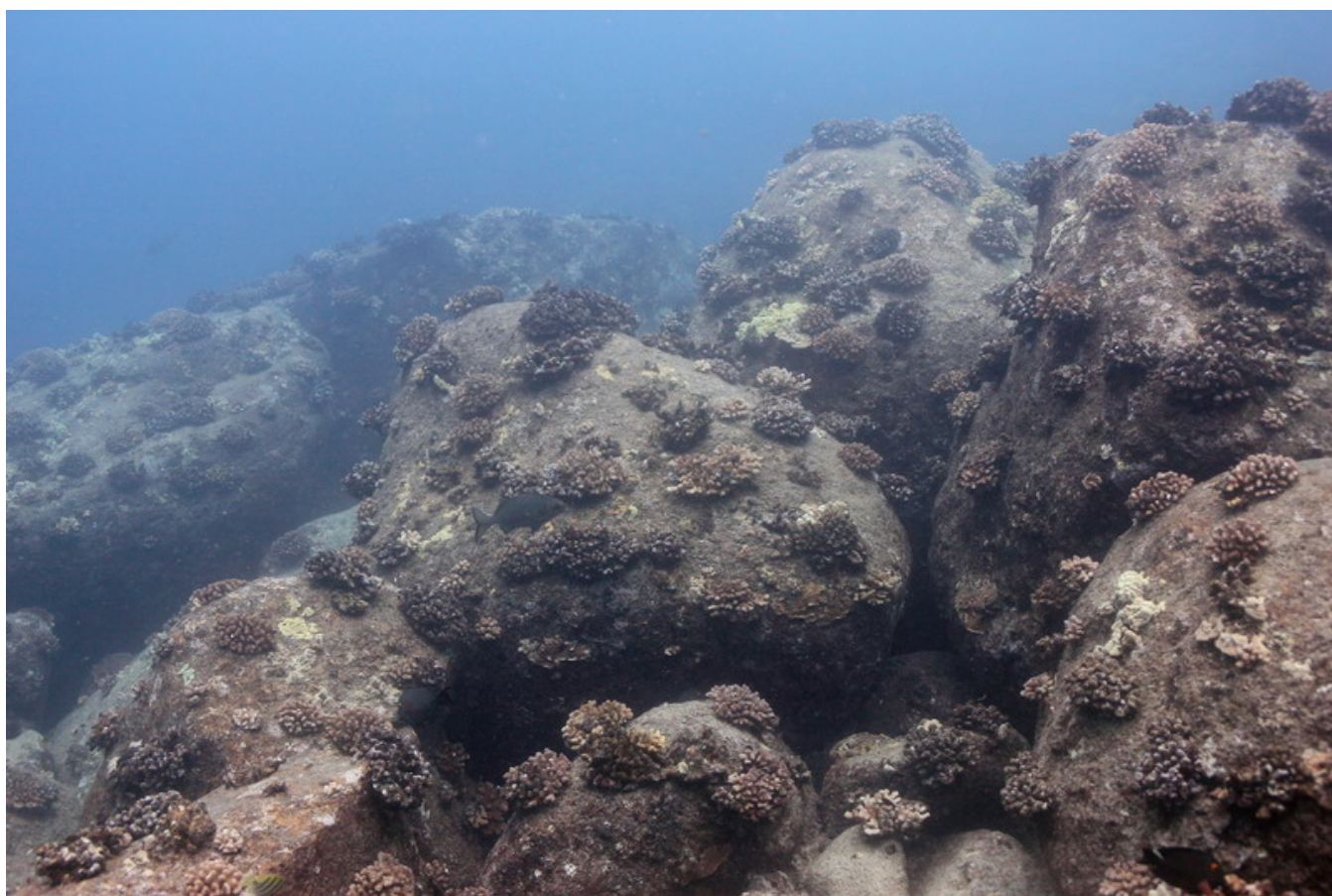




Kalaupapa National Historical Park Benthic Marine Community Monitoring Trend Report for 2006-2010

Pacific Island Network

Natural Resource Technical Report NPS/KALA/NRTR—2014/913



ON THE COVER

A typical benthic community at Kalaupapa National Historical Park, Moloka'i, Hawai'i. Organisms on the basalt boulders include the corals *Pocillopora meandrina* and *Porites lobata*, coralline algae, and the ubiquitous turf algae that occupies most of the available space. Photograph by: Courtesy of Kalaupapa National Historical Park, Moloka'i, Hawai'i.

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Eric Brown, Sylvester Lee, and Kimberly Tice

National Park Service
Kalaupapa National Historical Park
P.O. Box 2222
Kalaupapa, Moloka'i, Hawai'i 96742

Sheila A. McKenna

National Park Service
Inventory and Monitoring Program, Pacific Island Network
Hawai'i Volcanoes National Park
P.O. Box 52
Hawai'i National Park, Hawai'i 96718-0052

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All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data. In addition, data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

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Executive Summary

Kalaupapa National Historical Park (KALA) is located on the north shore of the island of Moloka'i and encompasses a wide variety of habitats from submerged marine resources to lowland coastal, mesic, and rainforest habitats as well as three offshore islands. The marine boundary of the park extends a quarter mile offshore around the park shoreline and encompasses approximately 2,000 acres. KALA is one of four parks within the Inventory and Monitoring (I&M) Program of the Pacific Islands Network (PACN) where marine Vital Signs (i.e. an indicator of physical, chemical, biological elements or ecosystem processes selected to represent the overall health or condition of natural resources within parks) for the fish and benthic communities are monitored by peer-reviewed standardized protocols.

The I&M PACN Benthic Marine Monitoring Protocol at KALA consists of five separate components that are obtained using underwater SCUBA surveys: 1) percent cover of substrate types, 2) presence/absence of disease/bleaching, 3) rugosity (dimensionless index of substrate complexity), 4) coral settlement rate, and 5) coral growth [optional] (Brown et al. 2011). From 2006-2010, a total of 150 transects (the sampling unit), each 25 m in length, were sampled. A split panel sampling design was used with 30 transects sampled annually. Fifteen transects were randomly established at the onset in 2006 as fixed or permanent transects and subsequently surveyed on an annual basis. The remaining 15 temporary transects were randomly selected each year and surveyed only in that year. Three methods were used to collect data at each transect: photoquadrats, rugosity chains, and coral settlement arrays. The optional coral growth component of the protocol was not conducted at KALA given the lack of park resources to undertake this activity.

This report examines the status and trends of the benthic marine community at all 150 transects at KALA from 2006-2010 as determined by implementation of the I&M PACN Benthic Marine Community Monitoring Protocol (Brown et al. 2011).

Spatial patterns for the benthic data indicated that:

1. Percent cover
 - Coral cover ranged from 1-26%. Transects with the highest coral cover were located near the northern tip of the peninsula, while the lowest coral cover values were concentrated near the eastern and western boundaries of the park.
 - Macroalgae percent cover ranged from 1-76%. No clear pattern was observed in the spatial distribution of macroalgae cover with high and low values documented throughout the park. Macroalgae cover was slightly higher near the eastern and western boundaries of the park below the cliffs.
 - Coralline algae percent cover ranged from 1-22%. Transects with the highest coralline algae cover were near the northeastern tip of the peninsula with consistently low cover throughout the rest of the park.
2. Coral disease

- The percentage of photoquadrats per transect showing evidence of coral disease or bleaching ranged from 0-15%. Transects with the highest incidence of disease/bleaching were located around the northern end of the peninsula and at one site on the western boundary of the park.

3) Rugosity

- Rugosity ranged from 1.12 to 2.20 and was generally higher near the northern tip and along the northeastern edge of the peninsula. Less vertical relief was found along the eastern and western sides of the peninsula below the cliff faces. Low variation in measurements indicated a relatively homogeneous substrate similar to the cover photo.

4) Coral settlement

- Coral settlement ranged from 19-474 larvae per square meter over a five month period. *Porites* sp. were the most common larvae identified, followed by *Montipora* sp. and *Pocillopora* sp. Settlement was highest near the northern tip of the peninsula, and lowest near the eastern and western boundaries of the park.

Ten taxa/substrate types covered 94% of the substrate. Turf algae was the most common substrate type, covering 66% of the substrate followed by macroalgae (14% split into five macroalgal taxa), corals (*Pocillopora meandrina*-6%, *Porites lobata*-2%), coralline algae (4%), and sand (<2%). The total number of unique coral species was 22 with an average of 4.2 ± 0.03 SE documented per transect. The entire assemblage was typical of a wave exposed north shore coral reef community in Hawai'i except for the paucity of *Montipora* spp. The top five coral species covered on average, $8.4\% \pm 0.5$ SE of the substrate.

Trends of the key variables or indicators from 2006-2010 showed that:

- Mean coral cover remained relatively stable at 9%.
- Mean macroalgae cover increased from an average of 8% in 2006 to 26% in 2008 and then 22% in 2010. This trend, however, was not significant due to the high variance with values ranging from 1% to 76% across years.
- Mean percent cover of coralline algae was relatively unchanged from 2006 to 2010 and averaged 4% across the five years.
- Mean turf algae percent cover decreased from 76% in 2006 to 60% in 2008 and then increased slightly up to 64% by 2010. This pattern mirrored the changes in macroalgae cover and suggests that the macroalgae blooms were simply growing out from the turf algae during those years.
- Coral species richness remained stable at an average of four species per transect indicating that the coral community composition was relatively stable.

- The percentage of photoquadrats showing signs of disease or bleaching was generally low and ranged from 0.3% in 2007 to a high of 4% in 2010 with an overall average of 1.3%. The increase in coral disease/bleaching was statistically significant across years.
- Rugosity index values were significantly different from 2006 to 2010 with a slight positive trend. Absolute change in the index (1.59 in 2006 to 1.64 in 2009), however, was low suggesting no ecologically relevant change in relief.
- Coral settlement rates were not statistically different among years due to the high variability within each year. The highest settlement rate was documented in 2008 at 214 larvae/m²/5 months and the lowest was in 2006 at 76 larvae/m²/5 months with an overall average of 103 larvae/m²/5 months. *Porites* sp. larvae were consistently the most abundant on the settlement tiles except for 2008 when *Montipora* sp. larvae were most abundant.

Possible explanations for each of the observed patterns are presented in the discussion. At present, the benthic community at Kalaupapa appears stable and is typical of other north shore assemblages in community composition (Jokiel et al. 2004).

Acknowledgments

We would like to thank Randall Watanuki, other KALA staff, and all the volunteers at Kalaupapa National Historical Park for their continuing logistical support in implementing the I&M PACN Benthic Marine Monitoring Protocol to collect data for this report. We could not have done the work without this support.

List of Terms and Acronyms

KALA: Kalaupapa National Historical Park

PACN: Pacific Island Network

I&M: Inventory and Monitoring Program

Introduction

The benthic marine community in the Pacific Island Network (PACN) is an ecologically complex system with a diverse taxonomy, including algae, corals and other invertebrates. In most tropical marine parks, coral reefs form the geomorphologic framework of the ecosystem. These ecosystems have been compared to tropical rainforests because of their high species diversity and complex interactions (Connell 1978, Birkeland 1997). Corals are sensitive to various sources of environmental threats and cumulative degradation, making them a good indicator of tropical nearshore marine ecosystem health (Jameson et al. 1998). Many stressors on the marine environment have a terrestrial origin, and most are associated with human activity (Bruckner et al. 2005). Primary stressors or impacts to coral reefs include disease, sedimentation, eutrophication, contaminants, storms and smaller-scale physical disturbances, alien species, biotic outbreaks of voracious coral predators (e.g., Crown-of-Thorns seastars, *Acanthaster planci*), coastal development, and global climate change.

Coral reef ecosystems provide many goods and services ecologically, culturally and economically. They help protect shorelines from storm damage and wave erosion, thereby sheltering coastal human communities and coastal zone infrastructure (Moberg and Folke 1999, Cesar and Chong 2004). Coral reefs are also essential to the traditional lifestyles and cultures of Hawaiian, Samoan, Chamorro, Carolinean and other peoples in the islands throughout the PACN. Furthermore, coral reefs provide critical elements of commerce from local and charter-sport fishing, as well as other visitor recreational activities (e.g., snorkeling, scuba diving, boating), which are major economic drivers throughout the Pacific Islands (Cesar et al. 2002, Waddell 2005). Because of the ecological, cultural and economic importance of coral reef ecosystems, it is critical that the PACN parks continue to collect scientifically rigorous data on the current health and long-term trends of these crucial habitats.

The PACN Inventory and Monitoring (I&M) program is one of 32 National Park Service (NPS) I&M Networks across the country facilitating collaboration, information sharing, and economies of scale in natural resources monitoring. The NPS I&M program was funded by Congress in 2001 to implement peer-reviewed standardized protocols to collect data on numerous Vital Signs for natural resources. A Vital Sign is an indicator of physical, chemical, biological elements or ecosystem processes selected to represent the overall health or condition of natural resources within parks. The PACN benthic marine community Vital Sign is most closely linked with the marine fish Vital Sign, and monitoring efforts are co-located and sampled at the same time to maximize data value. A copy of the benthic marine protocol can be found on the National Park Service website, <http://science.nature.nps.gov/im/units/pacn/monitor/benthic.cfm>. This Vital Sign monitoring protocol is implemented in four parks: Kaloko Honokohau National Historical Park (KAHO), Kalaupapa National Historical Park (KALA), National Park of American Samoa (NPSA), and War in the Pacific National Historical Park (WAPA).

Kalaupapa National Historical Park is located in Hawai'i on the north shore of the island of Moloka'i, and encompasses not only submerged marine resources, but also lowland coastal, mesic, and rainforest habitats (Figure 1). This park is one of the few in the NPS system that includes entire watersheds and their adjacent nearshore marine habitats within its boundaries. The park preserves and interprets the history and story of the Kalaupapa settlement and Hansen's disease patients, but public visitation is restricted by state permit to 100 people per day.

Encompassing approximately 2,000 ac, the marine boundary of the park extends from the shoreline to a quarter mile offshore, where waters are about 33 m deep. Significant marine resources include threatened (green sea turtle [*Chelonia mydas*]) and endangered (monk seal [*Monachus schauinslandi*], humpback whale [*Megaptera novaeangliae*]) species, high wave energy coral reef communities, and relatively intact marine intertidal and fish resources. The hard bottom substrate consists of basalt pavement and boulders colonized by coral communities with <25% coral cover (Fung Associates, Inc. and SWCA Environment Consultants 2010). Sandy bottoms extend out from the rivers draining the three principal watersheds within the park. Several offshore islands within the park boundaries also contain relatively intact marine assemblages typical of vertical, exposed coastlines (Coles et al. 2008). The primary physical disturbance to the marine community consists of large (8 to 10 m) northwest Pacific swells in the winter months (October – April) (Fung Associates, Inc. and SWCA Environment Consultants 2010).

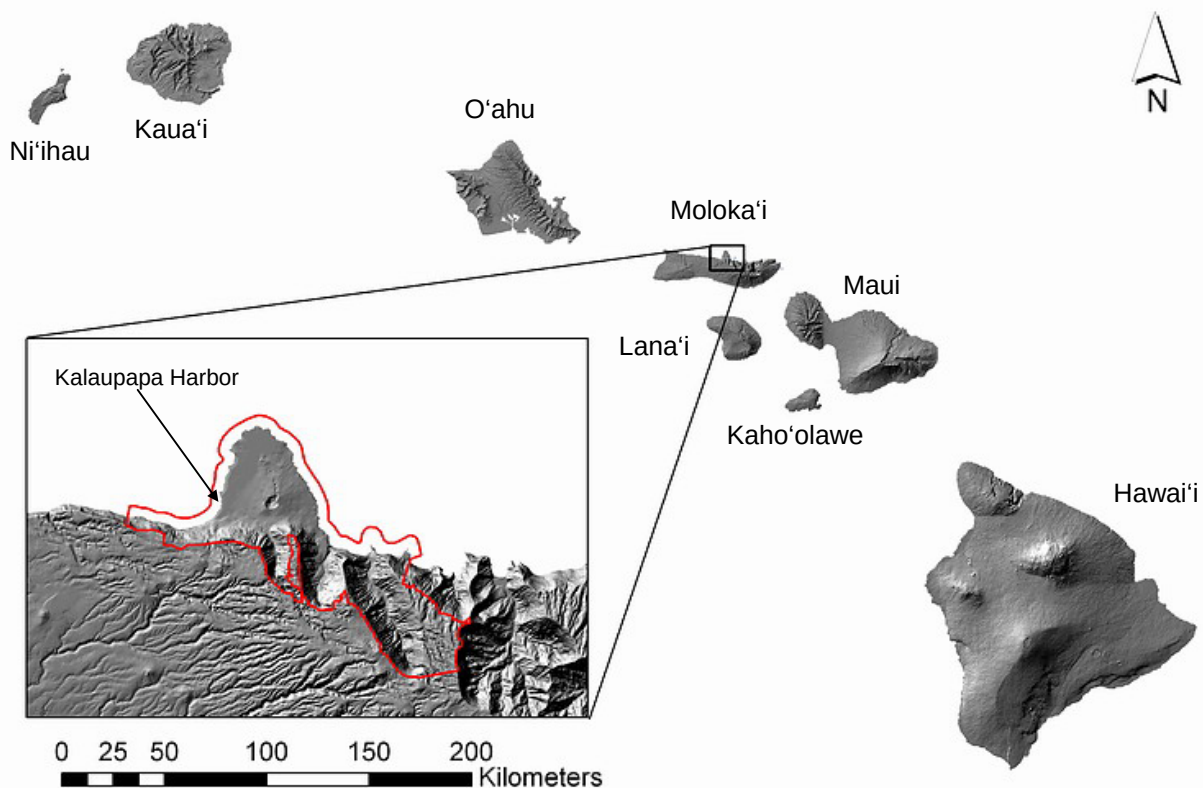


Figure 1. Map of the main Hawaiian Islands showing Kalaupapa National Historical Park with the park boundary delineated as a red line in the inset.

To collect scientifically rigorous data on the status and long-term trends of the coral reefs at KALA, a monitoring program was initiated in 2006 that consisted of four components: 1) substrate percent cover surveys, 2) presence/absence of disease/bleaching, 3) rugosity (dimensionless index of substrate complexity), and 4) coral settlement. Note that the optional coral growth component of the benthic protocol was not conducted at KALA due to the lack of park resources to undertake this activity. These four components addressed the two monitoring questions and corresponding objectives in the PACN benthic marine community protocol. The

questions are 1) what are the changes over time in the composition (e.g., species or assemblage) and physical structure (rugosity) of the coral reef benthos? And, 2) what are the changes over time in settlement and health of target coral assemblages, species, or individuals? First, long-term changes in the percent cover of benthic groups may be indicative of variation in certain environmental stressors or drivers. For example, an increase in algal cover has often been associated with eutrophication (increased nutrient levels) or a reduction in the number of herbivorous invertebrates or fishes (Hughes 1993).

Second, monitoring the incidence and location of coral disease and/or bleaching is important to managers and may facilitate research activities that examine causal mechanisms. In addition, physical conditions (e.g., temperature) that are often correlated with disease or bleaching are monitored through other Vital Signs to help explain trends in this variable.

Third, rugosity is a measure of structural complexity of the benthos. Rugosity comes from the latin word “rugosus” which means rough and wrinkled. Changes in rugosity may indicate large scale changes in benthic community structure, composition, function, and condition as well as influence the overlying communities (Connell et al. 1997). Rugosity will vary widely over space, and while rugosity may not vary much temporally, it will be sensitive to large disturbance events (e.g., typhoons). Research has established a strong correlative link between rugosity and abundance of fishes (Friedlander and Parrish 1998) and mobile invertebrates (Aronson et al. 1994, Rogers et al. 1994, Minton 2000).

Fourth, coral reef populations must successfully reproduce and recruit to persist. Many corals are long lived, and the presence of adult individuals that are less sensitive to stressors than earlier life history stages (Basch and Keesing 1996, Basch and Pearse 1996, Richmond 1997, Minton et al. 2007) can mask serious incipient problems of population demography and community persistence and resilience (Richmond 1997). While not immediately evident (i.e., adult population appears healthy), the failure of juveniles to recruit can result in relatively rapid degradation of the coral reef ecosystem as adults senesce or experience mortality from natural or anthropogenic disturbances (Basch et al. 2007). It should be noted that this protocol is focusing on settlement rate rather than actual recruitment. Settlement rate provides an integrated measure of larval supply, suitable substrate, and water quality. Measuring recruitment would require tracking survival of the juveniles and the subsequent contribution to the adult community.

The purpose of this report is to document the status of the benthic marine community at KALA and examine changes or trends from 2006 to 2010. First, the spatial patterns integrated over time were analyzed for percent cover of coral, macroalgae, and coralline algae, as well as for the frequency of coral disease/bleaching and the rate of coral settlement. Second, the top ten taxa were observed each year and were noted. Finally, trends in the entire assemblage from 2006-2010 were plotted for percent cover of coral, macroalgae and coralline algae, as well as the frequency of coral disease/bleaching, and the rate of coral settlement.

Methods

Sampling Locations

A split panel design was used with 30 transects (25 m long) sampled annually between 2006 and 2010 (Brown et al. 2011). All transects were randomly selected using ArcGIS® within the KALA sampling frame, irrespective of any ecological gradients (Figure 2). The frame includes all fore-reef slope, hard bottom communities between 10 and 20 m depths within the park's legislated boundaries plus adjacent coastal areas that may impact (or be impacted by) the park. Fifteen fixed (permanent) transects were randomly selected at the onset of the monitoring program in 2006 and marked with stainless steel pins for relocation purposes. These sites were subsequently sampled each year. The remaining 15 temporary transects were randomly selected each year of monitoring and sampled only once without replacement. Transects were located in the field using a GPS unit.

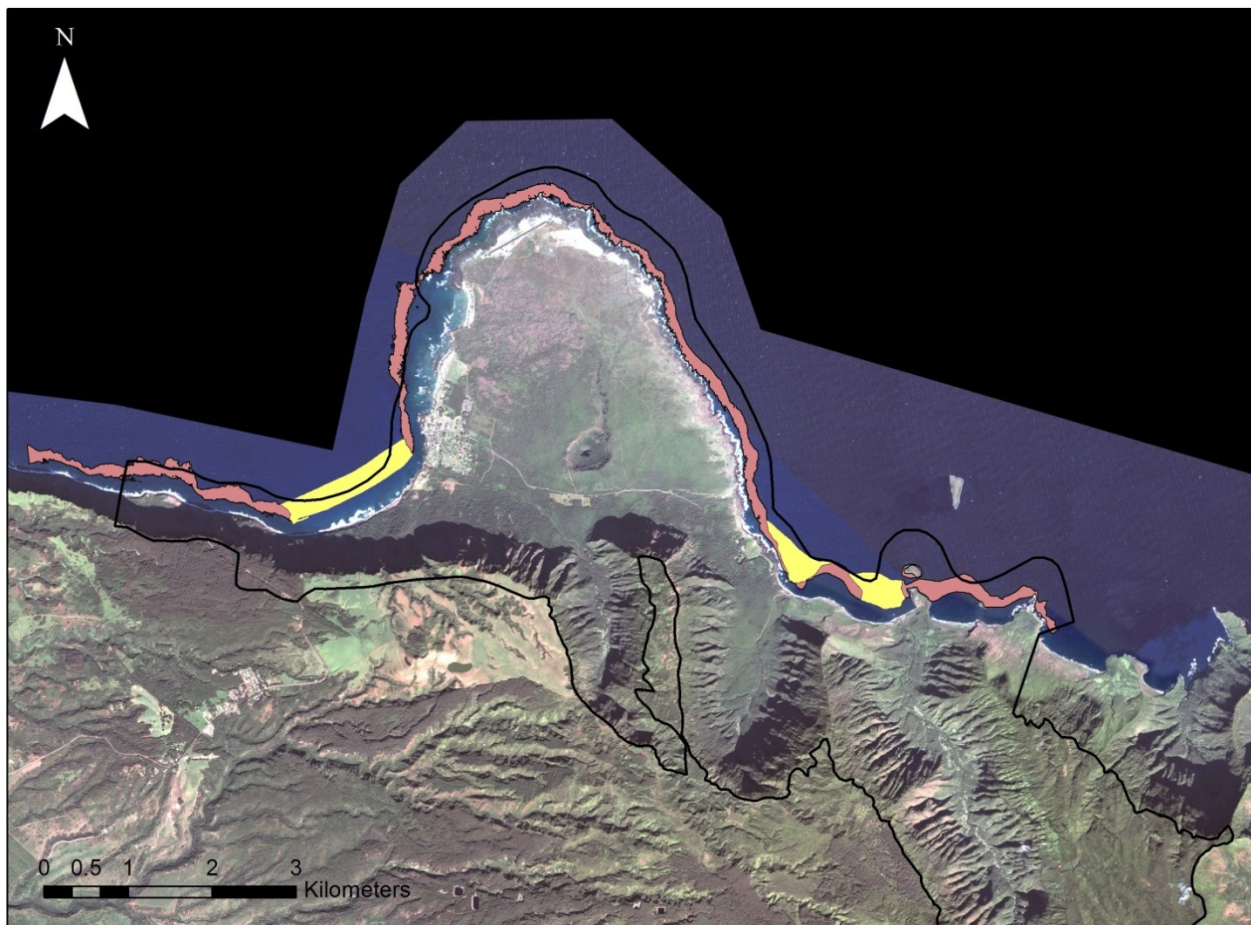


Figure 2. Sampling frame between 10 m and 20 m depth on hard bottom substrate (light red polygon) at Kalaupapa National Historical Park. Sand habitat is shown by yellow polygons. Black line indicates park boundary including $\frac{1}{4}$ mile into the marine environment.

Survey Methods

Percent cover, presence/absence of disease, and rugosity surveys occurred during the summer months from July through August. Coral settlement tiles were deployed in April and retrieved in

September of each year to span the time period of peak coral spawning activity (Kolinski and Cox 2003).

The location, bearing, survey date, and depth of transects, which constitute the sampling unit, were recorded after each dive. Three standard methods were used to collect data in each sampling unit: photoquadrats (Jaap et al. 2000), rugosity chain (McCormick 1994), and coral settlement arrays (Mundy 2000, Basch et al. 2007). Using SCUBA, one 25 m transect line consisting of a fiberglass tape was positioned parallel to the reef crest along a constant depth contour. Starting at 0 m, photographs were taken at 1 m intervals along each transect from a perpendicular angle at a height of 0.5 m above the substrate. These 26 photoquadrats (approximate dimensions 0.50 m X 0.36 m) were treated as subsamples within the transect sampling unit. As a result, the photoquadrats were not fixed plots and were variable in space from one year to the next. Total area sampled on each transect was approximately 4.5 m² for a total area of ~135 m² across all 30 transects each year. Actual area sampled varied according to surface topography/rugosity.

Rugosity was measured using the chain and tape method (McCormick 1994). A light brass chain, marked off in 1 m intervals, was draped over the bottom and contoured along the entire length of each 25 m transect. The amount of chain necessary to span the distance (contour distance = cd) between the two marker pins was divided by the straight line tape measurement (linear horizontal distance = ld) to generate an index of spatial relief or rugosity of $r = cd/ld$. Smaller index values (i.e. close to 1.0) indicated a relatively flat substrate in comparison to values >2.0 which were highly rugose. Rugosity was not measured on fixed transects in 2010 in an effort by the I&M program to decrease dive times, and therefore, increase the safety margin in the protocol. In addition, a preliminary trend analysis on just the fixed transects from 2006 to 2009 indicated no significant difference among years (Wilks $F_{3, 12} = 2.7$, $p = 0.09$). Consequently, the protocol was revised to increase the rugosity sampling interval on fixed transects to once every 3-5 years. If a significant event does occur (e.g. hurricane, earthquake, or decadal wave swell) in the interim, then rugosity measurements on fixed transects would be resumed the following year along with the temporary transects.

The larval supply of corals within the park was examined by providing artificial substrates for larval settlement and then documenting abundance and distribution patterns using a dissecting scope (English et al. 1997). Terracotta tiles were selected as the artificial substrate because of their convenience, similarity to other preferred surfaces, e.g., ceramic (Harriott and Fisk 1987), and their prominence in settlement studies (e.g., Hughes et al. 2000, Mundy 2000, Kojis and Quinn 2001, Basch et al. 2007), thereby facilitating comparisons of settlement rates at many spatial scales. A pair of terracotta tiles were deployed 2.5 m inshore of the transect at the 0, 12.5 and 25 m marks at all 15 fixed transects several weeks prior to the onset of the peak summer spawning period for the major reef-building coral genera (e.g., *Montipora* spp. and *Porites* spp.). The tiles were collected after approximately five months in September following the cessation of peak spawning.

Image analysis of photoquadrats was conducted using Photogrid[®] software (Bird 2002). Fifty points were randomly selected by the program for each quadrat image, and the object under each point was identified to the lowest possible taxon (species, where possible) for coral, macroalgae, macroinvertebrates, cyanobacteria and other benthic substrate types (e.g. turf algae, crustose

coralline algae, sand). Previous studies in Hawaii have found that at least 50 points per image were needed to adequately characterize the substrate (Brown et al. 2004). The generic macroalgae category was used for algae that could not be identified, appeared fleshy, filamentous, or calcified, often with conspicuous branching or blades, and had a height greater than approximately 2-3 cm. Those algal species less than 2 cm tall, and with no apparent structure, were classified as turf algae. Percent cover of each taxon/substrate type was then calculated by dividing the number of points identified for each taxon/substrate type on a given transect by the total number of points analyzed for that transect. Coral species richness was calculated by summing the total number of unique coral species observed in all photoquadrats on each transect. For simplicity, this approach was the only method used to measure species richness rather than some weighted or proportional technique.

For each photoquadrat, the presence/absence of bleaching or disease-like signs was also recorded, and the percent of photoquadrats per transect that showed evidence of disease/bleaching was then calculated. Disease symptoms included lesions and rings or bands that demarcated live healthy tissue from dead tissue, while bleaching was indicated by a whitening of the coral tissue signifying a loss of the symbiotic zooxanthellae.

After retrieval, coral settlement tiles were placed in a 10% bleach solution for at least 24 hours and then rinsed in fresh water for another 24 hours. The plates were then analyzed under a dissecting microscope at 60X magnification, and newly settled coral larvae were identified to the lowest possible taxonomic level (typically genus). The plate surface, dimensions of each settled larvae (in mm), and deployment dates were also recorded. Coral settlement rates were extrapolated to number of larvae settled per square meter per five month period for each year.

Data Analysis

A general linear mixed model in the R statistical software (ver. 2.15.3, *lmer* in the *lmerTest* package) was used for trend estimation of percent substrate cover data by taxa, coral species richness, coral disease/bleaching, and rugosity (R Core Team 2012). Percent substrate cover data by taxa for coral, macroalgae, coralline algae, and coral disease/bleaching were arcsine-square root transformed to meet the assumptions of normality (Zar 1999). A logit transformation was used for percent turf algae cover since the range of values was >20% and <80% (Starceovich 2013). The raw data for coral species richness and rugosity were used since these data sets met the assumptions of normality and homogeneity of variance. The main substrate types (coral, macroalgae, coralline algae, turf algae), coral species richness, coral disease/bleaching, and rugosity were analyzed separately in the general linear mixed model with substrate cover type, species richness, coral disease/bleaching and rugosity as the dependent variables. The p-values for the t-statistic at $\alpha = 0.05$ were based on a Satterthwaite approximation for denominator degrees of freedom.

For all data sets, a unique identifier for transect number was treated as a random site effect along with year. The inclusion of the random effect for year in the model addressed the temporal autocorrelation among sites surveyed at the same time. The *lmerTest* package defaults to compound symmetric correlation structure, which assigns the same correlation to all sites measured in the same year and this correlation is also the same for all years. It is a general structure, and Pinheiro and Bates (2004) state that it is useful for short time series since there is not enough time to model the decay of an autoregressive model. Compound symmetry

correlation structure, however, may be too simplistic for longer time series; therefore, it will be evaluated in later trend reports. Similarly, the site-level random effect is the same for each site across all years and the same variance component is contributed to the total variance for all measurements for a particular site. In the model a standardized covariate was generated for trend estimation and entered as a fixed factor in the model with the year variable starting at year 0. This variable was more stable than the Year covariate for trend estimation and will be useful in future iterations of the trend reports (Starcevich 2013). The trend analysis also incorporated both fixed and temporary transects to examine temporal patterns for trend estimation with increased spatial distribution for robust status estimation (Starcevich 2013). In future years with a larger data set, it may be informative to conduct additional analyses with just fixed or temporary transects to examine the measurement effects of sampling in the same location compared to new areas. This analysis was not conducted in the present study, however, due to the small data set.

To examine trends in the rate of total coral settlement from 2006 to 2010, a general linear model repeated measures ANOVA in Statistica 10.0 (StatSoft 2011) was used with coral settlement rate (Number m^{-2} 5 months $^{-1}$) as the dependent variable. A mixed model was not necessary since the settlement tiles were only deployed at the fixed transects each year. Prior to analysis, data were $\ln(x+1)$ transformed to meet the assumptions of normality and homogeneity of variances (Zar 1999). A Wilks multivariate test was used to identify significant differences among years to avoid issues with compound symmetry and sphericity. Raw data were plotted for ease of interpretation and broken out by the main taxonomic groups.

For both data sets, temporal autocorrelation was examined post hoc by assessing the homogeneity of random effects groups using paired plots of the site effects for each year. The slopes of the random sites were plotted against random site intercepts by year and included both fixed and temporary transects. The patterns were similar across years for the fixed transects with no obvious relationship, but a linear relationship did exist for the temporary transects. This result for the temporary transects, however, may be due to the lack of replication for a given site so it may be reasonable to assume independence among years and sites (Piepho and Ogutu 2002). Overall, the results indicated that the assumptions were met and that autocorrelation was not a significant issue.

See Starcevich (2013) for a complete description of the analysis and R programming code.

Results

A total of 15 fixed (once each year) and 75 temporary transects (total all years) were surveyed at Kalaupapa National Historical Park from 2006-2010 (Appendix A). The queries used to retrieve the data for the ArcGIS maps, charts, and statistical analyses are listed in Appendix B.

Status of Benthic Marine Community Characteristics

Average coral cover ranged from 0.5-24.0% at both fixed and temporary transects (Figure 3). Transects with the highest coral cover were located near the northern tip of the peninsula, while the lowest coral cover values were concentrated near the eastern and western boundaries of the park below the cliffs.

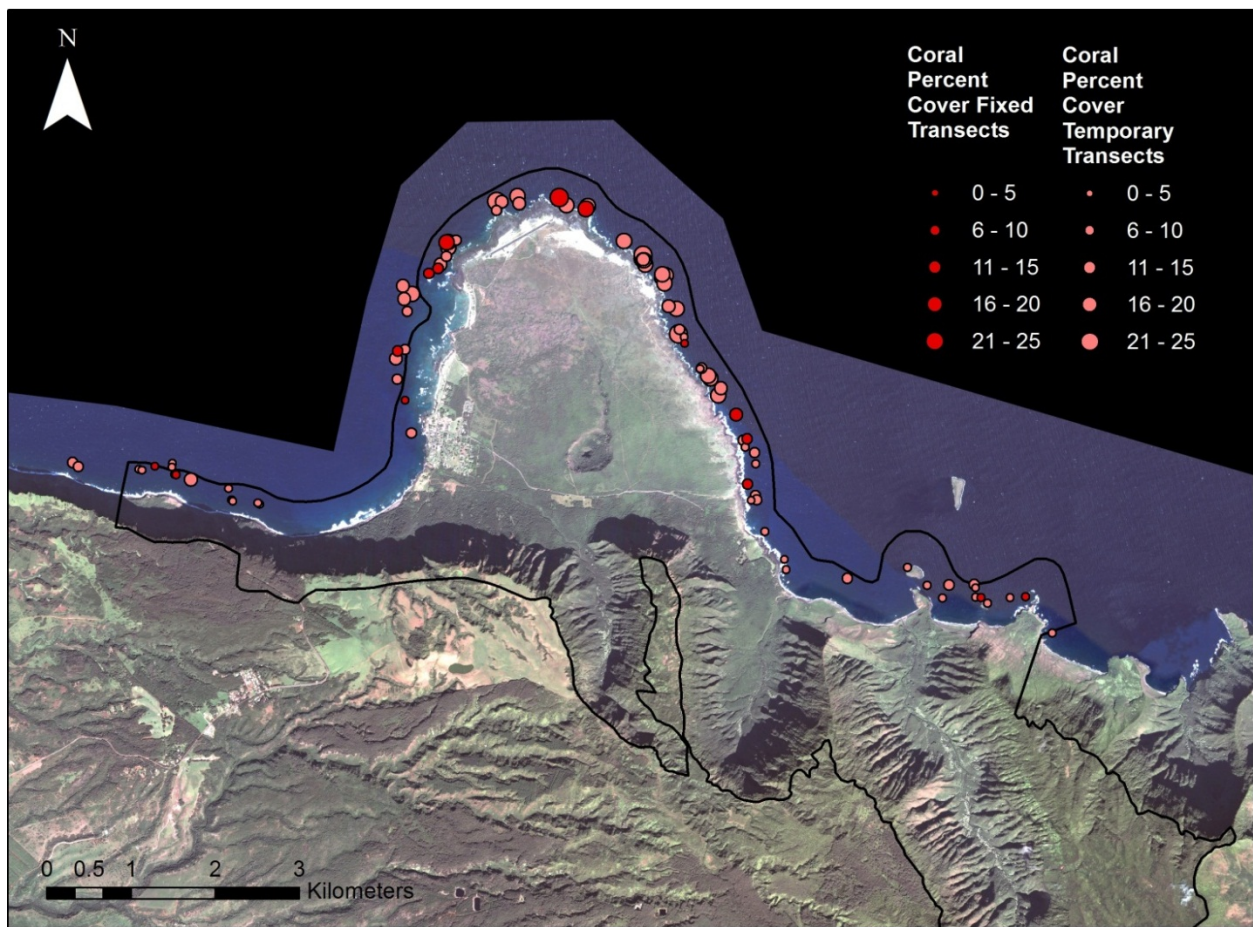


Figure 3. Percent coral cover averaged at the 15 fixed sites and the 75 temporary sites surveyed in Kalaupapa National Historical Park from 2006-2010 (N = 150 total transects [15 fixed sampled for 5 years, 75 temporary]).

Macroalgae percent cover ranged from 1.1 – 75.5% (Figure 4). No clear pattern was observed in the spatial distribution of macroalgae cover with high and low cover values found throughout the park. However, macroalgae cover did appear slightly higher near the eastern and western boundaries of the park below the cliffs.

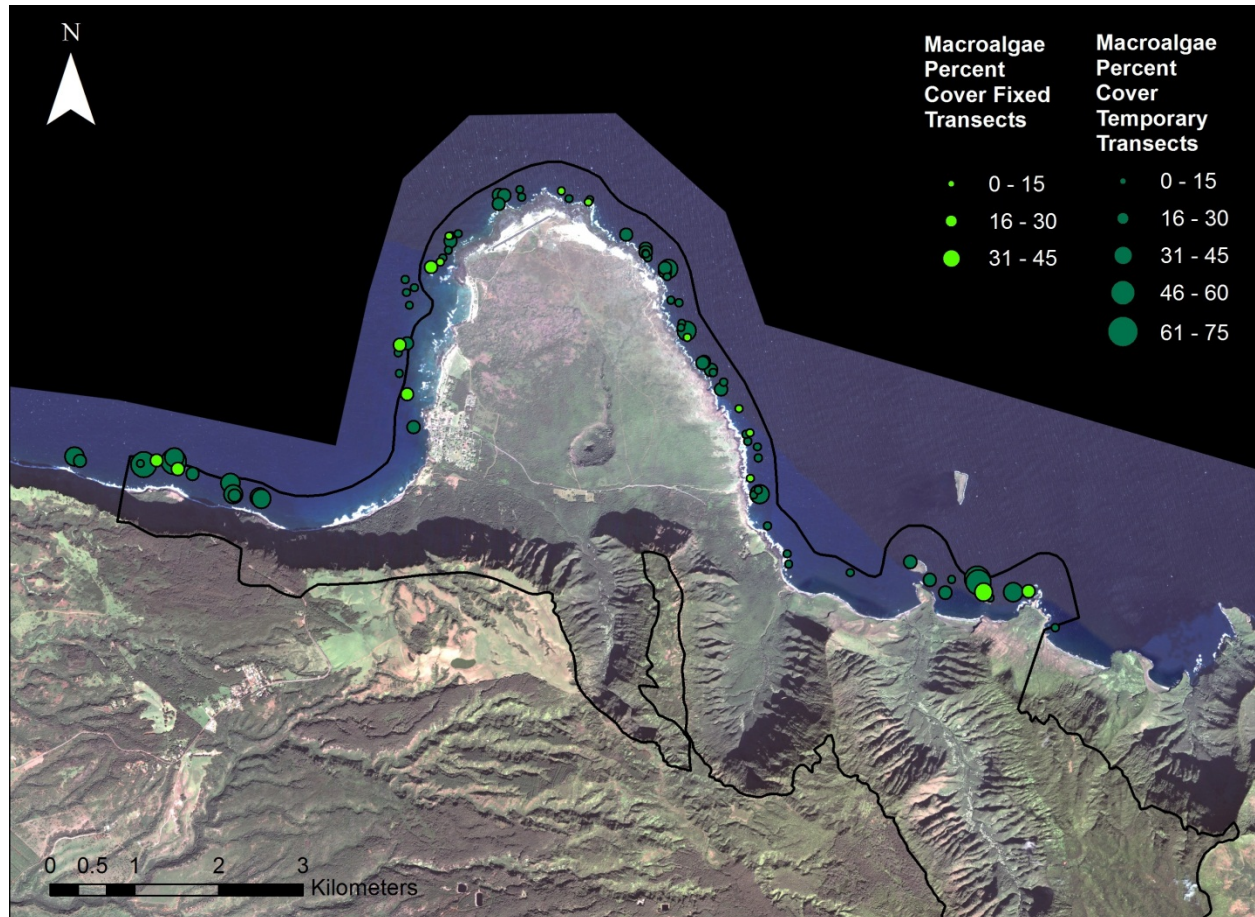


Figure 4. Percent macroalgae cover at the 15 fixed sites and 75 temporary sites surveyed in Kalaupapa National Historical Park from 2006-2010 (N = 150 total transects [15 fixed sampled for 5 years, 75 temporary]).

Coralline algae percent cover ranged from 0.5-21.5% (Figure 5). Transects with the highest coralline algae cover were located near the northeastern tip of the peninsula with consistently low cover throughout the rest of the park.

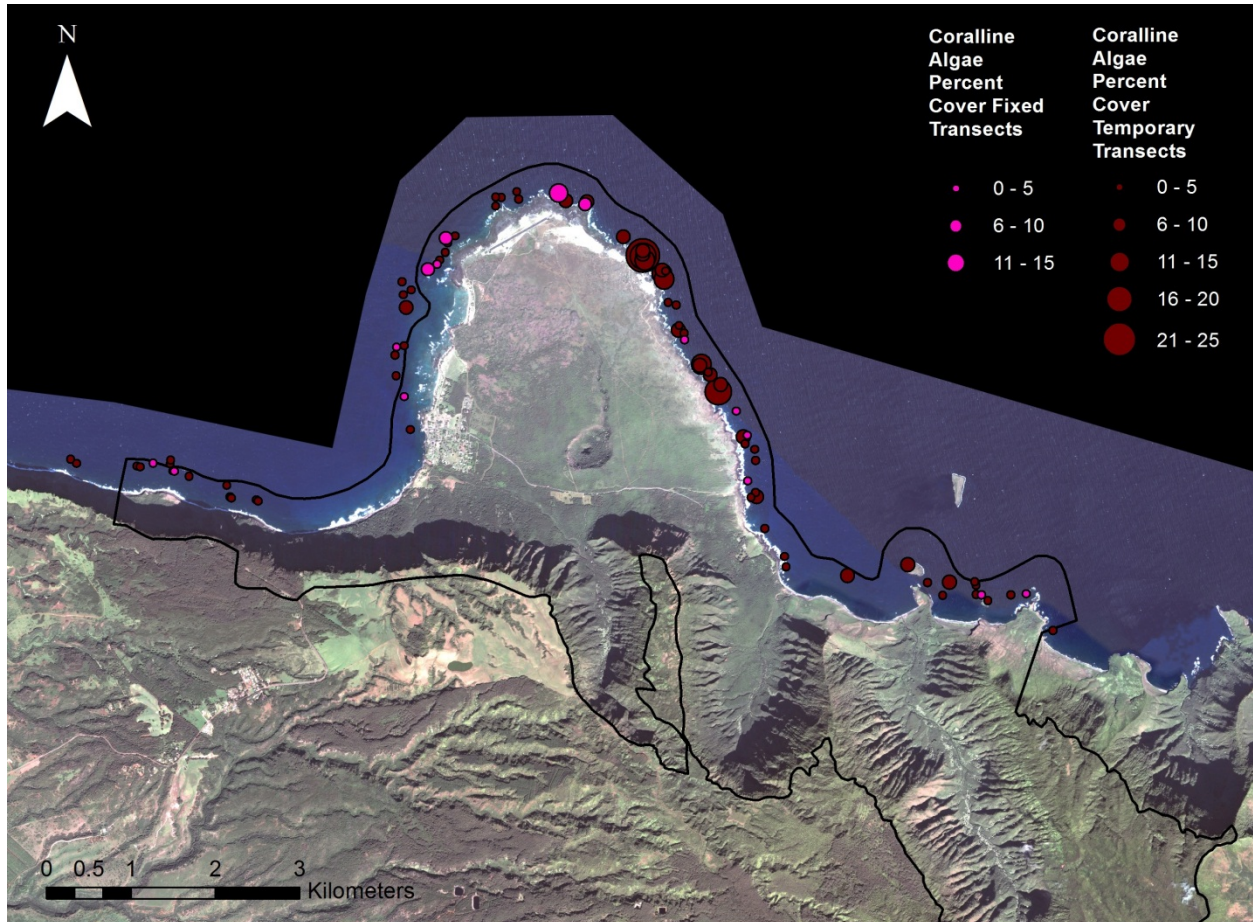


Figure 5. Percent coralline algae cover at 15 fixed sites and 75 temporary sites surveyed in Kalaupapa National Historical Park from 2006-2010 (N = 150 total transects [15 fixed sampled for 5 years, 75 temporary]).

The percentage of photoquadrats per transect showing evidence of coral disease or bleaching ranged from 0-15.4% (Figure 6). Transects with the highest incidence of disease or bleaching were located on the western portion and tip of the peninsula.

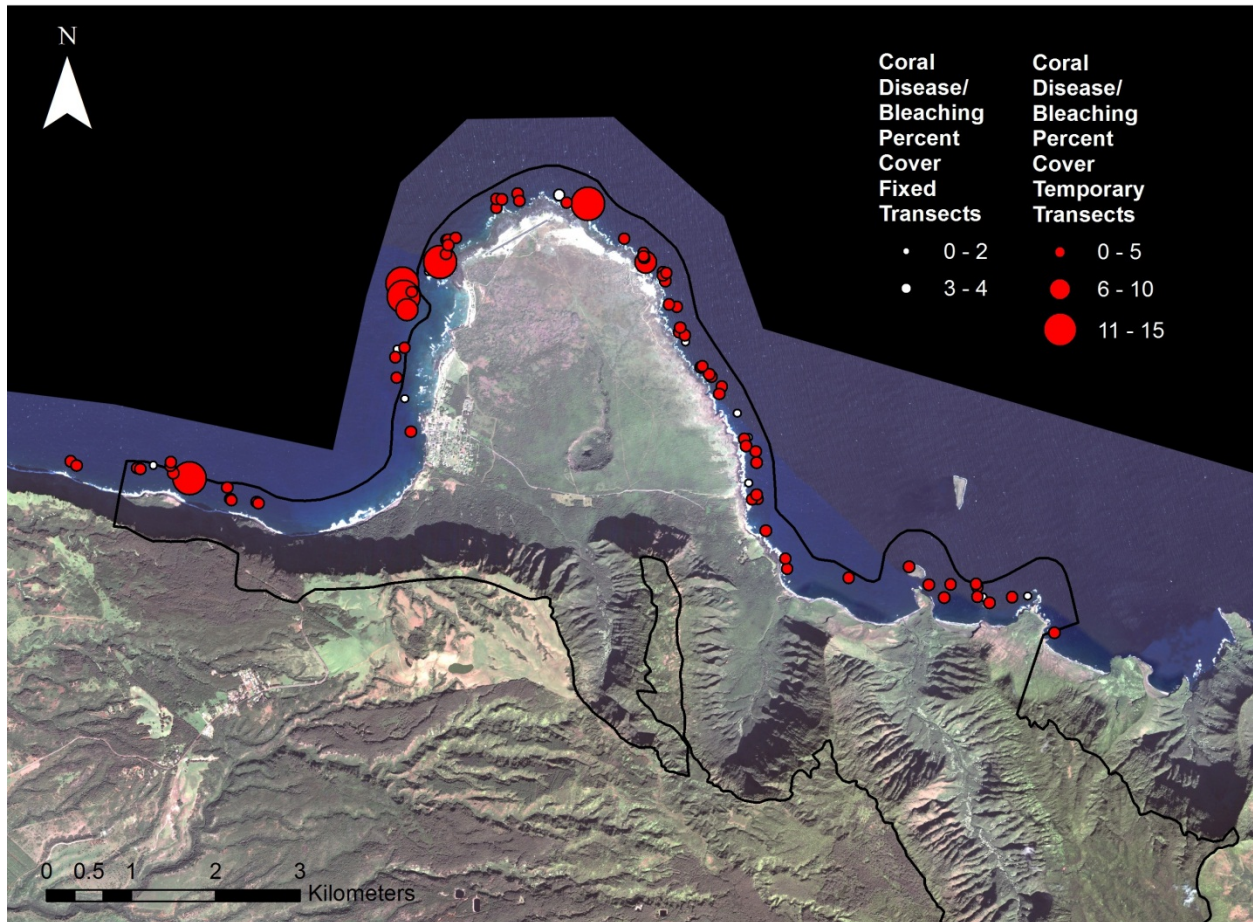


Figure 6. Percentage of photoquadrats at survey sites showing evidence of coral disease or bleaching in Kalaupapa National Historical Park from 2006-2010 (N = 150 total transects [15 fixed sampled for 5 years, 75 temporary]).

The rugosity index values ranged from 1.12 to 2.20 (Figure 7). Generally, the lower rugosity values and hence substrates with less vertical relief, were found at sites along the eastern and western sides of the peninsula along the cliff face. Rugosity was highest near the northern tip and along the northeastern edge of the peninsula.

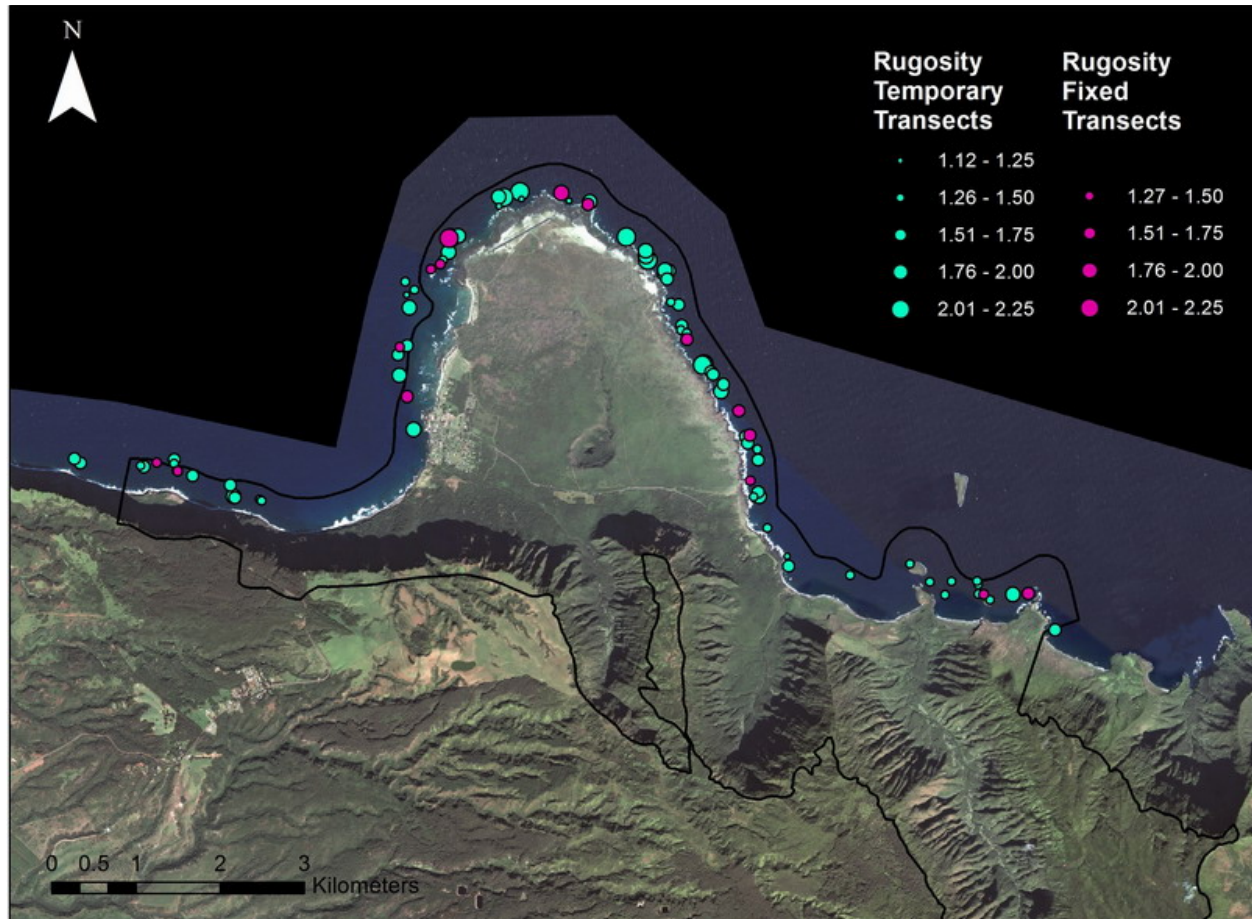


Figure 7. Rugosity index values at 15 fixed sites and 75 temporary sites surveyed in Kalaupapa National Historical Park from 2006-2010 (N = 135 total transects [15 fixed sampled for 4 years, 75 temporary]). Fixed transects were not surveyed in 2010.

Coral settlement ranged from 18.8- 473.6 larvae per square meter over a five month period (Figure 8). *Porites* sp. were the most common larvae identified, followed by *Montipora* sp. and *Pocillopora* sp. Settlement was highest near the northern tip of the peninsula, and lowest near the eastern and western boundaries of the park.

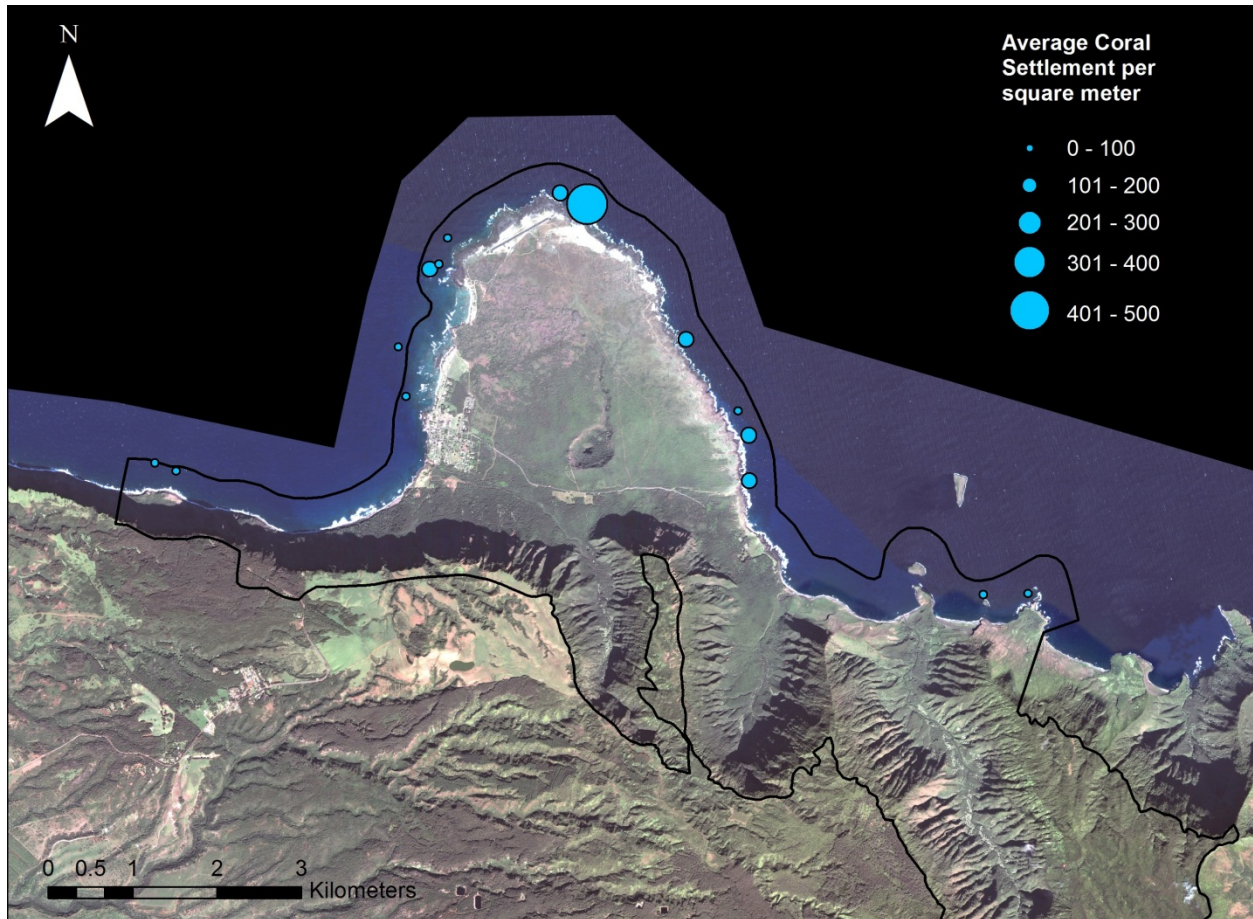


Figure 8. Average number of coral larvae per square meter settling from April to September at 15 fixed survey sites in Kalaupapa National Historical Park from 2006-2010.

Top Ten Taxa

Ten substrate types/taxa covered 93.8% of the substrate observed in photoquadrats at Kalaupapa from 2006-2010 (Figure 9). Turf algae was by far the most common substrate category, covering 66.2% of the substrate sampled. Four macroalgal taxa, *Dictyota* sp., *Sargassum* sp., Rhodophyta, and *Padina* sp. and Cyanobacteria, were found in the top ten substrate types, covering 14.5% of the benthos. The most common coral species in Kalaupapa was *Pocillopora meandrina*, which accounted for 6.0% cover. The coral *Porites lobata* was also in the top ten taxa, and accounted for 2.1% of the total cover. Coralline algae covered 4.2% of the substrate, while sand covered <2%. The total number of identified, unique coral species was 24 with an average of 4.2 ± 0.03 SE documented per transect. The top five coral species covered, on average, $8.4\% \pm 0.5$ SE of the total substrate with *Pocillopora meandrina* accounting for 70.6% of the coral cover, followed by *Porites lobata* (25.3%), *Montipora patula* (2.2%), *M. capitata* (1.0%), and *Porites lutea* (0.8%) (Figure 10). These five coral species accounted for 95.5% of the total coral cover at KALA. It should be noted that all of the top ten taxa were native species and the non-native species only comprised <1% of the total benthic cover.

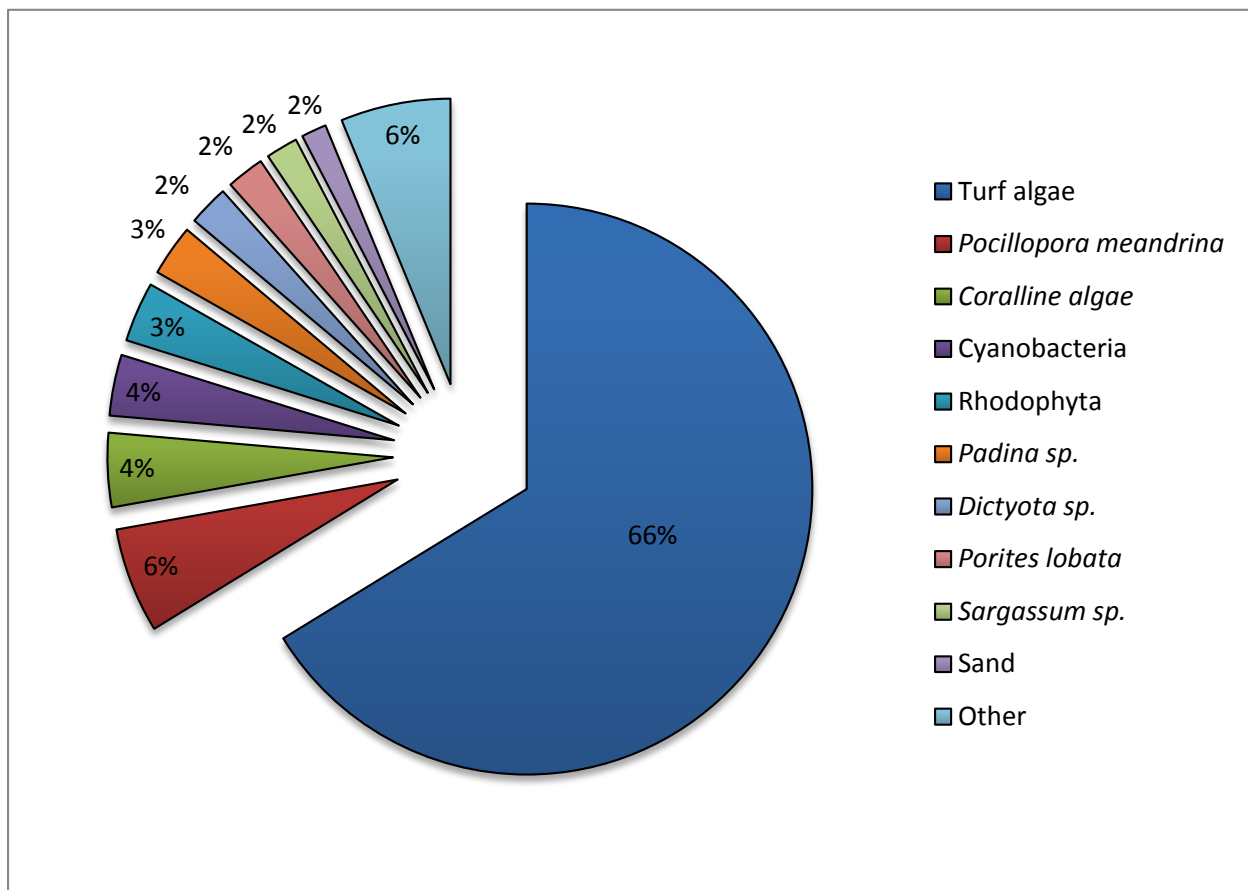


Figure 9. Percent cover for the top ten substrate types/taxa from 2006-2010 transects (N = 150 total transects [15 fixed sampled for 5 years, 75 temporary]).

Table 1. Alphabetical listing of identified coral species found at KALA. Family and common names are included along with the scientific name. All species are native to Hawai'i and common names are from Fenner (2005).

Family	Species	Common Name*
Faviidae	<i>Cyphastrea ocellina</i>	Ocellated
Faviidae	<i>Leptastrea bewickensis</i>	Bewick
Faviidae	<i>Leptastrea pruinosa</i>	Spotted
Faviidae	<i>Leptastrea purpurea</i>	Crust
Agariciidae	<i>Leptoseris incrustans</i>	Swelling
Acroporidae	<i>Montipora capitata</i>	Rice
Acroporidae	<i>Montipora flabellata</i>	Blue Rice
Acroporidae	<i>Montipora incrassata</i>	Branching Rice
Acroporidae	<i>Montipora patula</i>	Sandpaper Rice
Agariciidae	<i>Pavona duerdeni</i>	Porkchop
Agariciidae	<i>Pavona varians</i>	Corrugated
Pocilloporidae	<i>Pocillopora eydouxi</i>	Antler
Pocilloporidae	<i>Pocillopora ligulata</i>	Thin Cauliflower
Pocilloporidae	<i>Pocillopora meandrina</i>	Cauliflower
Pocilloporidae	<i>Pocillopora molokensis</i>	Moloka'i Cauliflower
Pocilloporidae	<i>Pocillopora verrucosa</i>	Rasp
Poritidae	<i>Porites bernardi</i>	False Lichen
Poritidae	<i>Porites brighami</i>	Brigham's
Poritidae	<i>Porites compressa</i>	Finger
Poritidae	<i>Porites lobata</i>	Lobe
Poritidae	<i>Porites lutea</i>	Mound
Poritidae	<i>Porites solida</i>	Solid
Siderastreidae	<i>Psammocora nierstraszi</i>	Nierstrasz's
Dendrophylliidae	<i>Turbinaria</i> sp	Cup

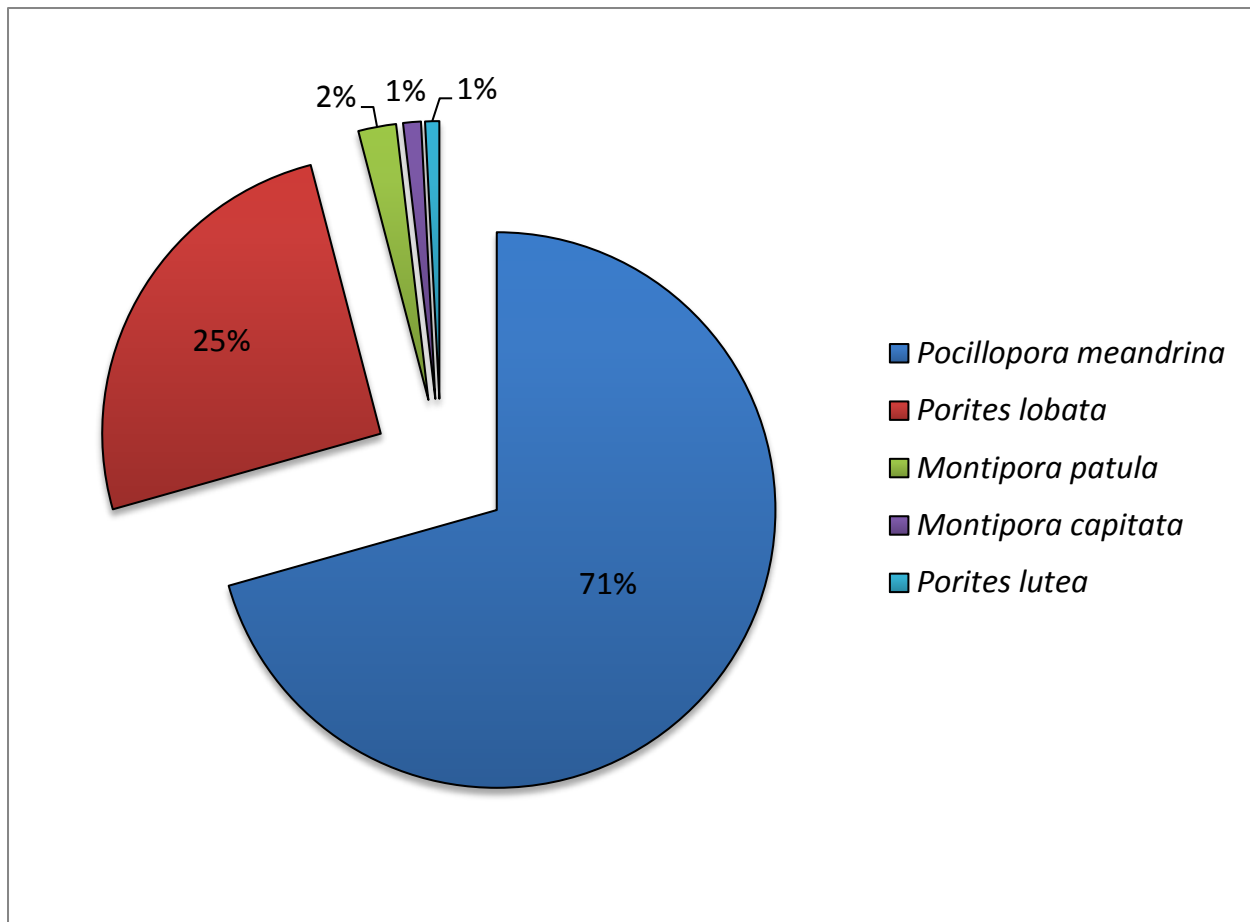


Figure 10. Relative benthic coral cover for the top five coral species from 2006-2010 transects (N = 150 total transects [15 fixed sampled for 5 years, 75 temporary]). Total coral cover averaged 8.4 ± 0.5 SE%.

Trends in Benthic Marine Community Characteristics

For the 30 transects (15 fixed and 15 temporary) surveyed, the four principle types of substrate types/taxa (coral, macroalgae, coralline algae, and turf algae) showed no significant trends in cover across the survey period from 2006 to 2010. Total mean coral cover for all 24 species documented remained relatively stable at an average of $8.8\% \pm 0.6$ SE from 2006-2010 (Figure 11). The two-sided trend test indicated no significant trend at an $\alpha = 0.05$ level ($t = -1.91$, $df = 2.95$, $p = 0.15$). Mean macroalgae cover increased from $7.6\% \pm 1.5$ SE in 2006 to $26.1\% \pm 2.4$ SE in 2008 and then dropped slightly to $21.9\% \pm 2.9$ SE in 2010 (Figure 12). The years with high macroalgae cover were most noticeable along the south facing shores with large blooms of *Sargassum* sp., *Padina* sp., and *Helminthocladia* sp. The trend, however, was not significant ($t = 2.06$, $df = 3.39$, $p = 0.12$) due to the high intra-annual variance, especially in 2008 and 2009. As noted earlier, macroalgae cover ranged from 1% to 76% across years. Mean percent cover of coralline algae was relatively unchanged from 2006 to 2010 and averaged $4.2\% \pm 0.8$ SE across the five years (Figure 13). The trend for coralline algae was not significant ($t = 0.47$, $df = 3.21$, $p = 0.67$). Mean turf algae percent cover decreased from $76.1\% \pm 1.6$ SE in 2006 to $59.5\% \pm 2.6$ SE in 2008 and then increased to $66.1\% \pm 2.8$ SE and $63.8\% \pm 2.5$ SE in 2009 and 2010, respectively (Figure 14). This pattern mirrored the changes in macroalgae cover and suggested that the macroalgae blooms were simply replacing the turf algae during those years. The change in turf algae cover across years, however, was not significant ($t = -1.93$, $df = 3.82$, $p = 0.13$). Overall mean turf algae cover was $66.7\% \pm 2.6$ SE.

Coral species richness ranged from an average low of 3.7 ± 0.4 SE species per transect in 2009 to a high of 4.4 ± 0.3 SE in 2006 with an overall average of 4.1 ± 0.1 SE species per transect (Figure 15). Actual coral species richness ranged from zero or no species to nine species on a transect. There was no significant difference in species richness from 2006 to 2010 ($t = -1.63$, $df = 3.75$, $p = 0.18$) indicating that the coral community composition was relatively stable.

The percentage of photoquadrats showing signs of disease or bleaching was generally low and ranged from a mean of $0.26\% \pm 0.18$ SE in 2007 to a high of $3.72\% \pm 0.87$ SE in 2010 with an overall average of $1.3\% \pm 0.2$ SE (Figure 16). The increase in coral disease/bleaching was significant during this study period ($t = 2.84$, $df = 7.49$, $p = 0.02$).

Rugosity index values did change significantly ($t = 2.89$, $df = 8.31$, $p = 0.02$) from 2006 to 2010 with a slight positive trend (Figure 17). Mean index values ranged from 1.59 ± 0.20 SE in 2006 to 1.64 ± 0.23 SE in 2009.

Coral settlement rates were different among years with 2008 having the highest settlement rate at 214.2 larvae/m²/five months ± 66.7 SE and 2006 having the lowest at 75.6 larvae/m²/five months ± 26.7 SE (Figure 18). The overall average of coral settlement from 2006 to 2010 was 103.4 larvae/m²/five months ± 13.8 SE. The Wilks multivariate within effects test, however, indicated that there was no significant trend over time ($F_{4, 11} = 2.99$, $p = 0.07$). *Porites* sp. larvae were consistently the most abundant on the settlement tiles except for 2008 when *Montipora* sp. larvae were most abundant. The majority of larvae settled on the vertical sides (52%) of the plates followed by the horizontal surfaces of the lower bottom (25%), upper top (17%), lower top (3%), and upper bottom (3%) of the plate pair.

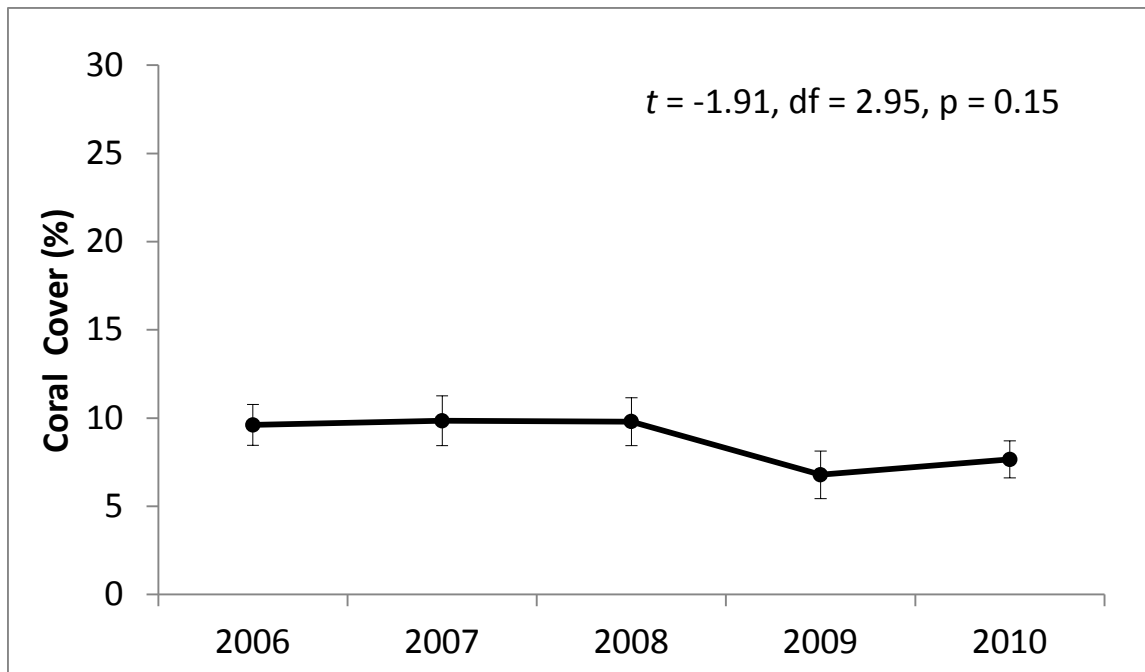


Figure 11. Mean annual percent coral cover at the 15 fixed survey sites and the 15 temporary transects surveyed in each year in Kalaupapa National Historical Park from 2006-2010. Error bars are one standard error of the mean. Trend analysis t statistics are displayed.

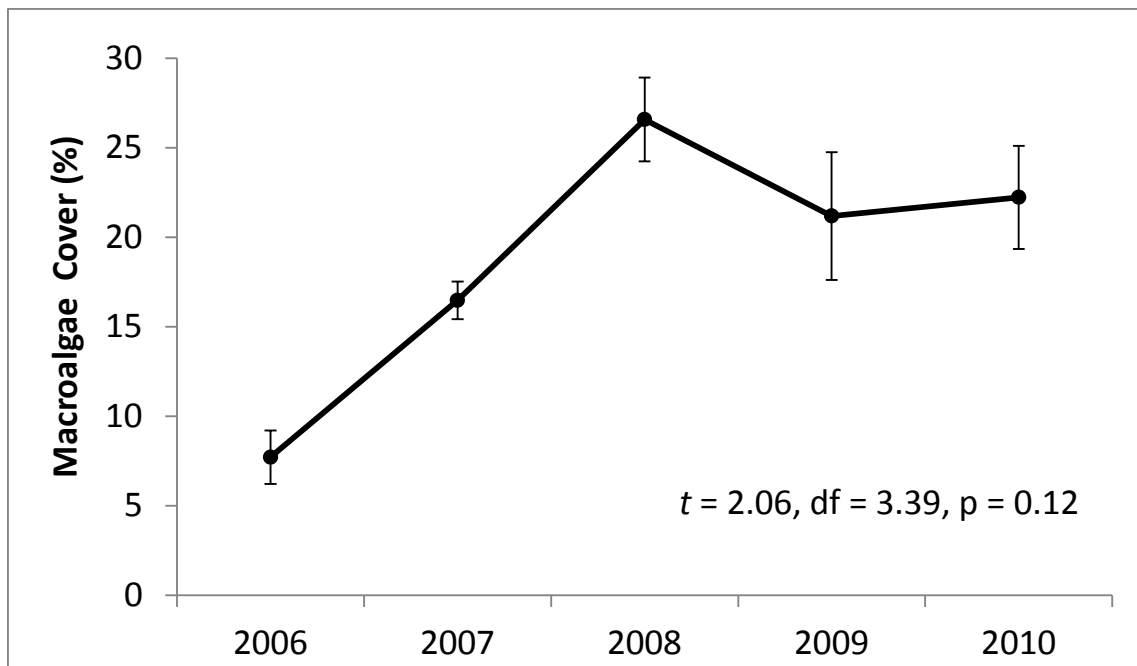


Figure 12. Mean annual percent macroalgae cover at the 15 fixed survey sites and the 15 temporary transects surveyed in that year in Kalaupapa National Historical Park from 2006-2010. Error bars are one standard error of the mean. Trend analysis t statistics are displayed.

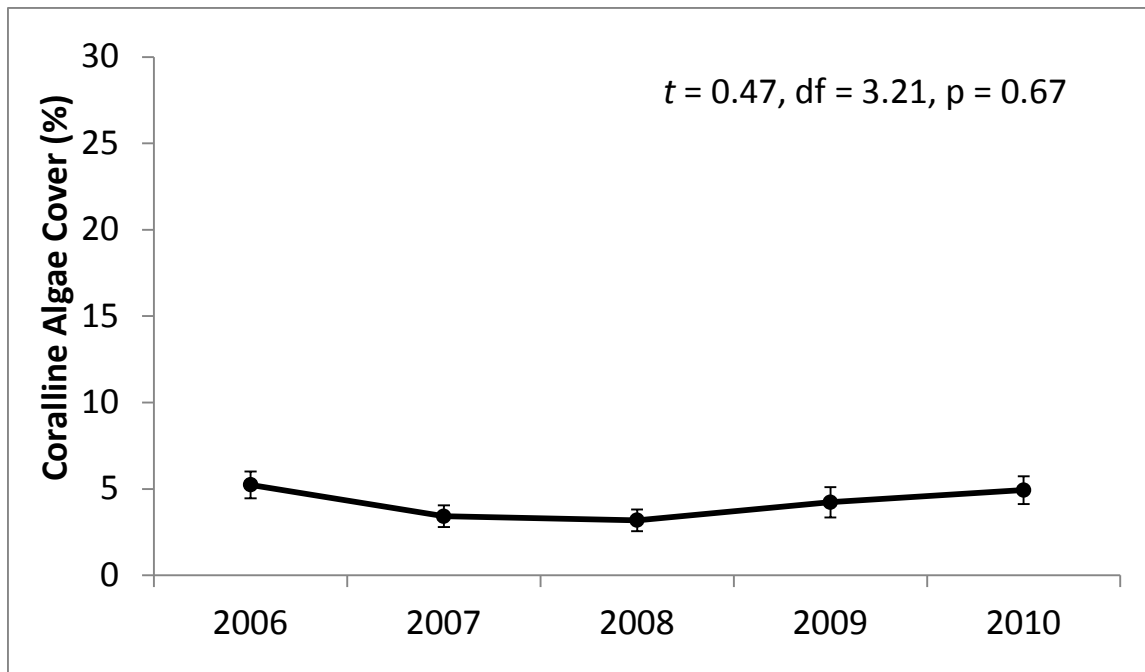


Figure 13. Mean annual percent coralline algae cover at the 15 fixed survey sites and the 15 temporary transects surveyed in that year in Kalaupapa National Historical Park from 2006-2010. Error bars are one standard error of the mean. Trend analysis t statistics are displayed.

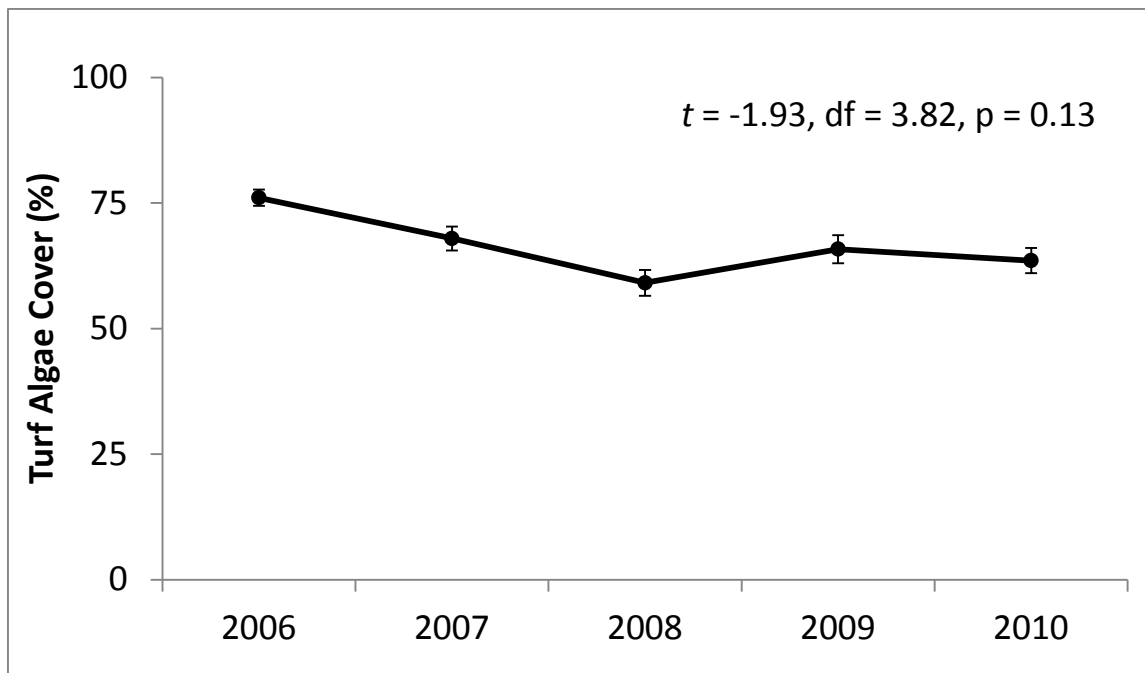


Figure 14. Mean annual percent turf algae cover at the 15 fixed survey sites and the 15 temporary transects surveyed in that year in Kalaupapa National Historical Park from 2006-2010. Error bars are one standard error of the mean. Trend analysis t statistics are displayed.

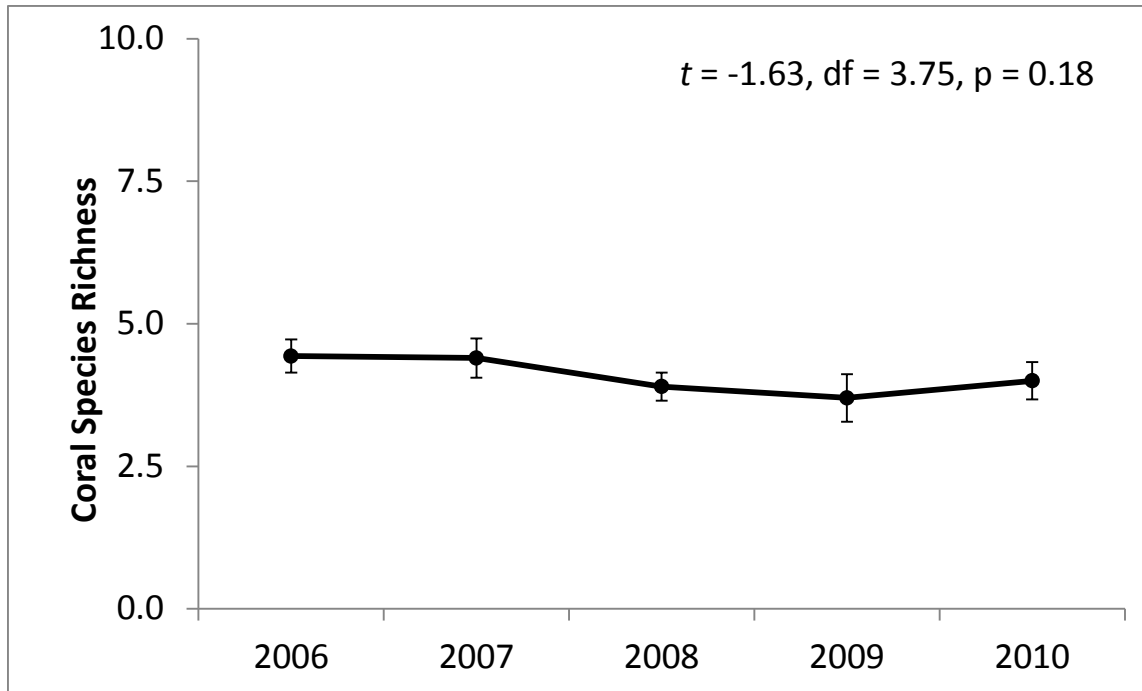


Figure 15. Mean annual coral species richness at the 15 fixed survey sites and the 15 temporary transects surveyed in that year in Kalaupapa National Historical Park from 2006-2010. Error bars are one standard error of the mean. Trend analysis t statistics are displayed.

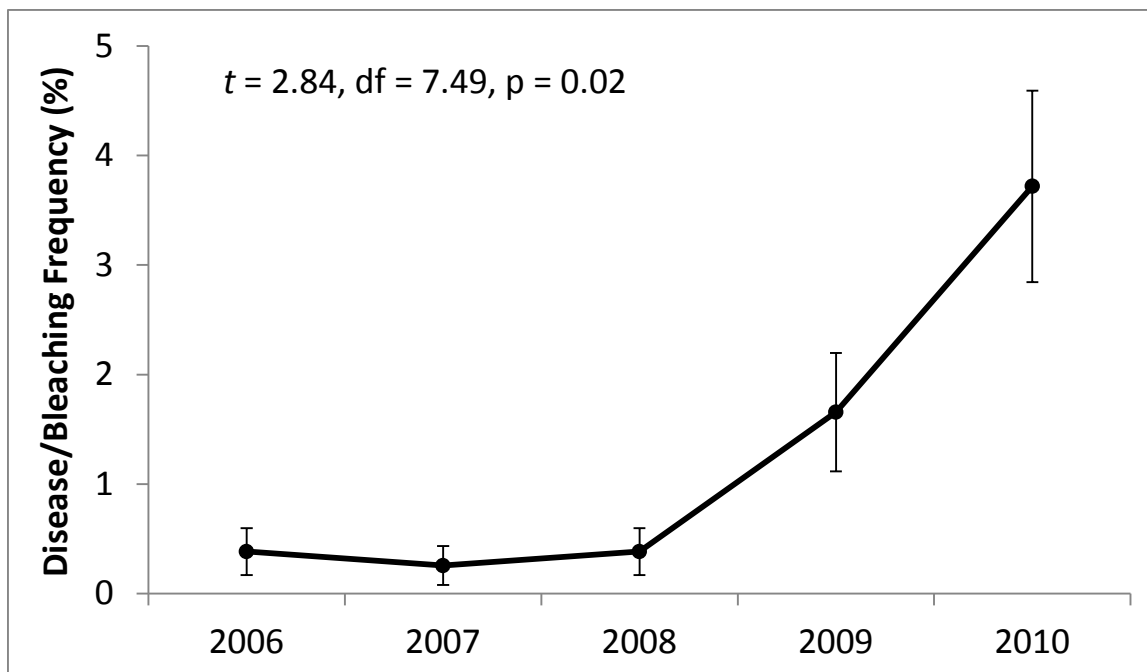


Figure 16. Mean annual percentage of photoquadrats with coral disease and bleaching at the 15 fixed survey sites and the 15 temporary transects surveyed in that year in Kalaupapa National Historical Park from 2006-2010. Error bars are one standard error of the mean. Trend analysis t statistics are displayed.

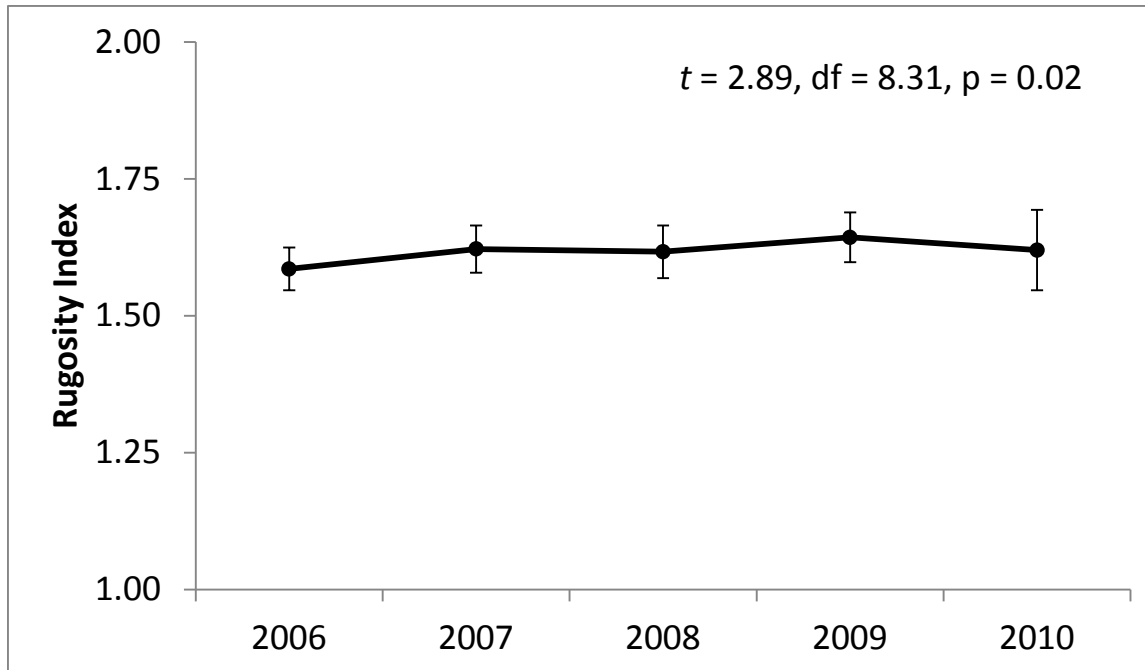


Figure 17. Mean annual rugosity at the 15 fixed survey sites and the 15 temporary transects surveyed in that year in Kalaupapa National Historical Park from 2006-2010. Fixed transects were not surveyed in 2010, but rugosity measurements were taken for the temporary transects. Error bars are one standard error of the mean. Trend analysis t statistics are displayed.

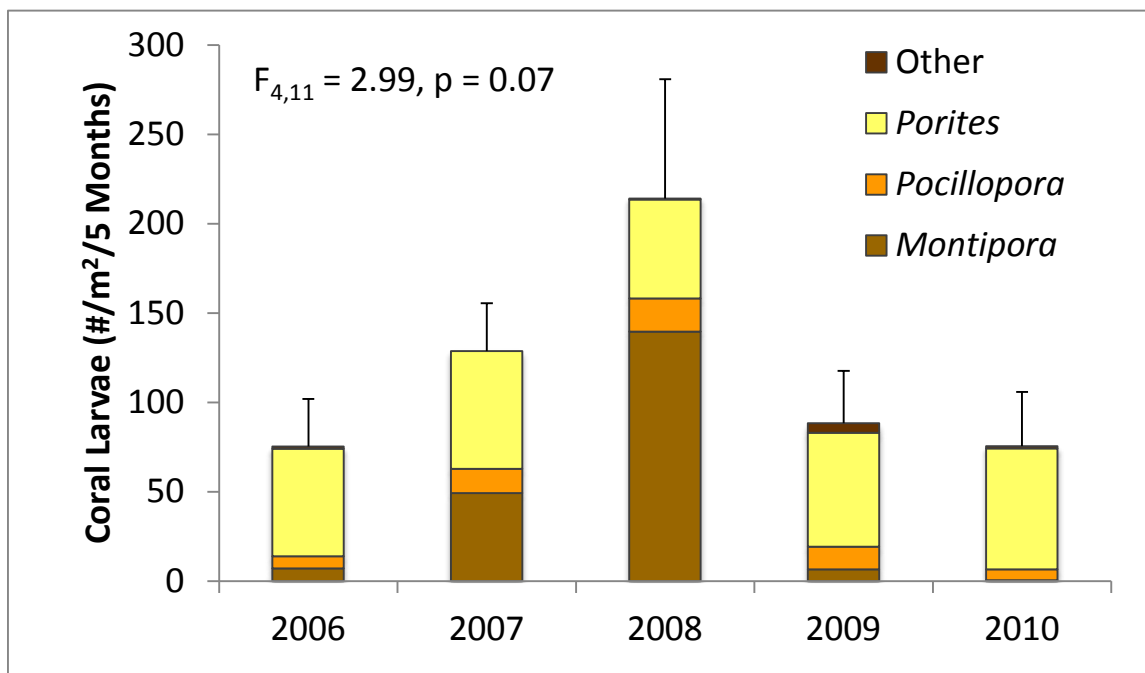


Figure 18. Coral larvae settlement rate (Number/m²/five month period) for each taxonomic group at the 15 fixed survey sites in Kalaupapa National Historical Park from 2006-2010. Error bars are one standard error of the mean. Trend analysis F statistics are displayed.

Discussion

Survey results from 2006-2010 indicated that transects with the highest coral (Figure 3) and coralline algae (Figure 5) cover were located near the northern tip of the peninsula. Coral settlement was also highest in this area (Figure 8). These remote sites are farthest from most anthropogenic activities on the peninsula (See Figure 3) and are more typical of oligotrophic reef areas. In addition, the peninsula appears to be a convergence zone for currents moving either east or west so larval settlement would be optimized in this location. Average coral cover for all 22 species at Kalaupapa (8.8%) is lower than the statewide average of 19.9% and lower than other wave exposed north shore sites ($11.6\% \pm 1.4$ SE) (Friedlander et al. 2008). Even the most wave exposed sites in the main Hawaiian Islands along the north shore of Kaua'i in Hanalei Bay (Jokiel et al. 2004) have higher average coral cover ($17.5\% \pm 1.2$ SE) than at Kalaupapa (Friedlander and Brown 2006). These results suggest that other factors are structuring coral communities around the peninsula in addition to wave exposure.

Additional factors that could influence coral community structure include spatial extent of shallow water habitat, geologic age of the island, stability of the habitat, anthropogenic events, and biological processes, such as coral settlement which are dictated by current patterns. For Kalaupapa and the entire island of Moloka'i, the spatial extent of shallow water habitat (depth <20 m) that is suitable for coral reef development is less than on Kaua'i (10% less), O'ahu (57%), Maui (2%), and Hawai'i (17%) (Rohmann et al. 2005). Examining habitat maps for only the wave exposed north shore sections of these islands, it is evident that the area around Kalaupapa has substantially less coral reef habitat available than the other islands and is restricted to a narrow band adjacent to the shoreline (NOAA – NCCOS 2007). This restricted range of suitable habitat would have inhibited development of an aggregate reef structure as seen on the south shore of Moloka'i.

In terms of geologic age, the Kalaupapa peninsula is one of the youngest areas in the Hawaiian archipelago at approximately 340,000 years old (Clague et al. 1982). Combined with sea level changes (e.g. Kayanne and Hongo 2011) and uplift from lithospheric flexure (Clague 1998), this peninsula is one of the most geologically dynamic areas in the archipelago, which may have further restricted coral reef development. The late stage volcanism, however, only applied to the peninsula itself, and therefore, does not account for the even lower coral cover along the cliff faces (Figure 3).

The stability of the substrate is also different than other wave exposed north shore sites. At Kalaupapa, the substrate consists of large basalt boulders that can move during large wave events (see cover photo). In contrast, the more typical north shore coral reefs of Kaua'i, O'ahu, and Maui are relatively flat with encrusting coral communities of *Montipora flabellata*, *M. patula*, and *M. capitata* (Jokiel et al. 2004) (Figure 19). These growth forms are resistant to wave energy stress and can cover large expanses of two-dimensional substrate that is stable. In contrast, *Pocillopora meandrina*, which is the most abundant coral at Kalaupapa (Figures 9 and 10) and also resistant to wave energy (Storlazzi et al. 2005) must contend with a potentially mobile substrate. Even though wave data have not shown any extreme wave events (U.S. Naval Oceanographic 2010, NOAA 2010, Stormsurfing 2010) and rugosity measurements have not indicated much substrate movement in the past five years, it is evident that these rounded boulders have shifted in preceding years, which would damage corals on the surface.



Figure 19. Typical substrate profile and coral community structure at Hanalei Bay, which is on the northern, wave-exposed coastline of Kauaʻi, Hawaiʻi. Photo by author on May 21, 2010.

The spatial pattern for rugosity didn't reveal any clear patterns. Rugosity was slightly higher on the peninsula than along the cliff faces (Figure 7), but the small variation in measurements indicated a fairly homogeneous habitat. The cover photo is indicative of the habitat.

Anthropogenic activities such as harbor construction, sewage drainage from the settlement, and upslope agricultural development may account for the lower coral cover closer to the cliff faces on the western side of the peninsula since all of these activities are more concentrated in this location. The similar coral cover distribution on the eastern side of the peninsula (Figure 3), however, suggests that anthropogenic impacts are not the major structuring force along the north shore since the spatial distribution of human activities and settlements have been historically inconsistent on both sides of the peninsula (McCoy 2007, Flexner 2010). Most of the initial pre-western contact settlements occurred in the major valleys (Hālawā, Wailau, Pelekunu, and Waikolu) on the eastern side of the peninsula. By the time the Hansen's disease settlement was established in 1866 at Kalawao and later moved to Kalaupapa in the early 1900's on the western side of the peninsula, human habitation in the eastern valleys with the exception of Hālawā, had largely disappeared (Flexner 2010). The major anthropogenic activities that have taken place near the tip of the peninsula include the initial airport construction in 1934 and subsequent renovation in 1992 (State of Hawaiʻi, 2014), the lighthouse construction from 1905 to 1909 (Dean 1989), and human habitation near the lighthouse prior to western contact (Manning and Neller 2005). These activities have been relatively short in duration compared to the human events closer to the cliff faces and in the major valleys (McCoy 2005). In any event,

anthropogenic activities, as noted above, do not appear to be the major factor influencing coral community development along this coastline.

The low coral settlement rates could also be limiting coral reef development around the park. Friedlander and Brown (2006) found that Hanalei Bay on Kaua'i had more than twice the coral cover and up to two orders of magnitude higher coral settlement rates than Kalaupapa when using the same artificial substrates (Table 2). These biological parameters appeared to sustain a robust and stable coral reef ecosystem despite the high wave energy and numerous anthropogenic stressors (Friedlander and Brown 2006). At other sites around Hawai'i, such as Olowalu and Honolua Bay (both on Maui), that have long-term data on coral cover, coral settlement was either similar or lower. In the case of Olowalu, coral cover has been relatively stable at the 8 m site with moderate coral settlement, but has declined 40% at the 3 m site since 1993 with low settlement rates (Brown 2004, Friedlander et al. 2008). Honolua Bay which has experienced an average decline of 78% at both sites in the bay has some of the lowest recorded settlement rates using the same methodology with terracotta tiles. Even Asan Bay on Guam, which has similar levels of coral cover to Kalaupapa at 10% (Nash et al. 2009), has extremely low levels of coral settlement that do not appear to be supporting the adult community assemblage (Minton et al. 2007, University of Guam, unpublished results). These results show the importance of coral settlement in sustaining the long-term viability of the coral communities and suggest that Kalaupapa has levels that are sufficient to maintain the current level of coral coverage, but nothing more substantial.

Currents, which are the main mode of dispersal for planktonic coral larvae have not been studied extensively around the park. Storlazzi et al. (2011) documented that the predominant surface currents adjacent to the settlement were parallel to shore with rising/incoming tidal currents flowing to the northern end of the peninsula and falling tidal currents flowing south (Figure 20). There did not appear to be a prevailing direction, which would limit larvae coming from outside sources. Additional current meters would need to be installed around the peninsula to clarify whether Kalaupapa serves as a source or sink population of coral larvae. Two lines of evidence suggest that Kalaupapa is not a sink population. First, coral settlement has been relatively low at Kalaupapa (Figure 18) for at least five years. It is possible that a settlement pulse may occur at longer time intervals (e.g. Coles and Brown 2007), but additional settlement data from 2011 and 2012 along with the high settlement rates in Hanalei during the same time period indicate otherwise. Second, the taxonomic composition of settling coral larvae (Figure 18) does not correspond well to the adult assemblage (Figure 10), which indicates that even self-seeding is not occurring. The fact that settlement and coral cover are consistently higher at the northern end of the peninsula, however, suggests that some convergence of currents does occur. In addition to ocean currents, other factors influencing coral settlement rates and the resulting adult community structure include adult fecundity, toxic chemicals, predation, and space availability (Richmond 1997). These factors may be examined in the future at KALA to help explain the existing spatial patterns in coral community structure.

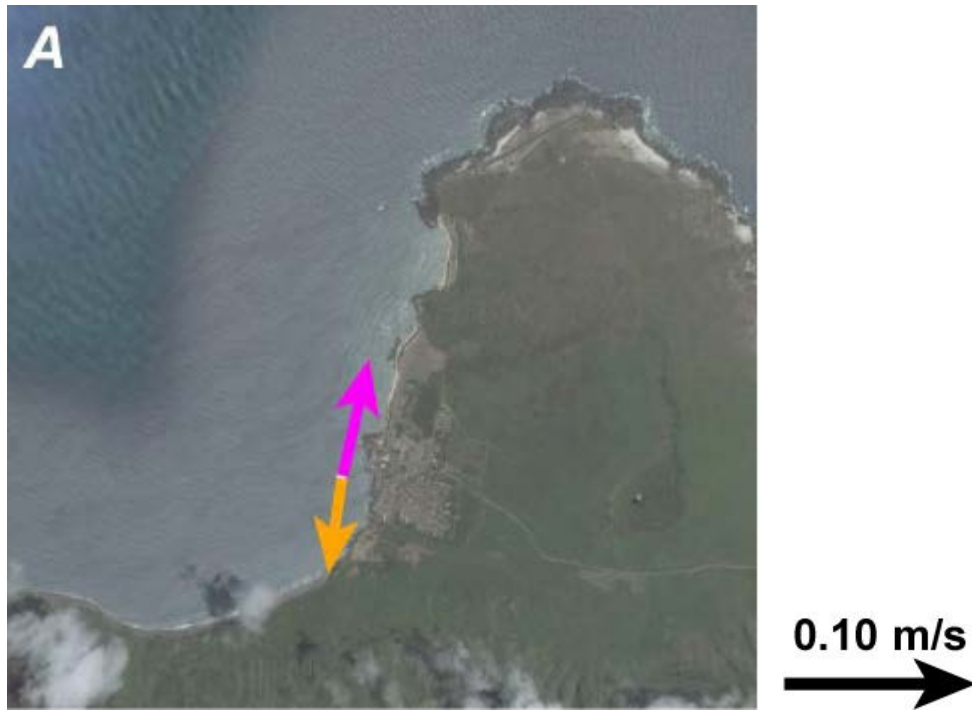


Figure 20. Map showing the relative magnitude and direction of near-surface tidal currents, in meters per second from true north. Magenta is flood tide and orange is ebb tide. A 0.10-m/s vector length is shown for scale. Figure from Storlazzi et al. (2011).

Table 2. Average settlement rates (larvae m⁻² yr⁻¹) on various artificial substrates for “invisible” (<2 mm diameter) coral larvae in Hawai‘i and in National Parks on Guam and the U.S. Virgin Islands. Range of settlement rates is at the scale of site. Note that this table does not include data from studies conducted on natural substrates or studies that did not report settlement rates per unit area.

Site, Island	Ocean	Substrate	Average Settlement Rate	Range of Settlement Rates	Latitude	Reference
Hanalei Bay, Kaua‘i	Pacific	Terracotta	7,924	403-15,386	22° N	Friedlander and Brown (2006)
Kāne‘ohe Bay, O‘ahu	Pacific	Terracotta	5,752	543-27544	21° N	Kolinski (2004)
Puamana, Maui	Pacific	Terracotta	415	8-1,792	21° N	Brown (2004)
Luminao, Guam	Pacific	PVC	209	0-2,433	13° N	Birkeland et al. (1981)
Olowalu, Maui	Pacific	Terracotta	122	95-233	21° N	Brown (2004)
Kalaupapa, Moloka‘i	Pacific	Terracotta	103	75-214	21° N	This Study
Waiakailio, Hawai‘i	Pacific	Terracotta	71	44-99	20° N	Basch (unpublished data)
Honolua Bay, Maui	Pacific	Terracotta	41	7-92	21° N	Brown (2004)
Kāne‘ohe Bay, O‘ahu	Pacific	Concrete	36	0-124	21° N	Fitzhardinge (1993)
Honokohau, Hawai‘i	Pacific	Terracotta	10	0-14	19° N	Basch (unpublished data)
Kāne‘ohe Bay, O‘ahu	Pacific	Concrete	8	0-16	21° N	Demers (1996)
St. Croix, Virgin Islands	Caribbean	Coral Slab	6	4-18	18° N	Rogers et al. (1984)
North Keahou, Hawai‘i	Pacific	Terracotta	1	0-1	19° N	Basch (unpublished data)
Asan Bay, Guam	Pacific	Terracotta	0.8	0-15	13° N	Minton et al. (2007)
Asan Bay, Guam	Pacific	PVC	0.5	0-51	13° N	Minton et al. (2007)
Kona, Hawai‘i	Pacific	Asbestos	0 ¹	0	19° N	Dollar (1975)

¹Dollar (1975) targeted juvenile corals > 2 mm

In comparison to coral cover, macroalgae cover was highest below the cliff faces on the east and west boundaries of the park. There are several possible explanations for the observed patterns. First, a cattle ranch and small town are located in the adjacent and upslope watershed of the western sites. During heavy rain events, sediment and potentially nutrients empty into the bay along the cliff and western portion of the peninsula (Figure 21). Sediment input coupled with resuspension (Rogers 1990, Field et al. 2008) and nutrient loading (e.g. Fabricius 2005) have been shown to influence coral reef development in Hawai'i (Jokiel 2008) and other parts of the world (Fabricius 2005). These events, however, do not impact the eastern sites which are at the base of relatively pristine watersheds. Therefore, the documented algal blooms at the eastern sites do not appear to be from anthropogenic sources. A second possibility is the lower fish herbivore abundance and biomass that exists on the cliff faces compared to the peninsula (Brown et al. 2012a, 2012b, 2012c, 2012d). The lower fish levels may be unable to keep algae blooms in check (Sjöo et al. 2011). A third possibility is the improvement in photographic technology since 2008, potentially allowing observers to distinguish turf algae down to genus and therefore, categorize more substrate as macroalgae (Personal Observation). This explanation, however, is not as likely because larger scale seascape shots, which do not benefit from the improved technology, show clear evidence of macroalgae blooms in recent years (Figure 22). Apparently, some event such as a change in precipitation patterns triggered the higher coverage in macroalgae and the low level of herbivore abundance was unable to graze down the algae blooms (See discussion below on changes in macroalgae cover).

Coral disease and/or bleaching incidence was highest around the northern end of the peninsula and at one site on the western boundary of the park (Figure 6). The pattern was variable both spatially and temporally. For example, other sites along the western boundary, including the fixed sites, had relatively low levels of disease/bleaching. This spatially variable pattern was similar at the northern sites, which was unexpected given the distance from potential stressors. Several explanations exist. First, the temporal pattern does show an increase in the frequency of disease/bleaching (Figure 16) so the spatial pattern could be real given the integration of the temporal data into the figure. Previous studies have demonstrated that disease outbreaks or bleaching events can occur rapidly and have been influenced by increased sea surface temperatures (Jokiel and Brown 2004), sedimentation (Nowlis et al. 1997), airborne pathogens (e.g., Sahara dust storms [Shinn et al. 2000]), and anthropogenic contaminants (Fabricius 2005). Second, as mentioned previously, there could be a convergence of currents at the northern end of the peninsula that transports disease/bleaching vectors along with coral larvae. Finally, KALA staff has become better educated on the distinction between the disease/bleaching categories and perhaps observers are labeling photographs in this category more frequently. This explanation is somewhat confounded, however, by the improving photographic equipment, which has enabled observers to more clearly differentiate disease/bleaching from normal senescence. Patterns in disease and bleaching will be watched closely in subsequent years given the rapid decline on some coral reefs in certain areas of the world (e.g. Miller et al. 2006) and the dual threat of increasing sea surface temperatures and ocean acidification from global climate change. These two threats will most likely increase the incidence and severity of bleaching events and disease outbreaks on coral reefs (Hoegh-Guldberg et al. 2007). It is possible that these two stressors may be already manifesting themselves at KALA, but this is difficult to ascertain given the short time period of this study.



Figure 21. Sediment discharge into the ocean from Waihānau and Piko'one streams along the southwestern shore of the peninsula on March 23, 2006. Photo by Eric Brown.

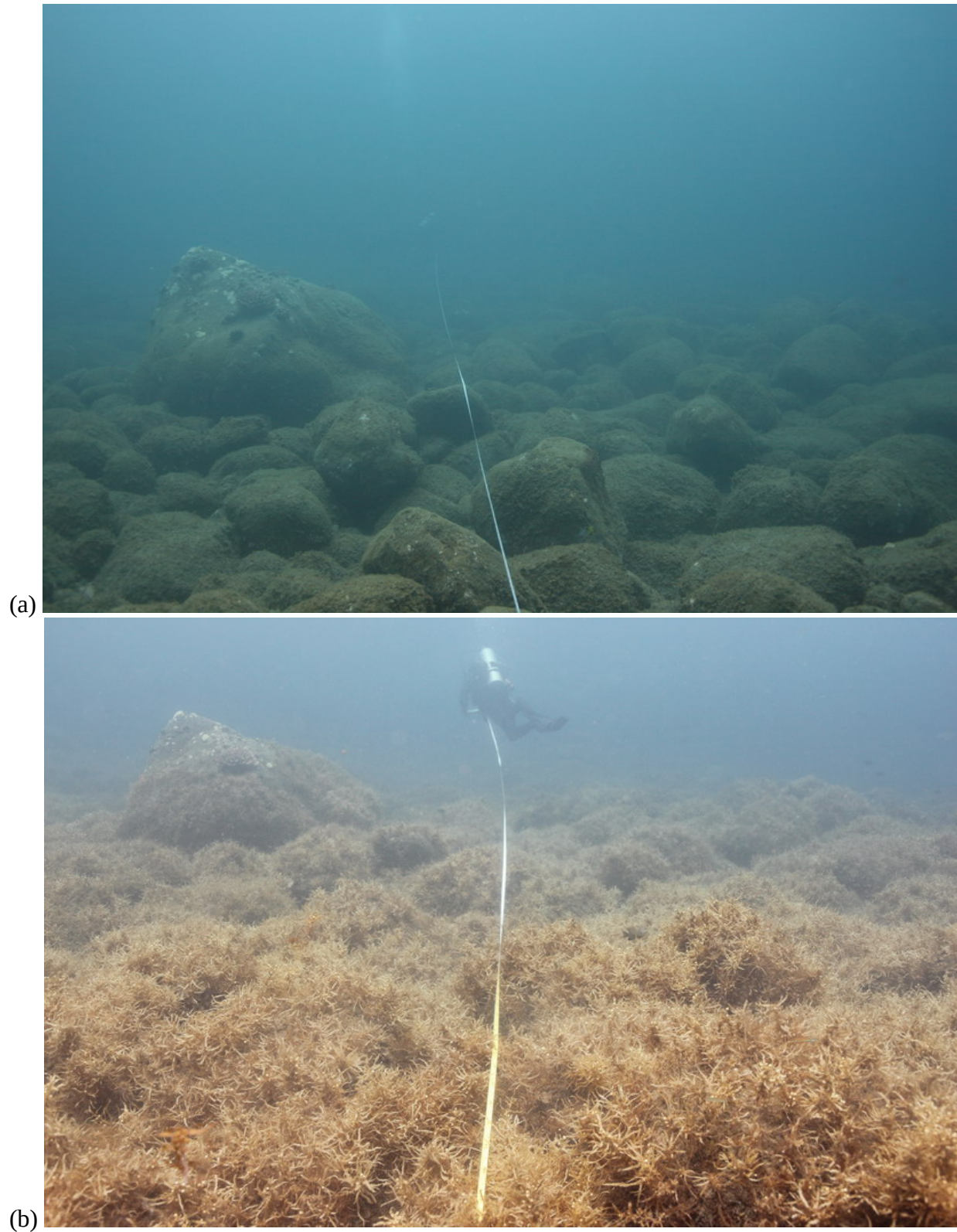


Figure 22. Fixed transect 15 in August, 2008 (a) and August, 2012 (b) showing a summertime increase in macroalgal cover over the four year period. Photos by Kazuki Kageyama (a) and Randall Watanuki (b).

Sea surface ocean temperatures recorded by the National Marine Fisheries Service (NMFS) for Koko Head, Oahu (1956–1992) and corrected Integrated Global Ocean Services System–National Meteorological Center (IGOSS–NMC) at the same location (1992–2012) indicate that overall temperatures have increased by more than 0.5° C since 1956 (Figure 23, See Jokiel and Brown 2004). Ocean cooling, however, has occurred since 2005, which predated this study and this trend has been corroborated by temperature meters within the park. Over a longer time period, however, ocean temperatures are expected to continue rising by 1.4 - 2.6 °C due to increased CO₂ emissions and the concomitant increase in atmospheric temperatures (IPCC 2013).

Ocean chemistry is also expected to change with increasing CO₂ emissions (IPCC 2013). In particular, pH is expected to decrease resulting in more acidic conditions and negatively impacting organisms (e.g. corals, mollusks, sea urchins, etc.) that secrete a calcium carbonate skeleton. Hoegh-Guldberg et al. (2007) project that by 2050, coral reef ecosystems will reach a tipping point and corals will be unable to calcify and grow. KALA began monitoring ocean pH semi-annually along with other parameters in 2009 as part of the PACN I&M water quality protocol (Jones et al. 2011), but to date, no temporal pattern in pH has emerged (NPS unpublished results).

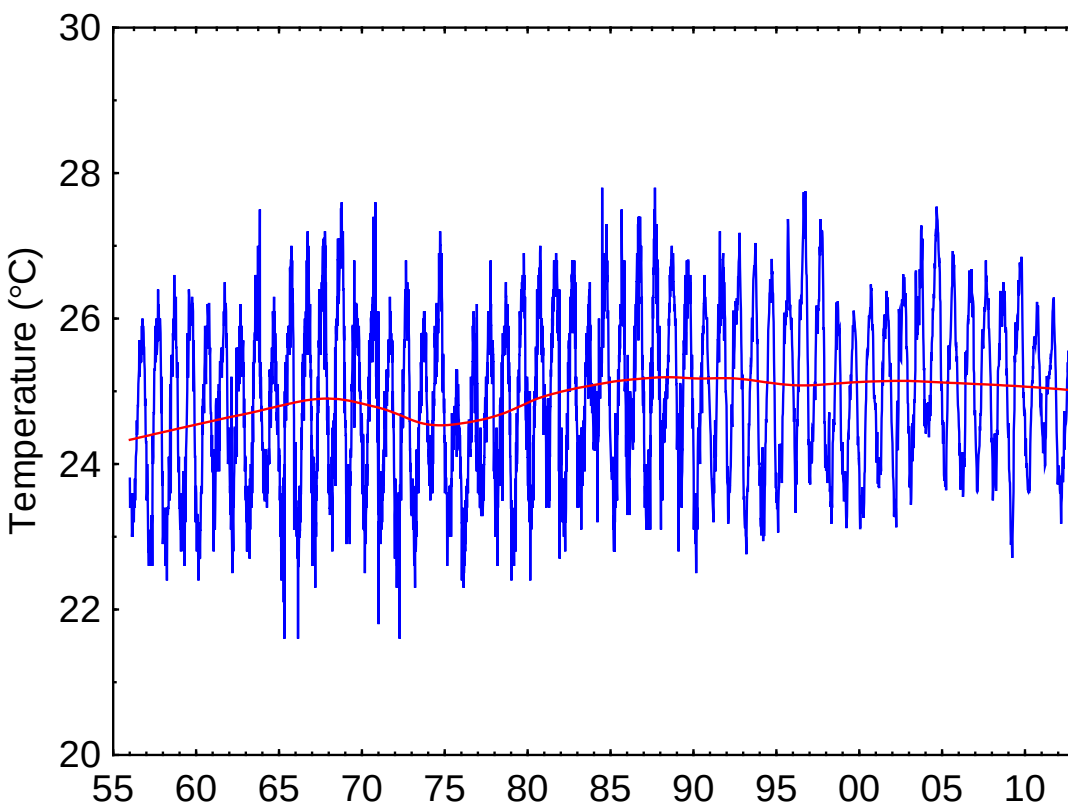


Figure 23. Combined sea surface temperature (SST) record using National Marine Fisheries Service (NMFS) data for Koko Head, Oahu (1956–1992) and corrected Integrated Global Ocean Services System–National Meteorological Center (IGOSS–NMC) temperature data (1992 to 2012; Modified from Jokiel and Brown 2004). The red line indicates a Lowess function fitted to the data.

Throughout the park, turf algae dominated the substrate, covering more than 66% of the benthos observed (Figure 9). Macroalgae and cyanobacteria covered almost 14% of the benthos and unidentified genera within the division Rhodophyta were the most common macroalgal group observed (Figure 9). The most commonly identified macroalgal taxa included the genera *Dictyota*, which includes four species commonly found throughout Hawai'i, *Sargassum*, which includes three common endemic Hawaiian species, and *Padina*, which includes four common or locally abundant species (Huisman et al. 2007). *Pocillopora meandrina*, the second most common taxon and the most abundant coral species observed, covered approximately 6% of the substrate. This species is one of Hawai'i's most common corals, and dominates in areas of heavy surge, like the north shore of Moloka'i (Fenner 2005). *Porites lobata*, the only other coral in the top ten taxa, is also common throughout the main Hawaiian Islands (Fenner 2005). The low variance in species richness for both transects and years (Figure 15) suggests that coral community composition was relatively homogeneous within the park. This assemblage pattern was somewhat typical of north shore environments with the low abundance of macroalgae and corals coupled with the high abundance of turf algae, and few non-native species (<1% cover). Perhaps, the most unusual aspect was the noticeable lack of *Montipora* spp. (0.3% of the total substrate cover, 3.2% of the coral cover) in the coral community and on the settlement plates. As discussed earlier, this may be a function of substrate type and current patterns.

Trend analysis indicated that coral cover (Figure 11), coral species richness (Figure 15), and coralline algae (Figure 13) remained relatively stable from 2006-2010. Several factors probably contributed to this stability. First, is the remoteness of this area from human perturbation. There are no roads leading into the settlement and the nearest harbor is more than 50 km from the western boundary of the park. There is one cattle ranch along the southwestern boundary of the park above the cliff face, but the sediment discharge from large scale rain events empties into a sandy bay with no coral outcroppings and dissipates within days (Personal observation). The human population at Kalaupapa has declined 92% from a peak of 1,177 in 1900 down to 90 in 2010 (U.S. Census Bureau 2013). A recent study examining the potential leeching of human sewage into the ocean found no evidence of nutrient enrichment; even after the installation of septic tanks in 2007 to replace the existing cesspools (KALA unpublished data, presented at 2012 International Coral Reef Symposium, Cairns, Australia). In addition, the population has been relatively stable for the past decade with light fishing and diving pressure (Tom 2011). Second, is the lack of any large scale natural disasters in the past five years, including big wave events (US Naval Oceanographic Office 2010, NOAA 2010, Stormsurfing 2010), hurricanes, tsunamis, or earthquakes. Admittedly, changes in these parameters may have occurred in previous years, but given the paucity of substrate cover data for the north shore of Moloka'i it is difficult to ascertain.

In contrast, macroalgae cover has almost tripled during this time period from 8% to 22% (Figure 12), while turf algae cover decreased by approximately 13% (Figure 14). These macroalgae blooms may be the result of low herbivore abundance and biomass at the sites coupled with some event that initiated the algal growth. Perhaps the 32% decline in rainfall coupled with hotter temperatures (3% increase in maximum temperature) since 1993 (Remote Automated Weather Station 2013) has led to the recent macroalgae blooms. Martins et al. (2008) found in a Portugal estuary that during periods of low rainfall and warmer temperatures, *Ulva intestinalis* experienced spring blooms in contrast to high rainfall periods when productivity was limited. Whitledge (1993) noted similar patterns with the brown alga *Aureoumbra lagunensis* in Texas.

Neither of these examples, however, were in tropical reef ecosystems so this relationship between rainfall and macroalgae blooms will continue to be examined in coming years with additional substrate and climatological data.

Even though the rugosity measurements showed a significant increase from 2006 to 2010 (Figure 17), the maximum difference in mean index values was only 0.05 (1.59 in 2006 versus 1.64 in 2009). This small value is well within the measurement error of the method (Brown unpublished data), and therefore, the trend did not appear to be relevant to their ecology. Most likely the statistical significance in the trend was due to the low variance among sites enabling small differences among years to be detected.

In comparison to other sites around Hawai'i, the overall mean rugosity index value of 1.62 was almost identical to the average of 1.60 at 60 sites reported by Friedlander et al. (2003). Kalaupapa, however, had higher rugosity (1.62 versus 1.44) than other north shore reefs exposed to the northwest swells. This result was likely due to the large boulder habitat at Kalaupapa covered by branching corals from the genus *Pocillopora* compared to the smoother and more uniform substrate found at the other north shore sites that were covered by encrusting *Montipora* species (see previous discussion on substrate stability). The highest mean rugosity values in Hawai'i were found in sheltered areas such as Kāne'ohe Bay on O'ahu (1.81) and along wave protected southern shorelines (1.71) (Friedlander et al. 2003). These spatially complex reef habitats typically were dominated by branching corals such as *Porites compressa* and large lobate corals such as *P. lobata* and *P. lutea* (Jokiel et al. 2004). This index will be explored further with the marine fish data as an explanatory variable for spatial patterns (e.g. Friedlander et al. 2007).

Further observations will be needed to determine whether these are real long-term trends, annual fluctuations in substrate cover types, or measurement error associated with the methodology. In terms of coral cover, Storlazzi et al. (2011) did note that during the summer months, high-frequency internal waves propagated past the instrument site fronting the settlement, advecting deep, cool, more nutrient-rich waters up into the warm, oligotrophic surface waters. This phenomenon may be important for coral reef ecosystem health and stability by buffering seasonal temperature increases and concurrently providing a consistent nutrient source for reef organisms. The stability in the coral community structure and processes, therefore, may be real. Further data collection and rigorous statistical analyses in subsequent reports will help us learn if the observed trends are significant and cause for management concern, as long-term change in the percent cover of invertebrate and algal taxa or assemblages may be indicative of variation in certain environmental stressors or drivers. For example, an increase in algal cover has often been associated with eutrophication (increased nutrient levels) from land sources and/or a reduction in the number of herbivorous invertebrates or fishes (Hughes 1993). Co-location of this benthic marine monitoring protocol with the marine fish monitoring protocol and the water quality monitoring protocol will allow us to determine if any such associations exist at Kalaupapa.

Literature Cited

- Aronson, R. B., P. J. Edmunds, W. F. Precht, D.W. Swanson, and D. R. Levitan. 1994. Large scale, long-term monitoring of Caribbean coral reefs: simple, quick, inexpensive techniques. *Atoll Research Bulletin* 421: 1-19.
- Basch, L.V., and J. Keesing. 1996. Ecology of marine benthic invertebrate juveniles. *Oceanologica Acta* 19: 466-467.
- Basch, L.V., and J. S. Pearse. 1996. Consequences of larval feeding environment for settlement and metamorphosis of a temperate echinoderm. *Oceanologica Acta* 19: 273-285.
- Basch, L.V., J. Eble, D. Shafer, J. Zamzow, and W.J. Walsh. 2007. Recruitment dynamics and dispersal of key coral reef species in a network of National Parks and Marine Protected Areas in Hawaii: Some preliminary findings. Draft Technical Report, PCSU-HPI-CESU [Pacific Cooperative Studies Unit and Hawaii Pacific Islands Cooperative Ecosystems Studies Unit], U.S. National Park Service, National Oceanic and Atmospheric Administration, University of Hawaii, Manoa, Hawaii Division of Aquatic Resources, Manoa, Hawaii.
- Bird, C. 2002. Photogrid® software. Available at <http://www2.hawaii.edu/~cbird/PhotoGrid/frames.htm> (accessed June 2003).
- Birkeland, C. 1997. Symbiosis, fisheries and economic development on coral reefs. *Trends in Ecology and Evolution* 12: 364-367.
- Birkeland, C., D. Rowley, and R. H. Randall. 1981. Coral recruitment patterns at Guam. *Proceedings of the 4th International Coral Reef Symposium, Manila, Philippines, June 1980*: 339-344.
- Brown, E. K. 2004. Reef coral populations: spatial and temporal differences observed on six reefs off West Maui. Dissertation. University of Hawai'i, Honolulu, Hawai'i.
- Brown, E., E. Cox, P. Jokiel, K. Rodgers, W. Smith, B. Tissot, S. L. Coles, and J. Hultquist. 2004. Development of benthic sampling methods for the Coral Reef Assessment and Monitoring Program (CRAMP) in Hawai'i. *Pacific Science* 58: 145-158.
- Brown, E., D. Minton, R. Daniel, F. Klasner, L. Basch, A. Snyder, P. Craig, G. Dicus, K. DeVerse, and T. Jones. 2011. Pacific Island Network benthic marine community monitoring protocol: Version 2.0. Natural Resource Report NPS/PACN/NRTR—2011/339. National Park Service, Fort Collins, Colorado.
- Brown, E., K. Tice, and T. Jones. 2012a. Kalaupapa National Historical Park (KALA) marine fish monitoring program annual report for 2006: Pacific Island Network. Natural Resource Data Series NPS/PACN/NRDS—2012/281. National Park Service, Fort Collins, Colorado.
- Brown, E., K. Tice, and T. Jones. 2012b. Kalaupapa National Historical Park (KALA) marine fish monitoring program annual report for 2007: Pacific Island Network. Natural Resource Data Series NPS/PACN/NRDS—2012/282. National Park Service, Fort Collins, Colorado.

- Brown, E., K. Tice, and T. Jones. 2012c. Kalaupapa National Historical Park (KALA) marine fish monitoring program annual report for 2008: Pacific Island Network. Natural Resource Data Series NPS/PACN/NRDS—2012/283. National Park Service, Fort Collins, Colorado.
- Brown, E., K. Tice, and T. Jones. 2012d. Kalaupapa National Historical Park (KALA) marine fish monitoring program annual report for 2009: Pacific Island Network. Natural Resource Data Series NPS/PACN/NRDS—2012/310. National Park Service, Fort Collins, Colorado.
- Bruckner, A., K. Buja, L. Fairey, K. Gleason, M. Harmon, S. Heron, T. Hourigan, C. Jeffrey, J. Kellner, R. Kelty, and others. 2005. Threats and stressors to U.S. Coral Reef Ecosystems. Pages 12-44 in J. Waddell, editor. *The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2005*. Technical Memorandum 11, NOAA [National Oceanic and Atmospheric Administration], NOS [National Oceanic Service], NCCOS [National Centers for Coastal Ocean Science], Silver Spring, Maryland.
- Cesar, H., P. van Beukering, S. Pintz, and S. Dierking. 2002. Economic valuation of the coral reefs of Hawaii. Hawaii Coral Reef Initiative Research Program Final Report. National Oceanic and Atmospheric Administration, Coastal Ocean Program and University of Hawaii, Honolulu, Hawaii.
- Cesar, H., and C. K. Chong. 2004. Economic valuation and socioeconomics of coral reefs: Methodological issues and three case studies. Pages 14-40 in M. Ahmed, C. K. Chong and H. Cesar, editors. *Proceedings for International Consultative Workshop on Economic Valuation and Policy Priorities for Sustainable Management of Coral Reefs*. WorldFish Center Conference Proceedings 70.
- Clague, D. A., C. Dao-Gong, R. Murnane, M. H. Beeson, M. A. Lanphere, G. B. Dalrymple, W. Friesen, and R.T. Holcomb. 1982. Age and petrology of the Kalaupapa Basalt, Molokai, Hawaii. *Pacific Science* 36: 411–420.
- Clague, D. A. 1998. Geology. Pages 37-46 in: S. P. Juvik and J. O. Juvik, editors. *Atlas of Hawai‘i*, 3rd edition. University of Hawai‘i Press. Honolulu, Hawai‘i.
- Coles, S. L. and E. K. Brown. 2007. Twenty-five years of change in coral coverage on a hurricane impacted reef in Hawai‘i: The importance of recruitment. *Coral Reefs* 26: 705-717.
- Coles, S. L., L. Giuseffi, and M. Hutchinson. 2008. Assessment of species composition, diversity and biomass in marine habitats and subhabitats around offshore islets in the main Hawaiian Islands. Final Report prepared for the Hawai‘i Coral Reef Initiative and the National Fish and Wildlife Foundation. Bishop Museum Technical Report 39, Honolulu, Hawai‘i.
- Connell, J. H. 1978. Diversity in tropical rain forests and coral reefs. *Science* 199: 1302-1310.
- Connell, J. H., T. P. Hughes, and C. C. Wallace. 1997. A 30-year study of coral abundance, recruitment, and disturbance at several scales in space and time. *Ecological Monographs* 67: 461-488.
- Dean, L. 1989. The Kalaupapa Lighthouse. *The Hawaiian Journal of History* 23: 137-169

- Demers, P. 1996. The "edge effect" on a submerged coral reef: Sedimentation as controlling factor for coral survival, growth, and recruitment. Thesis, University of Hawaii, Honolulu, Hawai'i.
- Dollar, S. J. 1975. Zonation of reef corals off the Kona coast of Hawaii. Thesis. University of Hawaii, Honolulu, Hawai'i.
- English, S., C. Wilkinson, and V. Baker. 1997. Survey manual for tropical marine resources, 2nd edition, Australian Institute of Marine Science, Townsville, Australia.
- Fabricius, K. E. 2005. Effects of terrestrial runoff on the ecology of corals and coral reefs: review and synthesis. *Marine Pollution Bulletin* 50: 125–146.
- Fenner, D. 2005. Corals of Hawaii: a field guide to the hard, black, and soft corals of Hawaii and the Northwest Hawaiian Islands, including Midway. Mutual Publishing, Honolulu, Hawaii.
- Field, M. E., S. A. Cochran, J. B. Logan, and C. D. Storlazzi. 2008. The coral reef of south Moloka'i, Hawai'i- portrait of a sediment-threatened fringing reef. U.S. Geological Survey Scientific Investigations Report 2007-5101.
- Fitzhardinge, R. C. 1993. The ecology of juvenile Hawaiian corals. Dissertation. University of Hawaii Honolulu, Hawai'i.
- Flexner, J. 2010. Archaeology of the recent past at Kalawao: Landscape, place, and power in a Hawaiian Hansen's disease settlement. Dissertation, University of California, Berkeley, California.
- Friedlander, A. M., and J. D. Parrish. 1998. Habitat characteristics affecting fish assemblages on a Hawaiian coral reef. *Journal of Experimental Marine Biology* 224: 1-30.
- Friedlander, A. M., E. K. Brown, P. L. Jokiel, W. R. Smith, and S. K. Rodgers. 2003. Effects of habitat, wave exposure, and marine protected area status on coral reef fish assemblages in the Hawaiian archipelago. *Coral Reefs* 22: 291-305.
- Friedlander, A. M. and E. K. Brown. 2006. Hanalei benthic communities since 1992: spatial and temporal trends in a dynamic Hawaiian coral reef ecosystem. Hawai'i Cooperative Studies Unit Technical Report HCSU-003. Hawai'i Cooperative Studies Unit, Pacific Aquaculture and Coastal Resources Center, University of Hawai'i – Hilo, Hawai'i.
- Friedlander, A. M, E. K. Brown, and M. E. Monaco. 2007. Defining reef fish habitat utilization patterns in Hawaii: implications for the effective design of marine protected areas. *Marine Ecology Progress Series* 351: 221-233.
- Friedlander, A., G. Aeby, R. Brainard, E. Brown, K. Chaston, A. Clark, P. McGowan, T. Montgomery, W. Walsh, I. Williams, and others. 2008. The State of Coral Reef Ecosystems of the Main Hawaiian Islands. Pages 219-261 in J. Waddell (editor), *The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2008*. NOAA

Technical Memorandum NOS NCCOS 11. NOAA/NCCOS Center for Coastal Monitoring and Assessment's Biogeography Team. Silver Spring, MD.

Fung Associates Inc. and SWCA Environmental Consultants. 2010. Assessment of natural resources and watershed conditions for Kalaupapa National Historical Park. Natural Resource Report NPS/NRPC/WRD/NRR—2010/261. National Park Service, Fort Collins, Colorado.

Harriott, V. J., and D. A. Fisk. 1987. A comparison of settlement plate types for experiments on the recruitment of scleractinian corals. *Marine Ecology Progress Series* 37: 201-208.

Hoegh-Guldberg O., P. J. Mumby, A. J. Hooten, R. S. Steneck, P. Greenfield, E. Gomez, C. D. Harvell, P. F. Sale, A. J. Edwards, K. Caldeira, and others. 2007. Coral reefs under rapid climate change and ocean acidification. *Science* 318: 1737–1742.

Hughes, T. P. 1993. Coral reef degradation: A long-term study of human and natural impacts. Pages 208-213 in *Proceedings of the Colloquium on Global Aspects of Coral Reefs, Health, Hazards, and History*, University of Miami, Florida.

Hughes, T. P., A. H. Baird, E. A. Dinsdale, N. A. Moltschaniwskyj, M. S. Pratchett, J. E. Tanner, and B. L. Willis. 2000. Supply-side ecology works both ways: the link between benthic adults, fecundity, and larval recruits. *Ecology* 81: 2241-2249.

Huisman, J. M, I. A. Abbott, and C. M. Smith. 2007. Hawaiian reef plants. University of Hawaii Sea Grant College Program, Report No. UNIH-SEAGRANT-BA-03-02, Honolulu, Hawaii.

IPCC, 2013: Summary for Policymakers. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Jaap, W. C., J. W. Porter, J. Wheaton, K. Hackett, M. Lybolt, M. Callahan, C. Tskos, G. Yanev, and P. Dustan. 2000. Coral reef monitoring project executive summary. EPA Science Advisory Panel. December 5-6, 2000, Key Colony Beach, Florida.

Jameson, C., M. Erdmann, G. Gibson, and K. Potts. 1998. The development of biology criteria for coral reef ecosystem assessment. *Atoll Research Bulletin* 450-458: 1-108.

Jokiel, P. L., E. K. Brown, A. Friedlander, S. K. Rodgers, and W. R. Smith. 2004. Hawaii Coral Reef Assessment and Monitoring Program: Spatial patterns and temporal dynamics in reef coral communities. *Pacific Science* 58: 159-174.

Jokiel, P. L., and E. K. Brown. 2004. Global warming, regional trends and inshore environmental conditions influence coral bleaching in Hawaii. *Global Change Biology* 10: 1627-1641.

- Jokiel, P. L. 2008. Biological and ecological functioning of coral reefs in the main Hawaiian Islands. Pages 489-518 in B.M. Riegl and R.E. Dodge, editors. *Coral Reefs of the USA*. Springer, New York, USA.
- Jones, T., K. DeVerse, G. Dicus, D. McKay, A. Farahi, K. Kozar, and E. Brown. 2011. Water quality vital signs monitoring protocol for the Pacific Island Network: Volume 1; Version 1.0. Natural Resource Report NPS/PACN/NRR—2011/418. National Park Service, Fort Collins, Colorado.
- Kayanne, H. and C. Hongo. 2011. Sea level change and its effect on reef growth. Pages 966-973 in D. Hopley, editor. *Encyclopedia of modern coral reefs*. Springer, Netherlands.
- Kojis, B. L., and N. J. Quinn. 2001. The importance of regional differences in hard coral recruitment rates for determining the need for coral restoration. *Bulletin of Marine Science* 69: 967-974.
- Kolinski, S. P. and E. F. Cox. 2003. An update on modes and timing of gamete and planula release in Hawaiian scleractinian corals with implications for conservation and management. *Pacific Science* 57: 17-27.
- Kolinski, S. P. 2004. Sexual reproduction and the early life history of *Montipora capitata* in Kāneʻohe, Bay, Oʻahu, Hawaiʻi. Dissertation. University of Hawaiʻi, Honolulu, Hawaiʻi.
- Manning, E. and E. Neller. 2005. Kahio benchmark survey. Pages 32-40 in M. D. McCoy, editor. *Kalaupapa Archaeology: A Collection of Five Archaeological Surveys in Kalaupapa National Historical Park, Hawaiʻi*. Report submitted to National Park Service by University of California, Berkeley.
- Martins, I., A. Marcotegui, and J. S. Marques. 2008. Impacts of macroalgal spores on the dynamics of macroalgae in a eutrophic estuary: High *versus* low hydrodynamic seasons and long-term simulations for global warming scenarios. *Marine Pollution Bulletin* 56: 984-998.
- McCormick, M. 1994. Comparison of field methods for measuring surface topography and their associations with a tropical reef fish assemblage. *Marine Ecology Progress Series* 112: 87-96.
- McCoy, M. D. 2005. Introduction. Pages 1-8 in M. D. McCoy, editor. *Kalaupapa Archaeology: A Collection of Five Archaeological Surveys in Kalaupapa National Historical Park, Hawaiʻi*. Report submitted to National Park Service by University of California, Berkeley.
- McCoy, M. D. 2007. Revised Late Holocene Culture History for Molokaʻi Island, Hawaiʻi. *Radiocarbon* 49: 1273-1322.
- Miller, J., R. Waara, E. Muller, and C. Rogers. 2006. Coral bleaching and disease combine to cause extensive mortality on reefs in the US Virgin Islands. *Coral Reefs* 25: 418.
- Minton, D. 2000. Role of architectural complexity in the structure of a marine phytal community. Dissertation. University of Hawaii, Manoa, Honolulu, Hawaii.

- Minton, D., I. Lundgren, and A. Pakenham. 2007. A two-year study of coral recruitment and sedimentation in Asan Bay, Guam. Unpublished Report, National Park Service, War in the Pacific National Historical Park, Hagatna, Guam.
- Moberg, F., and C. Folke. 1999. Ecological goods and services of coral reef ecosystems. *Ecological Economics* 29: 215-233.
- Mundy, C. N. 2000. Coral recruitment: a new method for attachment of artificial settlement plates to the reef substratum. *Coral Reefs* 19: 24-131.
- Nash, C., V. Doan, K. Kageyama, A. Atkinson, A. Davis, J. Miller, J. Patterson, M. Patterson, B. Ruttenberg, R. Waara, , and others. 2009. Coral Reefs in U.S. National Parks: A snapshot of status and trends in eight parks. Natural Resource Report NPS/NRPC/NRR – 2009/091.
- NOAA National Centers for Coastal Ocean Science (NCCOS). 2007. Atlas of the shallow-water benthic habitats of the main Hawaiian Islands. NOAA Technical Memorandum NOS NCCOS 61, Biogeography Team. Silver Spring, MD. 331 pp.
- NOAA. 2010. National Weather Service – Honolulu. Available at http://www.prh.noaa.gov/hnl/pages/gfe_graphics.php (accessed daily from August 2010 to December 2010).
- Nowlis, J. S., C. M. Roberts, A. H. Smith, and E. Siirila. 1997. Human-enhanced impacts of a tropical storm on nearshore coral reefs. *Ambio* 26: 515-521.
- Piepho, H. P. and J. O. Ogutu. 2002. A simple mixed model for trend analysis in wildlife populations. *Journal of Agricultural, Biological, and Environmental Statistics* 7(3): 350-360.
- Pinheiro, J. C. and D. M. Bates. 2004. *Mixed-Effects Models in S and S-PLUS*. Springer: New York.
- R Core Team. 2012. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL <http://www.R-project.org/>
- Remote Automated Weather Station. 2013. Available at <http://www.raws.dri.edu/wraws/hiF.html> (accessed 31 January 2013).
- Richmond, R. H. 1997. Reproduction and recruitment in corals: critical links in the persistence of reefs. Pages 360-364 *in* C. Birkeland, editor. *Life and death of coral reefs*. Chapman & Hall, New York, New York.
- Rogers, C. S, H. C. Fitz III, M. Gilnack, J. Beets, and J. Hardin. 1984. Scleractinian coral recruitment patterns at Salt River submarine canyon, St. Croix, U.S. Virgin Islands. *Coral Reefs* 3: 69-76.
- Rogers, C. S. 1990. Responses of coral reefs and reef organisms to sedimentation. *Marine Ecology Progress Series* 62: 185–202.

- Rogers, C. S., G. Garrison, R. Grober, A. M. Hillis, and M. A. Franke. 1994. Coral reef monitoring manual for the Caribbean and western Atlantic. National Park Service, Virgin Islands National Park, Central, U.S. Virgin Islands.
- Rohmann, S. O., J. J. Hayes, R. C. Newhall, M. E. Monaco, and R. W. Grigg. 2005. The area of potential shallow-water tropical and subtropical coral ecosystems in the United States. *Coral Reefs* 24: 370-383.
- Shinn, E. A., G. W. Smith, J. M. Prospero, P. Betzer, M. L. Betzer, V. Garrison, and R. T. Barber. 2000. African dust and the demise of Caribbean coral reefs. *Geophysical Research Letters* 27: 3029-3032.
- Sjöö, G., E. Mörk, S. Andersson, and I. Melander. 2011. Differences in top-down and bottom-up regulation of macroalgal communities between a reef crest and back reef habitat in Zanzibar. *Estuarine, Coastal and Shelf Science* 91: 511-518.
- State of Hawaii. 2014. State of Hawai‘i, Department of Transportation. Airports Division web site. <http://hawaii.gov/lup/airport-information/airport-history> (accessed 29 June 2014).
- Storlazzi, C. D., E. K. Brown, M. E. Field, K. Rodgers, and P. L. Jokiel. 2005. A model for wave control on coral breakage and species distribution in the Hawaiian Islands. *Coral Reefs* 24: 43-55.
- Storlazzi, C. D., M. K. Presto, and E. K. Brown. 2011. Coastal circulation and water column properties off Kalaupapa National Historical Park, Molokai, Hawaii, 2008–2010: U.S. Geological Survey, Reston. Open-File Report 2011-1154.
- Starcevich, L. A. H. 2013. Trend and power analysis for National Park Service marine data from 2006 to 2010: Pacific Island Network. Natural Resource Technical Report NPS/PACN/NRTR—2013/771. National Park Service, Fort Collins, Colorado.
- StatSoft, Inc. 2011. STATISTICA (data analysis software system), version 10. www.statsoft.com.
- Stormsurfing. 2010. Wave model – Hawaii web site. Available at <http://www.stormsurfing.com/cgi/display.cgi?a=hi> (accessed daily from August 2010 to December 2010).
- Tom, S. K. 2011. An investigation of the cultural use and population characteristics of ‘opihi (Mollusca: *Cellana* spp.) at Kalaupapa National Historical Park. Thesis. University of Hawai‘i-Hilo, Hawai‘i.
- U. S. Census Bureau. 2013. Kalawao County, Hawaii Quicklinks. Available at <http://quickfacts.census.gov/qfd/states/15/150051k.html> (accessed 15 March 2013).
- U. S. Naval Oceanographic Office. 2010. Wave Model (WAM) web site for Hawai‘i. Available at <https://oceanography.navy.mil/legacy/web/products/geo.htm> (accessed daily from December 2000 to July 2010).

- Waddell, J. E., editor. 2005. The state of coral reef ecosystems of the United States and Pacific Freely Associated States: 2005. Technical Memorandum 11, NOAA [National Oceanic and Atmospheric Administration], NOS [National Oceanic Service], NCCOS [National Centers for Coastal Ocean Science], Silver Spring, Maryland.
- Whitledge, T. E. 1993. The nutrient and hydrographic conditions prevailing in Laguna Madre, Texas before and during a brown tide bloom. Pages 71.1-71.6 *in* T. J. Smayda, and Y. Shimizu, editors. Toxic Phytoplankton Blooms in the Sea. Elsevier, Amsterdam, Netherlands.
- Zar, J. H. 1999. Biostatistical analysis, 4th edition. Prentice Hall, Upper Saddle River, NJ.

Appendix A. Metadata for Kalaupapa National Historical Park from 2006-2010.

Appendix A. Metadata for Kalaupapa National Historical Park from 2007. Coral settlement tiles were only deployed at fixed transects.

Survey Date	Transect	Transect Type	Latitude	Longitude	Deployed	Retrieved	Bearing	Depth (m)	Rugosity
8/2/2006	1	Fixed	21.18705	-157.01559	4/25/2006	9/6/2006	90	17.8	1.41
8/2/2006	2	Fixed	21.18609	-157.01321	4/25/2006	9/6/2006	120	12.8	1.45
8/10/2006	3	Fixed	21.19380	-156.98687	4/25/2006	9/6/2006	0	14.2	1.72
8/2/2006	4	Fixed	21.19911	-156.98765	4/25/2006	9/6/2006	30	18.4	1.42
8/8/2006	5	Fixed	21.20736	-156.98396	4/25/2006	9/6/2006	90	11.5	1.43
7/24/2006	6	Fixed	21.20795	-156.98288	4/28/2006	9/6/2006	30	12.7	1.30
8/10/2006	7	Fixed	21.21069	-156.98184	4/28/2006	9/6/2006	60	20.7	2.00
7/24/2006	8	Fixed	21.21538	-156.96892	4/27/2006	9/5/2006	90	14.8	1.94
7/25/2006	9	Fixed	21.21411	-156.96586	4/28/2006	9/5/2006	120	14.8	1.65
8/1/2006	10	Fixed	21.19950	-156.95477	4/27/2006	9/5/2006	150	15.6	1.49
8/9/2006	11	Fixed	21.19179	-156.94896	4/27/2006	9/5/2006	150	15.2	1.62
8/9/2006	12	Fixed	21.18918	-156.94775	4/27/2006	9/5/2006	180	16.8	1.70
8/8/2006	13	Fixed	21.18428	-156.94775	4/27/2006	9/6/2006	150	12.8	1.42
8/15/2006	14	Fixed	21.17179	-156.92124	4/27/2006	9/6/2006	210	13.8	1.44
8/15/2006	15	Fixed	21.17183	-156.91610	4/27/2006	9/6/2006	270	13.6	1.49
8/8/2006	1	Temporary	21.19024	-156.98621			0	12.5	1.80
7/24/2006	2	Temporary	21.19825	-156.98783			30	19.1	1.68
7/25/2006	3	Temporary	21.21557	-156.97370			40	18.1	2.13
7/27/2006	4	Temporary	21.20847	-156.95935			140	14.0	1.85
7/27/2006	5	Temporary	21.20602	-156.95699			160	19.2	1.70
8/1/2006	6	Temporary	21.20322	-156.95565			180	18.8	1.58
8/1/2006	7	Temporary	21.20057	-156.95546			160	13.8	1.50
8/1/2006	8	Temporary	21.19571	-156.95186			150	13.3	1.56
8/1/2006	9	Temporary	21.19466	-156.95069			160	17.8	1.66
8/8/2006	10	Temporary	21.18903	-156.94818			180	11.4	1.65
8/8/2006	11	Temporary	21.18648	-156.94680			180	17.8	1.60
8/9/2006	12	Temporary	21.17617	-156.94366			15	13.4	1.12
8/16/2006	13	Temporary	21.17405	-156.93648			90	12.2	1.44
8/16/2006	14	Temporary	21.17180	-156.92561			270	12.8	1.34
8/16/2006	15	Temporary	21.17320	-156.92486			90	17.0	1.49

Appendix A. Metadata for Kalaupapa National Historical Park from 2007. Coral settlement tiles were only deployed at fixed transects (continued).

Survey Date	Transect	Transect Type	Latitude	Longitude	Deployed	Retrieved	Bearing	Depth (m)	Rugosity
8/9/2007	1	Fixed	21.18705	-157.01559	4/11/2007	9/4/2007	90	17.8	1.49
8/9/2007	2	Fixed	21.18609	-157.01321	4/11/2007	9/4/2007	120	12.8	1.39
8/9/2007	3	Fixed	21.19380	-156.98687	4/12/2007	9/4/2007	0	14.2	1.65
8/7/2007	4	Fixed	21.19911	-156.98765	4/12/2007	9/4/2007	30	18.4	1.43
8/7/2007	5	Fixed	21.20736	-156.98396	4/11/2007	9/4/2007	90	11.5	1.44
8/2/2007	6	Fixed	21.20795	-156.98288	4/12/2007	9/4/2007	30	12.7	1.25
8/8/2007	7	Fixed	21.21069	-156.98184	4/12/2007	9/4/2007	60	20.7	2.16
7/19/2007	8	Fixed	21.21538	-156.96892	4/12/2007	9/5/2007	90	14.8	1.88
7/19/2007	9	Fixed	21.21411	-156.96586	4/12/2007	9/5/2007	120	14.8	1.62
7/31/2007	10	Fixed	21.19950	-156.95477	4/12/2007	9/5/2007	150	15.6	1.49
8/1/2007	11	Fixed	21.19179	-156.94896	4/12/2007	9/5/2007	150	15.2	1.61
8/1/2007	12	Fixed	21.18918	-156.94775	4/11/2007	9/5/2007	180	16.8	1.75
8/1/2007	13	Fixed	21.18428	-156.94775	4/11/2007	9/5/2007	150	12.8	1.42
8/7/2007	14	Fixed	21.17179	-156.92124	4/12/2007	9/5/2007	210	13.8	1.43
8/7/2007	15	Fixed	21.17183	-156.91610	4/12/2007	9/5/2007	270	13.6	1.56
8/9/2007	1	Temporary	21.18673	-157.01744			0	17.1	1.39
8/8/2007	2	Temporary	21.18615	-157.01336			30	14.7	1.43
8/7/2007	3	Temporary	21.19925	-156.98676			40	12.9	1.68
8/2/2007	4	Temporary	21.20917	-156.98192			140	12.6	1.87
8/2/2007	5	Temporary	21.21090	-156.98083			160	20.0	1.81
7/19/2007	6	Temporary	21.21404	-156.97612			180	11.2	1.20
8/2/2007	7	Temporary	21.21501	-156.97608			160	17.7	1.93
7/31/2007	8	Temporary	21.20906	-156.95940			150	15.9	1.76
7/19/2007	9	Temporary	21.20869	-156.95939			160	16.2	1.86
7/31/2007	10	Temporary	21.20696	-156.95723			180	17.7	1.91
7/31/2007	11	Temporary	21.20659	-156.95720			180	15.0	1.91
8/1/2007	12	Temporary	21.18767	-156.94690			160	18.8	1.43
8/1/2007	13	Temporary	21.17508	-156.94350			90	11.7	1.62
8/7/2007	14	Temporary	21.17117	-156.92049			270	12.4	1.35
8/2/2007	15	Temporary	21.16790	-156.91311			90	11.4	1.69

Appendix A. Metadata for Kalaupapa National Historical Park from 2008. Coral settlement tiles were only deployed at fixed transects (continued).

Survey Date	Transect	Transect Type	Latitude	Longitude	Deployed	Retrieved	Bearing	Depth (m)	Rugosity
7/21/2008	1	Fixed	21.18705	-157.01559	4/7/2008	9/23/2008	90	17.5	1.46
7/22/2008	2	Fixed	21.18609	-157.01321	4/15/2008	9/23/2008	120	12.9	1.43
8/27/2008	3	Fixed	21.19380	-156.98687	4/7/2008	9/23/2008	0	14.2	1.63
7/22/2008	4	Fixed	21.19911	-156.98765	4/15/2008	9/23/2008	30	18.5	1.43
7/23/2008	5	Fixed	21.20736	-156.98396	4/16/2008	9/23/2008	90	11.2	1.52
7/22/2008	6	Fixed	21.20795	-156.98288	4/16/2008	9/23/2008	30	12.7	1.27
7/23/2008	7	Fixed	21.21069	-156.98184	4/16/2008	9/23/2008	60	20.9	2.20
8/19/2008	8	Fixed	21.21538	-156.96892	4/8/2008	9/22/2008	90	15.0	2.04
8/19/2008	9	Fixed	21.21411	-156.96586	4/8/2008	9/22/2008	120	15.9	1.69
8/27/2008	10	Fixed	21.19950	-156.95477	4/9/2008	9/22/2008	150	16.3	1.51
8/26/2008	11	Fixed	21.19179	-156.94896	4/9/2008	9/23/2008	150	15.3	1.68
8/26/2008	12	Fixed	21.18918	-156.94775	4/9/2008	9/22/2008	180	17.3	1.64
8/26/2008	13	Fixed	21.18428	-156.94775	4/8/2008	9/23/2008	150	13.6	1.47
8/20/2008	14	Fixed	21.17179	-156.92124	4/8/2008	9/22/2008	210	14.3	1.45
8/20/2008	15	Fixed	21.17183	-156.91610	4/9/2008	9/22/2008	270	13.7	1.57
7/21/2008	1	Temporary	21.18759	-157.02499			90	18.1	1.63
7/21/2008	2	Temporary	21.18664	-157.01713			260	17.1	1.65
7/22/2008	3	Temporary	21.18690	-157.01365			90	16.6	1.44
7/22/2008	4	Temporary	21.20520	-156.98588			220	12.8	1.40
7/23/2008	5	Temporary	21.21017	-156.98165			200	11.5	1.47
8/25/2008	6	Temporary	21.21496	-156.97549			60	18.5	2.07
8/25/2008	7	Temporary	21.21478	-156.97348			60	13.0	1.17
8/20/2008	8	Temporary	21.21058	-156.96156			150	16.7	2.14
8/19/2008	9	Temporary	21.20685	-156.95679			150	21.4	1.98
8/27/2008	10	Temporary	21.20022	-156.95482			150	19.0	1.43
8/26/2008	11	Temporary	21.19597	-156.95210			120	14.6	1.60
8/26/2008	12	Temporary	21.19388	-156.95098			150	12.5	1.95
8/25/2008	13	Temporary	21.18260	-156.94673			320	16.2	1.79
8/25/2008	14	Temporary	21.17515	-156.92959			40	16.1	1.36
8/25/2008	15	Temporary	21.17324	-156.92198			300	16.3	1.43

Appendix A. Metadata for Kalaupapa National Historical Park from 2009. Coral settlement tiles were only deployed at fixed transects (continued).

Survey Date	Transect	Transect Type	Latitude	Longitude	Deployed	Retrieved	Bearing	Depth (m)	Rugosity
7/13/2009	1	Fixed	21.18705	-157.01559	4/13/2009	9/14/2009	90	17.6	1.57
7/13/2009	2	Fixed	21.18609	-157.01321	4/13/2009	9/14/2009	120	12.6	1.50
8/3/2009	3	Fixed	21.19380	-156.98687	4/13/2009	9/14/2009	0	14.1	1.64
7/17/2009	4	Fixed	21.19911	-156.98765	4/13/2009	9/14/2009	30	19.1	1.60
7/13/2009	5	Fixed	21.20736	-156.98396	4/13/2009	9/15/2009	90	11.4	1.51
8/5/2009	6	Fixed	21.20795	-156.98288	4/13/2009	9/15/2009	30	13.3	1.28
7/17/2009	7	Fixed	21.21069	-156.98184	4/13/2009	9/14/2009	60	21.2	2.19
7/15/2009	8	Fixed	21.21538	-156.96892	4/16/2009	9/15/2009	90	15.4	2.04
7/15/2009	9	Fixed	21.21411	-156.96586	4/16/2009	9/15/2009	120	15.8	1.62
7/16/2009	10	Fixed	21.19950	-156.95477	4/16/2009	9/15/2009	150	15.8	1.55
8/5/2009	11	Fixed	21.19179	-156.94896	4/16/2009	9/14/2009	150	14.7	1.90
7/16/2009	12	Fixed	21.18918	-156.94775	4/16/2009	9/14/2009	180	17.4	1.66
7/16/2009	13	Fixed	21.18428	-156.94775	4/16/2009	9/14/2009	150	13.2	1.52
8/5/2009	14	Fixed	21.17179	-156.92124	4/16/2009	9/14/2009	210	14.0	1.45
7/14/2009	15	Fixed	21.17183	-156.91610	4/16/2009	9/14/2009	270	13.6	1.64
7/13/2009	1	Temporary	21.18452	-157.00722			90	18.0	1.73
7/13/2009	2	Temporary	21.18330	-157.00689			120	12.2	1.79
8/3/2009	3	Temporary	21.18318	-157.00675			90	12.0	1.67
8/3/2009	4	Temporary	21.18296	-157.00387			90	20.2	1.44
7/17/2009	5	Temporary	21.19607	-156.98773			150	18.1	1.78
7/17/2009	6	Temporary	21.20331	-156.98645			210	15.0	1.94
8/5/2009	7	Temporary	21.21074	-156.98166			60	21.4	2.20
7/15/2009	8	Temporary	21.21452	-156.96810			320	12.9	1.18
8/5/2009	9	Temporary	21.20860	-156.95938			150	12.8	1.90
7/16/2009	10	Temporary	21.20352	-156.95656			150	13.1	1.49
7/16/2009	11	Temporary	21.18828	-156.94799			330	13.2	1.51
7/14/2009	12	Temporary	21.18254	-156.94736			330	11.6	1.37
7/14/2009	13	Temporary	21.17319	-156.92735			240	19.3	1.37
7/14/2009	14	Temporary	21.17187	-156.92183			330	11.6	1.44
7/14/2009	15	Temporary	21.17174	-156.91786			260	20.5	1.80

Appendix A. Metadata for Kalaupapa National Historical Park from 2010. Coral settlement tiles were only deployed at fixed transects (continued).

Survey Date	Transect	Transect Type	Latitude	Longitude	Deployed	Retrieved	Bearing	Depth (m)	Rugosity
8/2/2010	1	Fixed	21.18705	-157.01559	4/6/2010	9/13/2010	90	17.6	No Rug
8/3/2010	2	Fixed	21.18609	-157.01321	4/6/2010	9/13/2010	120	12.6	No Rug
8/12/2010	3	Fixed	21.19380	-156.98687	4/6/2010	9/13/2010	0	14.1	No Rug
8/4/2010	4	Fixed	21.19911	-156.98765	4/6/2010	9/13/2010	30	19.1	No Rug
8/4/2010	5	Fixed	21.20736	-156.98396	4/6/2010	9/14/2010	90	11.4	No Rug
8/3/2010	6	Fixed	21.20795	-156.98288	4/6/2010	9/14/2010	30	13.3	No Rug
8/4/2010	7	Fixed	21.21069	-156.98184	4/7/2010	9/13/2010	60	21.2	No Rug
8/11/2010	8	Fixed	21.21538	-156.96892	4/7/2010	9/14/2010	90	15.4	No Rug
8/12/2010	9	Fixed	21.21411	-156.96586	4/7/2010	9/14/2010	120	15.8	No Rug
8/11/2010	10	Fixed	21.19950	-156.95477	4/7/2010	9/14/2010	150	15.8	No Rug
8/10/2010	11	Fixed	21.19179	-156.94896	4/7/2010	9/14/2010	150	14.7	No Rug
8/11/2010	12	Fixed	21.18918	-156.94775	4/7/2010	9/14/2010	180	17.4	No Rug
8/5/2010	13	Fixed	21.18428	-156.94775	4/7/2010	9/14/2010	150	13.2	No Rug
8/10/2010	14	Fixed	21.17179	-156.92124	4/7/2010	9/14/2010	210	14.0	No Rug
8/5/2010	15	Fixed	21.17183	-156.91610	4/7/2010	9/14/2010	270	13.6	No Rug
8/3/2010	1	Temporary	21.18711	-157.02438			270	18.0	1.63
8/2/2010	2	Temporary	21.18733	-157.01358			60	12.2	1.52
8/2/2010	3	Temporary	21.18555	-157.01149			90	12.0	1.61
8/2/2010	4	Temporary	21.18282	-157.00368			120	20.2	1.41
8/10/2010	5	Temporary	21.20470	-156.98681			20	18.1	1.25
8/4/2010	6	Temporary	21.20609	-156.98695			180	15.0	1.34
8/4/2010	7	Temporary	21.20834	-156.98260			30	21.4	1.44
8/5/2010	8	Temporary	21.21439	-156.96568			270	12.9	1.78
8/11/2010	9	Temporary	21.20806	-156.95915			330	12.8	2.15
8/11/2010	10	Temporary	21.20101	-156.95536			170	13.1	1.57
8/11/2010	11	Temporary	21.19674	-156.95306			310	13.2	2.03
8/10/2010	12	Temporary	21.19685	-156.95282			150	11.6	2.10
8/5/2010	13	Temporary	21.18307	-156.94686			150	19.3	1.70
8/10/2010	14	Temporary	21.17921	-156.94587			150	11.6	1.31
8/5/2010	15	Temporary	21.17286	-156.92180			300	20.5	1.46

Appendix B: Database Queries Used to Generate Reports

Status Maps

Data	Excel File	Columns in Excel File	Database Query
Percent coral Cover	Benthic_Cover_Status_Maps	Coral%	qs_b021_Benthic_Cover_Percent_by_Type
Percent macroalgae cover	Benthic_Cover_Status_Maps	Algae%	qs_b021_Benthic_Cover_Percent_by_Type
Percent coralline algae cover	Benthic_Cover_Status_Maps	CorallineAlgae%	qs_b021_Benthic_Cover_Percent_by_Type
Percent turf algae cover	Benthic_Cover_Status_Maps	Turf Algae%	qs_b021_Benthic_Cover_Percent_by_Type
Coral species richness	Coral_Richness_Status_Maps	Richness	qs_cr021_Coral_Species_Richness_by_Transect
Coral disease	Coral_Disease_Status_Maps	Percent	qs_d021_Disease_%_of_Frames_by_Transect
Coral settlement	Coral_Settlement_Status_Maps	<i>Fungia</i> , <i>Leptastrea</i> , <i>Montipora</i> , <i>Pocillopora</i> , <i>Porites</i>	qs_cs021_Coral_Settlement_by_Transect

Trend Line Graphs

Data	Excel File	Columns in Excel File	Database Query
Percent coral Cover	Coral_Cover_Trends	All years	qs_c041_Coral_Cover_Trend
Percent macroalgae cover	Macroalgae_Cover_Trends	All years	qs_a041_Macroalgae_Cover_Trend
Percent coralline algae cover	Corallinealgae_Cover_Trends	All years	qs_ca041_Corallinealgae_Cover_Trend
Percent turf algae cover	Turfalgae_Cover_Trends	All years	qs_t041_Turfalgae_Cover_Trend
Coral species richness	Coral_Richness_Trends	All years	qs_c041_Coral_Species_Richness_Trend
Coral disease	Coral_Disease_Trends	All years	qs_d041_Coral_Disease_%_Trend

Tables

Data	Excel File	Columns in Excel File	Database Query
Metadata	Metadata	All columns	qs_md001_Metadata_by_Transect
Top ten substrate types/taxa	Benthic_Cover_Top_Ten_Table	FirstOfType,TaxonName, Percent	qs_b061_Benthic_Cover_Top_Ten

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 491/126784, October 2014

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