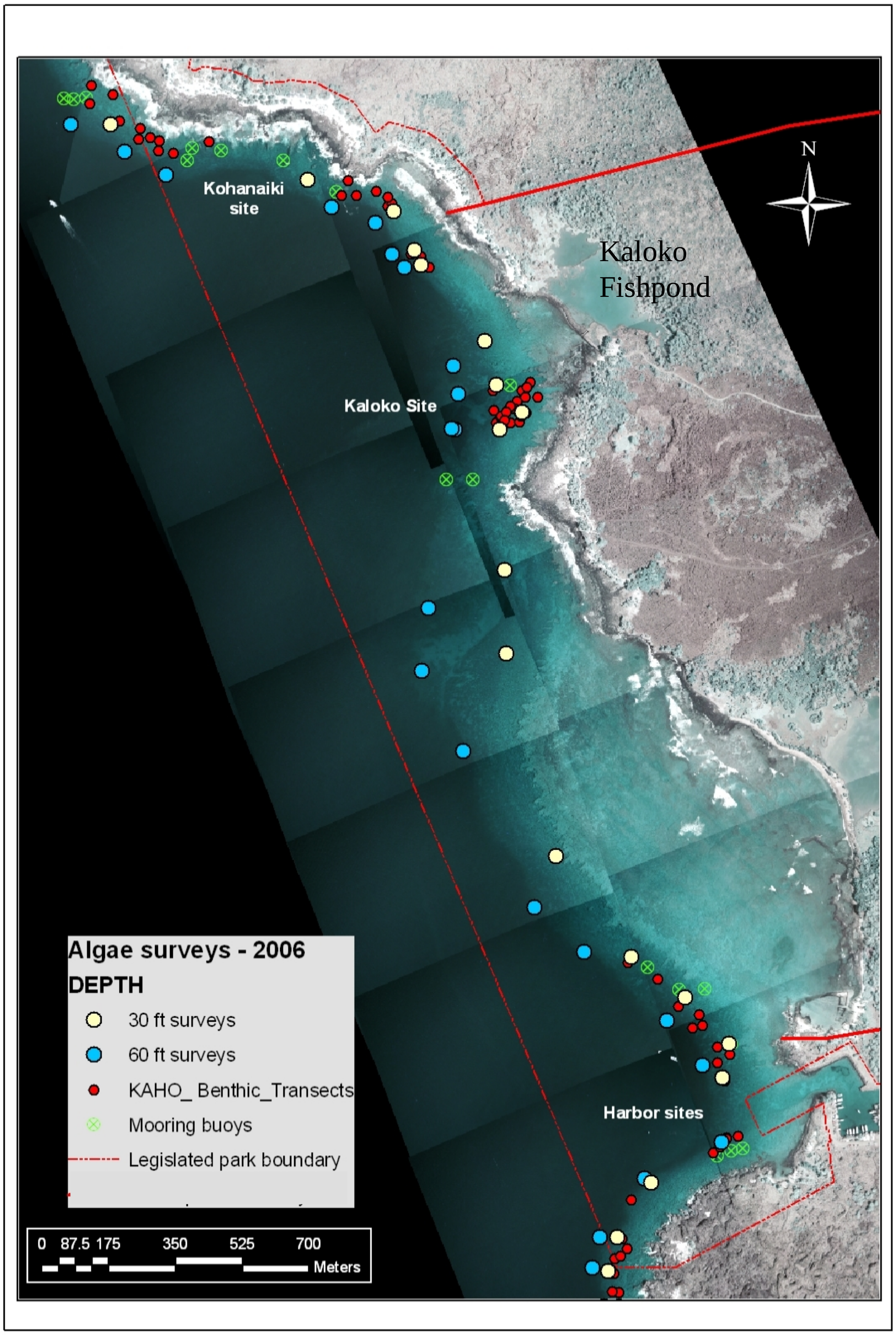

Figure A4. Macro algae survey sampling locations in relation to Kohanaiki, Kaloko, and Harbor photo transects. Note that the invasive algae *Acanthophora specifera* has been abundant in Kaloko Fishpond throughout the study.

APPENDIX IV: Puʻuhonua o Hōnaunau NHP Preliminary Algal Species List.

Inventory of algal species close to Puʻuhonua o Hōnaunau (PUHO) transects conducted by Cheryl Squair, University of Hawaiʻi, Mānoa, in July of 2006. Qualitative and quantitative surveys examined macroalgal species at 10- and 20-m depths.

Functional Groups
Filamentous turf
Wiry Turf
Crustose Coralline Algae (Geniculate)
Crustose Coralline Algae (Non-geniculate)
Brown crusts
Blue-green algae (Cyanophyta)

Chlorophyta
Caulerpa sp.
Caulerpa racemosa
Caulerpa serrulata
Halimeda opuntia
Neomeris sp.
Rhipidosiphon javensis
Ventricaria ventricosa

Rhodophyta
Amansia sp.
Asparagopsis taxiformis
Galaxaura marginata
Galaxaura sp.
Gelids
Gibsmithia sp.
Liagora sp.
Laurencia sp.
Peyssonnelia sp.
Portieria hornmannii
Predaea sp.

Phaeophyta
Dictyopteris sp.
Dictyota sp.
Lobophora variegata
Padina sp.
Stypopodium flabelliforme
Turbinaria ornata

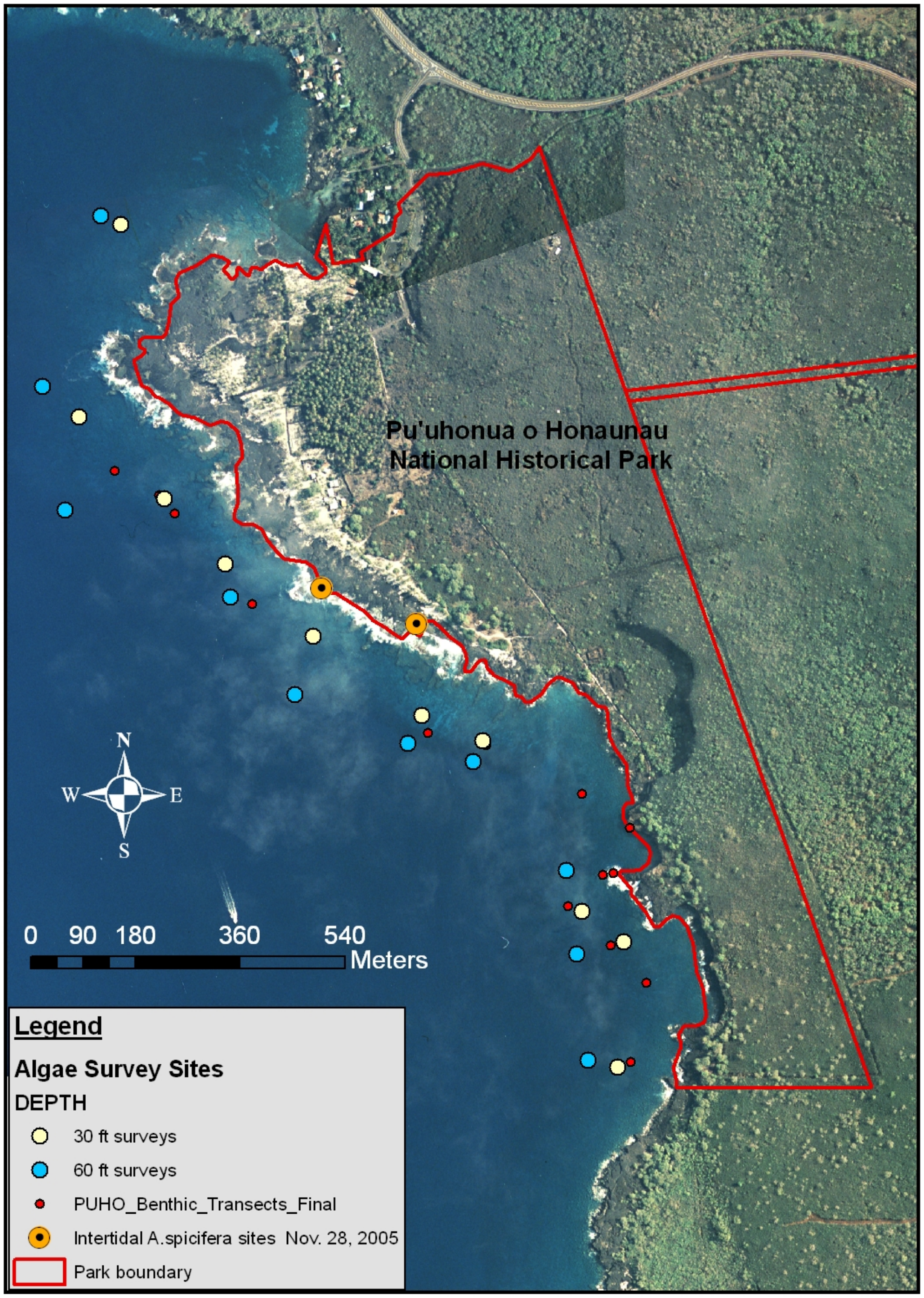

Figure A5. Macro algae survey sampling locations in relation to PUHO photo transects. Note the observation of invasive algae *Acanthophora spicifera* in two intertidal locations.

APPENDIX V: Location of all permanent benthic transects at Kaloko-Honokōhau National Historical Park. Harbor North, Aggregate Reef, and Harbor North Sites were surveyed in 2006 and 2007. Results are in Weijerman et al. 2014.