National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Kalaupapa National Historical Park Marine Fish Monitoring Program Trend Report for 2006-2010

Pacific Island Network

Natural Resource Report NPS/KALA/NRR—2015/1026

ON THE COVER
Bluespine unicornfish (*Naso unicornis*) and other herbivores at Kalaupapa National Historical Park, Molokaʻi, Hawaiʻi.
Photograph by: Kalaupapa National Historical Park, Molokaʻi, Hawaiʻi.

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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.

This report is available from NPS Inventory and Monitoring, Pacific Island Network (http://science.nature.nps.gov/im/units/pacn/index.cfm) and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/). To receive this report in a format optimized for screen readers, please email irma@nps.gov.

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Executive Summary

Kalaupapa National Historical Park (NHP) is located on the north shore of the island of Molokaʻi 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. Kalaupapa NHP 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 objective of I&M PACN Marine Fish Monitoring Protocol at Kalaupapa NHP is to annually determine the density and size of reef fishes at sites randomly selected on hard substrata between the 10 and 20 m depths (Brown et al. 2011b). 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 in 2006 as 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. Data collection consisted of a visual count and size estimation of all fishes within 25 x 5 m underwater belt transects. Scientific divers were used to conduct these surveys and focused on all diurnal or day-active fish species.

This report includes the status and trends of the fish populations observed at all 150 transects at Kalaupapa NHP from 2006-2010 as determined by implementation of the I&M PACN Benthic Marine Community Monitoring Protocol (Brown et al. 2011b).

Spatial patterns for the fish data indicated that:

- Fish species richness ranged from 11- 45 per transect with a total of 132 species documented from 2006-2010. Overall mean richness was 26.0 ± 7.1 SD species per transect from 2006-2010. No clear pattern was observed in the spatial distribution of fish species richness.

- Fish species density ranged from 0.3-4.9 fish m^{-2}. Overall mean was 1.5 ± 1.1 SD fish m^{-2} from 2006-2010. Fish density was higher around the northern tip of the peninsula, while the lowest fish densities were located along the eastern and western portions of the park.

- Fish biomass ranged from 8.1-1299.8 grams (g) m^{-2}. Overall mean was 208.7 ± 212.6 SD g m^{-2} from 2006-2010. No clear pattern was observed in the spatial distribution of fish biomass, with high and low values documented throughout the park. However, fish biomass was higher at several points along the peninsula, most likely due to large predators such as *Caranx melampygus* (bluefin trevally) and the introduced *Cephalopholis argus* (blue-spotted grouper).

- Fish diversity (H’) ranged from 0.7- 3.1 at all transects from 2006-2010. Overall mean was 2.15 ± 0.04 SE H’ from 2006-2010. No clear pattern was observed in the spatial distribution of fish diversity.

Ten fish species made up 63.5% of the total fish biomass. Of these, one was an apex predator, five were primary consumers, and four were secondary consumers. In terms of density, *Chromis vanderbilti*, a small planktivorous damselfish, was by far the most abundant species. This species was seven times more abundant than the next most common species in the park, the primary consumer *Kyphosus* spp. Five of the top ten most abundant species by density were primary consumers, and five were secondary consumers.

Trends for the fish data indicated that:

- Mean fish species richness remained relatively stable from 2006-2008 (mean 27.3 ± 0.8 SE species per transect), but declined significantly in 2009 (mean 23.7 ± 1.2 SE species per transect) and remained at this lower level in 2010 (mean 24.4 ± 1.0 SE species per transect).

- Mean fish species density remained relatively stable from 2006-2008 (mean 1.8 ± 0.1 SE fish m^{-2}) but declined in 2009 (mean 1.0 ± 0.1 fish m^{-2}) and then remained stable in 2010 (mean 1.3 ± 0.2 fish m^{-2}).

- Mean fish biomass remained relatively stable between 2006 and 2010 (mean 208.7 ± 17.4 SE g m^{-2}).

- Mean fish diversity (H') was relatively similar in all years from 2006-2010 (mean 2.15 ± 0.04 SE H'), except in 2008, when it was 1.9 ± 0.1 SE H'.

- 32 endemic fish species (24% of the total number of fish species) comprised 12.4% of the total fish density and 7.2% of the total fish biomass. This pattern did not appear to change from 2006 – 2010.

- Four invasive fish species, (3% of the total number of fish species), three introduced by humans and one recent colonizer, comprised 1.5% of the total fish density and 7.5% of the total fish biomass. The two primary introduced species (*Lutjanus kasmira* and *Cephalopholis argus* [peacock grouper]) accounted for 99% of the invasive fish biomass. This pattern also did not appear to change from 2006 – 2010.

Possible explanations for each of the observed patterns are presented in the discussion. At present, the fish assemblage at Kalaupapa appears to be stable and relatively healthy in terms of density and biomass compared to other sites around the main Hawaiian Islands (MHI).

Acknowledgments

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

List of Terms and Acronyms

PACN: Pacific Island Network

I&M: Inventory and Monitoring Program

Trophic groups: groups or organisms defined by nutritional habits and requirements

MHI: main Hawaiian Islands

NWHI: northwestern Hawaiian Islands

km: kilometers

m: meters

Introduction

The marine fish assemblage community in the Pacific Island Network (PACN) is an ecologically diverse system with numerous trophic groups intertwined within extensive coral reef ecosystems. 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). Because of their importance ecologically, culturally and economically, it is critical that Pacific Island Network (PACN) parks have scientifically rigorous data on the current health and long-term trends of the marine fish communities within their boundaries. Within coral reefs, marine fishes are one of the most visible and certainly the most exploited resource.

Coral reef fish assemblages are essential to the traditional lifestyles and cultures of Hawaiian, Samoan, Chamorro, Carolinean and other peoples in the islands throughout the PACN. Furthermore, coral reef fishes 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 these assemblages, it is critical that the PACN parks continue to collect scientifically rigorous data on the current health and long-term trends of these crucial fish communities as well as their associated 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 marine fish Vital Sign is most closely linked with the benthic marine Vital Sign, and monitoring efforts are co-located and sampled at the same time to maximize data value. A copy of the marine fish protocol can be found on the National Park Service website, http://science.nature.nps.gov/im/units/pacn/publications.cfm. This Vital Sign monitoring protocol is implemented in four parks: Kaloko-Honokōhau National Historical Park, Kalaupapa National Historical Park, National Park of American Samoa, and War in the Pacific National Historical Park.

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 (809 hectares), the marine boundary of the park extends from the shoreline to a quarter mile (0.4 km) 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 to10 m) northwest Pacific swells in the winter months (October – April) (Fung Associates, Inc. and SWCA Environment Consultants 2010).

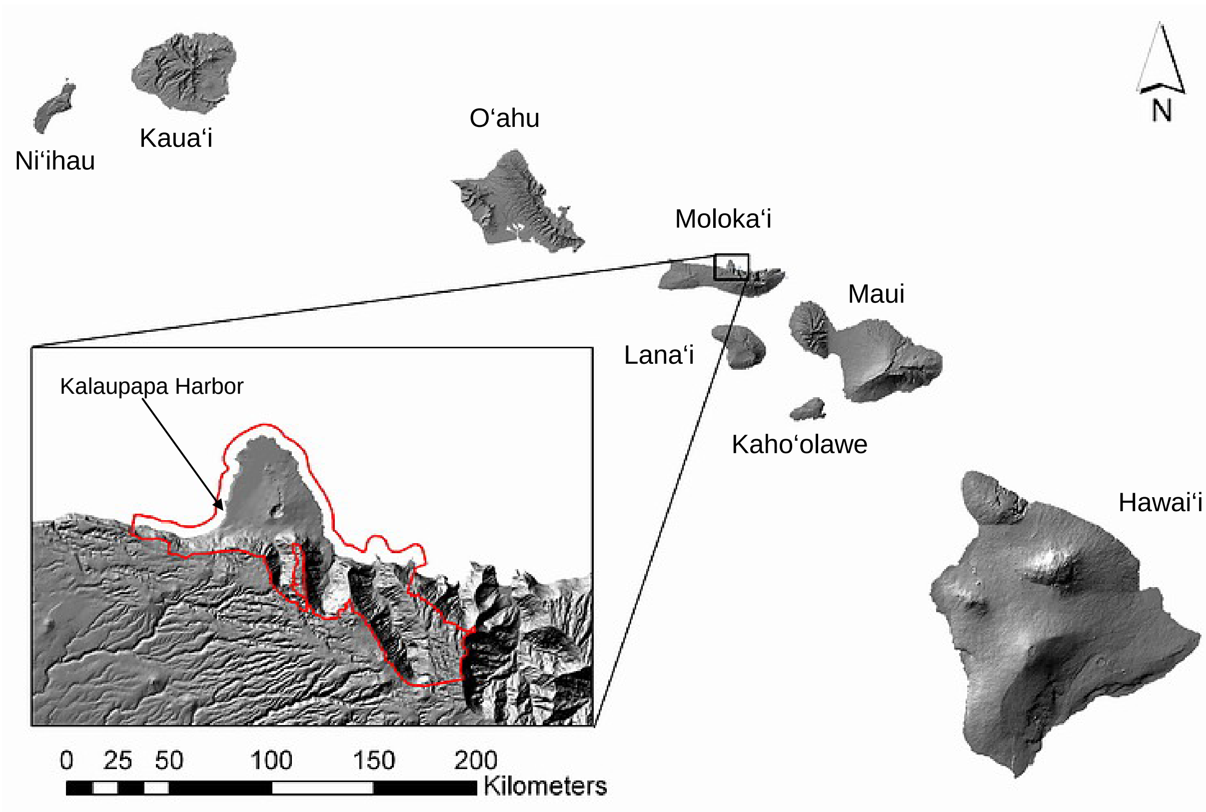

Figure 1. Map of the main Hawaiian Islands (MHI) showing Kalaupapa National Historical Park with the park boundary delineated as a red line in the inset.

The initial source of information on fish assemblages at Kalaupapa NHP is from Beets et al. (2010) who surveyed the reefs from 2004 to 2005. Their data on species richness, numerical density, biomass, and diversity was the first known study to document fish habitat utilization patterns within the park boundaries. Beets et al. (2010) reported that Kalaupapa NHP had the fish species most commonly found in Hawai‘i with high fish density and biomass compared to other areas around the state. Recently, Coles et al. (2008) surveyed the offshore islands in and around the park for unique fish species, numerical density levels, biomass, and diversity. Reef Environmental Education Foundation (REEF; www.reef.org) also has two sites on the north coast of Moloka'i that provide species checklist information in similar habitats to the park.

The methodology to monitor coral reef fishes has been developed over the past 25 years, resulting in several commonly used survey techniques (e.g., Bohnsack and Bannerot 1986, Rogers et al. 1994, English et al. 1997, Samoilys 1997, Sweatman et al. 1998, Atlantic and Gulf

Rapid Reef Assessment 2000, Hill and Wilkinson 2004). The technique adopted to collect scientifically rigorous data on the status and long-term trends of the fish communities for PACN consisted of a visual count and size estimation of fish by scientific divers along underwater 25 m x 5 m belt transects (Brown et al. 2011b). This non-destructive technique initiated in 2006 addressed one primary monitoring question and corresponding objective. The question is; what are the long-term trends in the numerical density, biomass, and size of reef fishes in a park? The primary objective is to annually determine the density, biomass, and size of one major component of the coral reef fish community—the diurnal or day-active fish species that are highly visible due to their mobile behavior and generally larger size. These species are the most heavily targeted by local fishers. While the small, cryptic or nocturnal species contribute to biodiversity and may be of ecological or management importance, the additional effort and time required to sample these fishes is not feasible with available resources in a park. Sample sites are randomly selected on hard substrata between the 10 and 20 meter depths (selected for ecologic and safety reasons).

The visual estimate of fish size is an important component of these surveys for several reasons. First, lengths allow a conversion from fish numbers to biomass by using established length-weight relationships (e.g., Friedlander et al. 2007). Second, lengths are often a useful indicator of fishing pressure or population dynamics, e.g., a trend of decreasing sizes may indicate overfishing, or recruitment year classes (Bejarano et al. 2013). Third, there is a strong positive correlation between fish size and fecundity (reproductive potential) which, along with recruitment success, is important in assessing ecological services provided by park fish assemblages (Saenz-Aqudelo et al. 2015).

Fishing is allowed in Kalaupapa NHP, but State of Hawaiʻi laws and County of Kalawao community rules regulate resource use within the park's marine waters (National Park Service, 2015). NPS law enforcement rangers, who are also deputized in the County of Kalawao, enforce these laws and community rules. The rules and regulations listed below vary depending on whether the fisher is a Hansen 's disease patient, employee resident, or visitor/guest.

Hansen's disease Patients are exempt from state laws regarding gear type, seasonal closure, bag limits and size limits. Community sentiment, however, does oppose the sale of any fisheries catch, especially outside of the settlement.

State and federal employees at Kalaupapa must follow state laws for seasonal closures, bag limits, gear types, and size limits. Employee residents are allowed to subsistence fish and take fish out for their families, but are discouraged from selling their catch. Community rules specifically prohibit employees from scuba diving except on behalf of the NPS marine research program.

Visitors on boats may legally fish and even travel within the park boundaries, but this is discouraged unless they are sponsored by patients or employee residents of Kalaupapa. Regardless of sponsorship, they must still follow state laws regarding seasonal closures, bag limits, gear types, and size limits. These fishing practices by people outside of the settlement, however, are discouraged by patients and employee residents and viewed as disrespectful of the stewardship ethic that is currently in place. It should be noted that commercial activities within the park boundary, such as charter dive boats and fishing vessels, must adhere to the park's enabling legislation which states that patients have a “first right of refusal to provide revenue-producing visitor services” (State of Hawaiʻi Public Law 96-565, Section 107). Sponsored visitors on boats who do come ashore have to follow the same rules and regulations as visitors who arrive by plane or on land (See “Onshore visitors” below).

Onshore visitors must have a park-based sponsor and are more tightly regulated than patients, government employees, or boat visitors. They may only pole and line fish from shore. They may not use nets or spears, pick intertidal invertebrates, or scuba dive at any point within the park. The Kalaupapa Patient Advisory Council instituted the rule to limit outside visitors from most fishing activities and picking intertidal invertebrates (Langlas et al. 2008). An additional rule for visitors is that they can fish within the settlement without an escort, but going outside of the settlement requires a patient or employee resident escort. Violators of these rules are banned from future visits. Even though it is not a community rule or state law, patients and employee residents prefer that any fishery resources caught within the park be consumed at Kalaupapa.

The purpose of this report was to examine the changes in the marine fish assemblage at Kalaupapa NHP from 2006 to 2010. First, an overview of fish assemblage characteristics from 2006 to 2010 is presented for species richness, density, biomass and diversity using spatial distribution maps. Second, the trophic composition of the entire assemblage averaged over the study period was examined for both density and biomass. Third, the top ten species from 2006 to 2010 in terms of density and biomass were listed to examine specific components of the assemblage. Fourth, trends in the entire assemblage from 2006-2010 were plotted for species richness, density, biomass, and diversity. Finally, temporal patterns for endemic and invasive fish species were examined in terms of fish density and biomass. It should be noted that there are no endangered or threatened marine fish species reported from Hawaiʻi (U. S. Fish Wildlife Service 2015).

Methods

Sampling Locations

A split panel design was used with 30 belt transects (25 m long x 5 m wide) sampled annually between 2006 and 2010 (Brown et al. 2011b). All transects were randomly selected using ArcGIS® within the Kalaupapa NHP sampling frame (Figure 2), which 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.

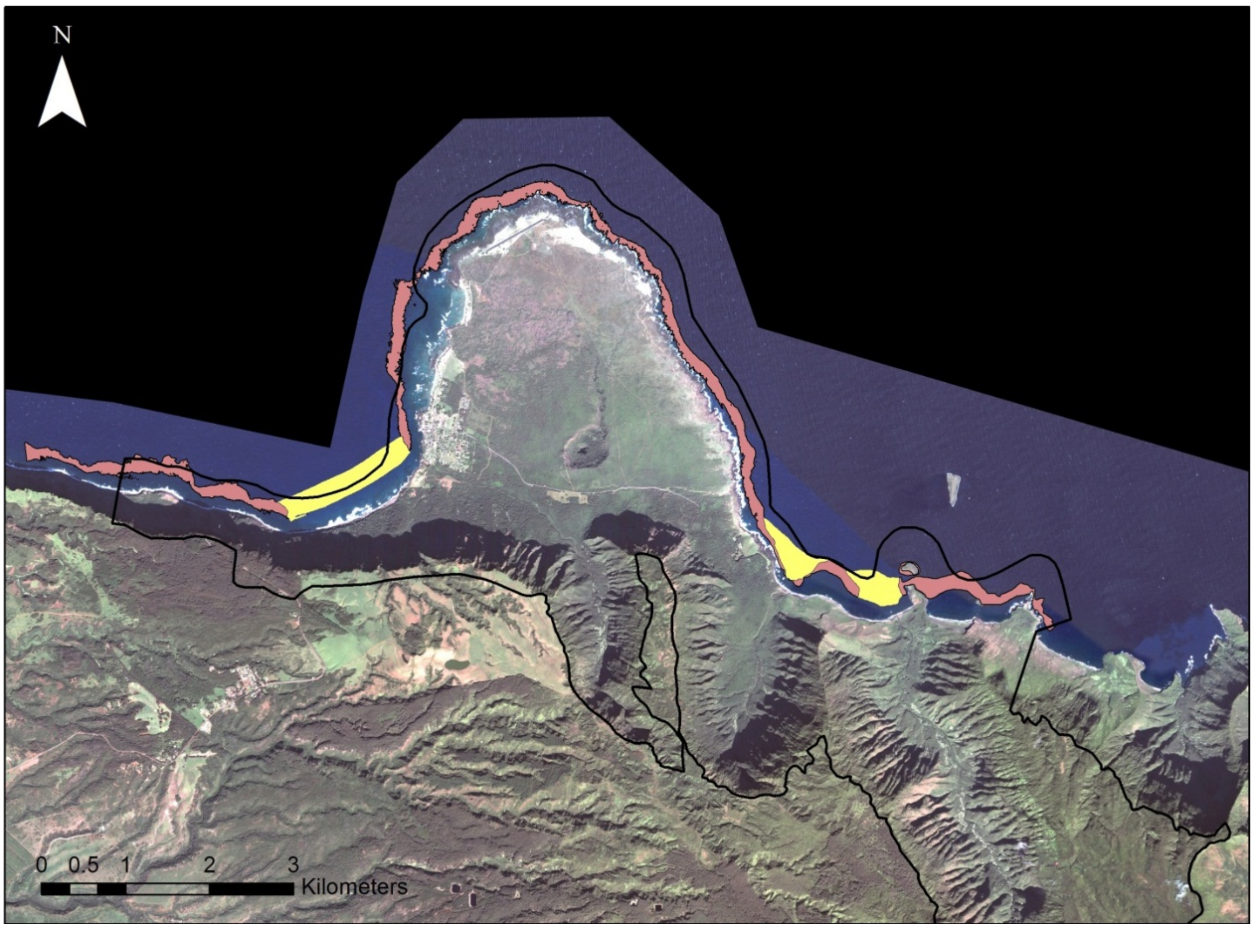

Figure 2. Sampling frame between 10 m and 20 m depth on hard bottom substrate (light red polygon) at Kalaupapa National Historical Park. Sand habitat is shown by yellow polygons. Black line indicates park boundary including ¼ mile (0.4 km) into the marine environment.

Survey Methods

Fish surveys occurred during the summer months from July through August in concurrence with the benthic and water quality protocols. At each site, the fish observer, using SCUBA, deployed a transect line along a constant depth contour which was typically parallel to shore. Locations, bearings, and depths of all transects are in Appendix A. The observer counted and estimated the total length (to the nearest centimeter) of all fishes encountered along the distance of this transect in the 5 m wide belt. Data were recorded on pre-printed waterproof forms attached to a slate. The location, bearing, survey date, and depth of transects, which constitute the sampling unit, were recorded after each dive. Total area sampled on each transect was 125 m^2 for a total area of 3750 m^2 across all 30 transects each year.

Data Analysis

Fish species richness for each transect was calculated by summing the number of different species observed per transect area (125 m^2).

Fish density at each transect was calculated as the total number of fish observed within each transect area of 125 m^2. This value was converted to number per square meter (no. m^{-2}) to facilitate comparisons with other studies.

Length estimates of fishes were converted to biomass using the following length-mass relationship derived for each species: Mass = a*(Standard Length)^b where a and b are species-specific constants for the allometric growth equation, standard length (SL) is in millimeters, and mass is in grams (Kulbicki et al. 1993, Friedlander et al. 2003). Total length was converted to standard length using conversion factors obtained from FishBase (www.fishbase.org). Length–mass fitting parameters were available for 150 species commonly observed on visual fish transects in Hawai'i from the Hawai'i Cooperative Fishery Research Unit (Friedlander et. al., 1997). This was supplemented with information from other published and web-based sources. In the cases where length–mass information did not exist for a given species, the parameters from similar bodied congeners are used. Biomass estimates for each transect were converted to grams per square meter (g m^{-2}) to facilitate comparisons with other studies worldwide.

The Shannon index (H’) was used to calculate species diversity within each transect using the following formula:

$$H' = -\sum_{i=1}^{S}(p_i \ln p_i)$$

where S is the total number of species and p_i is the frequency of the *i*th species in that transect.

To determine the trophic composition of the fish assemblage, each species was classified as a primary consumer, secondary consumer, or apex predator. In a coral reef ecosystem, primary consumers are fish that consume primary producers such as phytoplankton, seaweeds and sea grasses. Secondary consumers include larger reef fishes such as triggerfish, parrotfish, and wrasses that feed on the primary consumers as well as producers. Planktivores were included in this group for the graphical display, but several noteworthy species are discussed since planktivores have different spatial patterns over reef communities compared to other secondary consumers. Tertiary consumers or apex predators are the top of the food chain and include sharks, groupers, jacks, and the larger snappers. Information on fish trophic group classifications was obtained from Friedlander et al. (1997), FishBase, and other web-based sources.

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 fish species richness, density, biomass, and diversity (R Core Team 2012). To meet the assumptions of normality, data were transformed using a square root ($\sqrt{x}$) transformation for fish species richness and a log(x+1) transformation for density and biomass (Zar 1999). The raw data for diversity was used in the analysis since it was normally distributed. The main fish assemblage characteristics (fish species richness, density, biomass, and diversity) were analyzed separately in the general linear mixed model as the dependent variables. The Satterthwaite approximation for denominator degrees of freedom was used in the *lmerTest* package to generate p-values for the t-statistic at $\alpha = 0.05$ (Kuznetsova et al. 2013).

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 Pinhiero 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.

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 for the fixed transects displayed 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 is 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 Fish Assemblage Characteristics

Fish species richness ranged from 11 to 45 species per transect (125 m^2) from 2006 to 2010 with a total of 132 species found around the park (Figure 3). Transects with the highest species richness values (e.g., temporary transect 8 in 2007) were found near the northern tip of the peninsula while the transect with the lowest species richness (fixed transect 6 in 2006 and 2007) was found along the northwestern portion of the peninsula. Low species richness was also found along the southeastern portion of the peninsula to the easternmost boundary of the park.

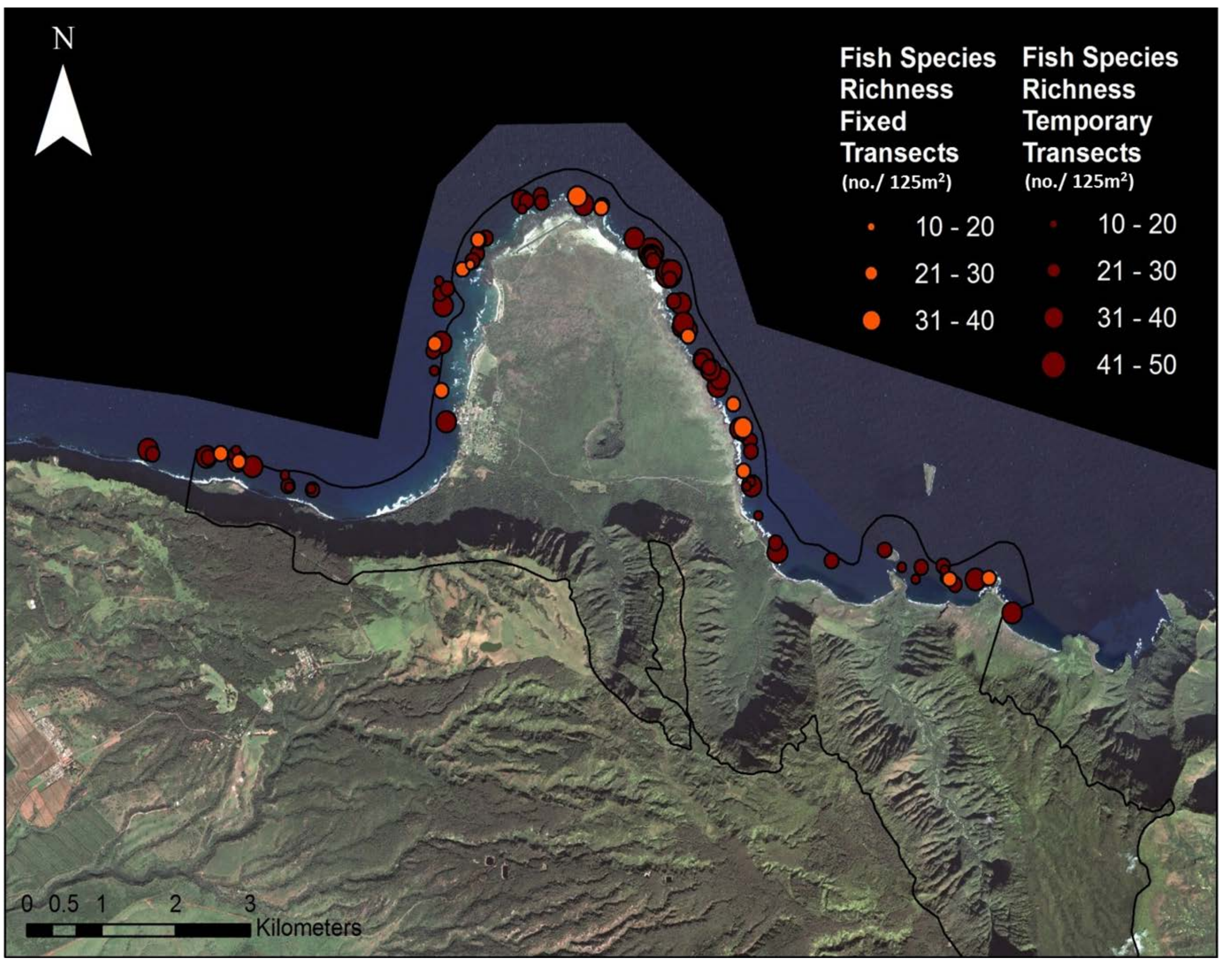

Figure 3. Fish species richness (no.125 m^{-2}) at the 15 fixed sites and 75 temporary sites surveyed in Kalaupapa National Historical Park from 2006-2010 (N = 150 total transects [15 fixed averaged over 5 years, 75 temporary]).

The density of fishes at all transects from 2006 to 2010 ranged from 0.3-4.9 fish m^{-2} (Figure 4). Transects with the highest densities (e.g., fixed transect 5 in 2008) were concentrated near the northwestern portion of the peninsula and extended around to the northeastern section. The lowest densities (e.g., temporary transect 13 in 2009) were located near the eastern and western boundaries of the park.

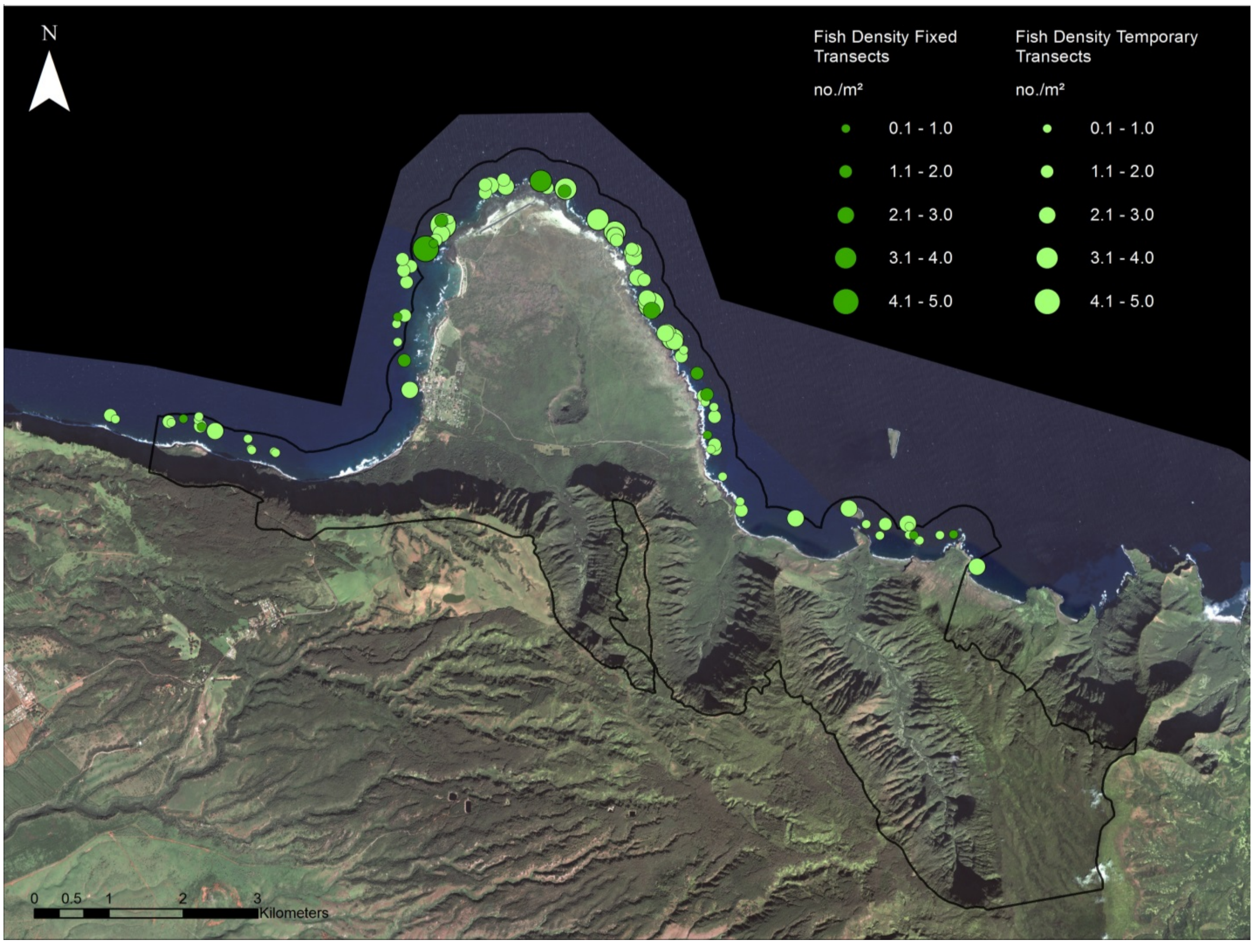

Figure 4. Fish density (no. m^{-2}) at the 15 fixed sites and 75 temporary sites surveyed in Kalaupapa National Historical Park from 2006-2010 (N = 150 total transects [15 fixed averaged over 5 years, 75 temporary]).

Fish biomass ranged between 4.1 and 1,299.8 g m^{-2} at all transects from 2006 to 2010 (Figure 5). Fixed transect 6, located along the northwestern coast of the peninsula, had the lowest biomass in 2007 at just 4.1 g m^{-2}. In comparison, temporary transect 10, located on the western side of the peninsula, had the highest biomass at 1,299.8 g m^{-2} in 2008, while temporary transect 3 in 2010, located on the western coast of the peninsula, also had a high biomass level of 1,212.1 g m^{-2}.

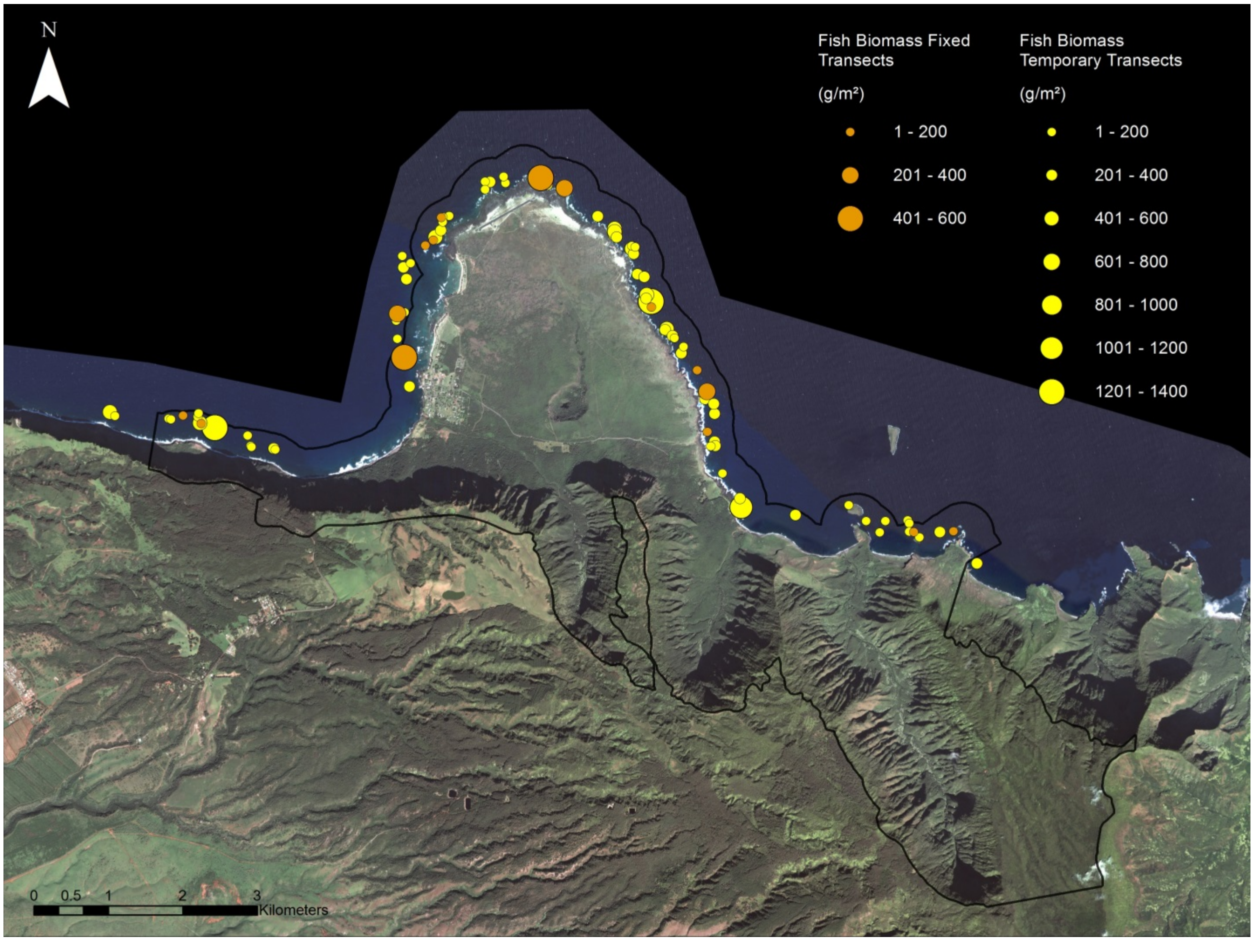

Figure 5. Fish biomass (g m^{-2}) at the 15 fixed sites and 75 temporary sites surveyed in Kalaupapa National Historical Park from 2006-2010 (N = 150 total transects [15 fixed averaged for 5 years, 75 temporary]).

Fish diversity (H') ranged from 0.73 to 3.13 at all transects from 2006 to 2010 (Figure 6). Temporary transect 5, which was surveyed in 2008 on the northwestern portion of the peninsula had the lowest species diversity at 0.73 H'. In contrast, fixed transect 11 on the southeastern section of the peninsula had the highest species diversity at 3.13 in 2009.

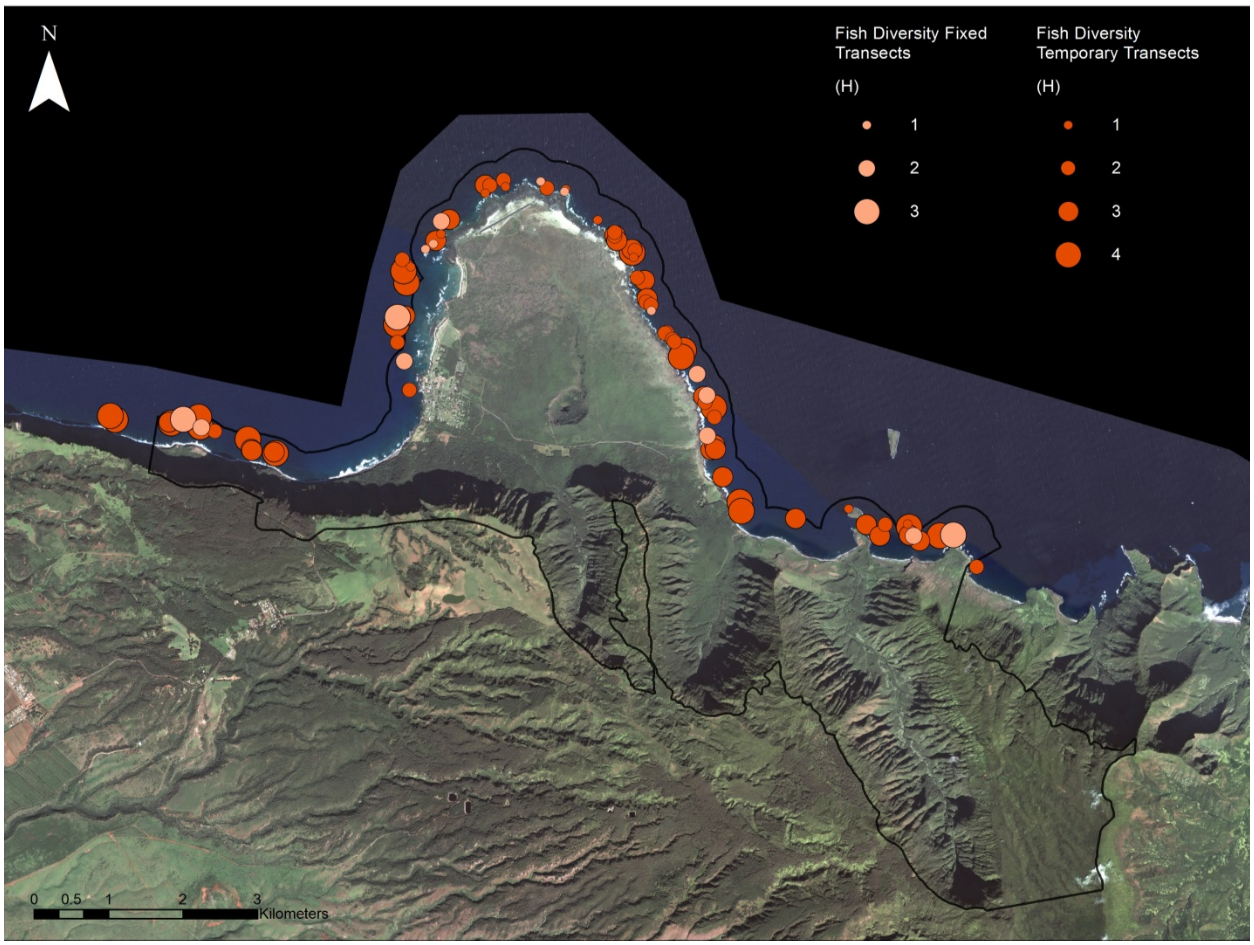

Figure 6 Fish diversity (H') at the 15 fixed sites and 75 temporary sites surveyed in Kalaupapa National Historical Park from 2006-2010 (N = 150 total transects [15 fixed averaged for 5 years, 75 temporary]).

Trophic Composition of the Fish Assemblage

The average trophic composition of the fish assemblage at Kalaupapa NHP from 2006 to 2010 varied in terms of density and biomass. Secondary consumers accounted for approximately 77% of the fish density observed during surveys from 2006-2010, with apex predators accounting for 1%, and primary consumers making up the remaining 22% (Figure 7). Planktivores comprised 54% of the total density and 70% of the secondary consumers. In comparison, the relative biomass of secondary consumers was only 36% (10% planktivores), compared to 10% for apex predators and 54% for primary consumers (Figure 8).

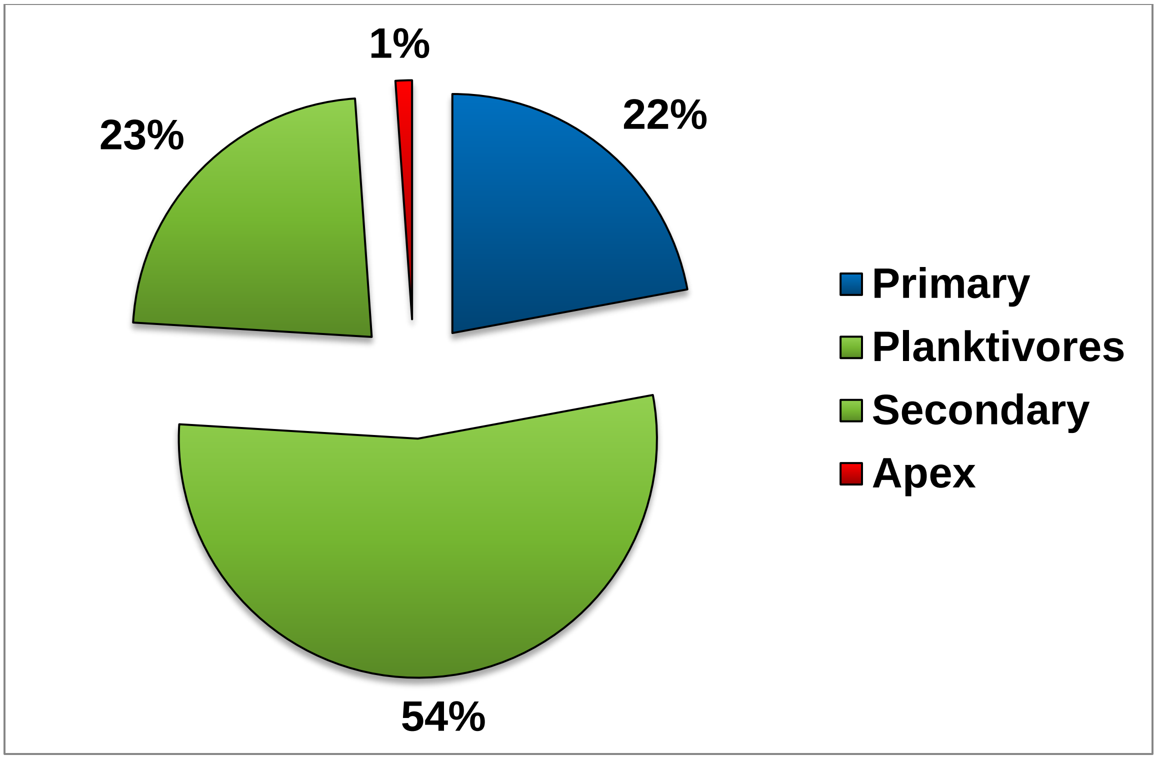

Figure 7. Relative density of fish consumer groups at Kalaupapa National Historical Park averaged from 2006-2010. Note that Planktivores (54%) are broken out from the other Secondary Consumers (23%).

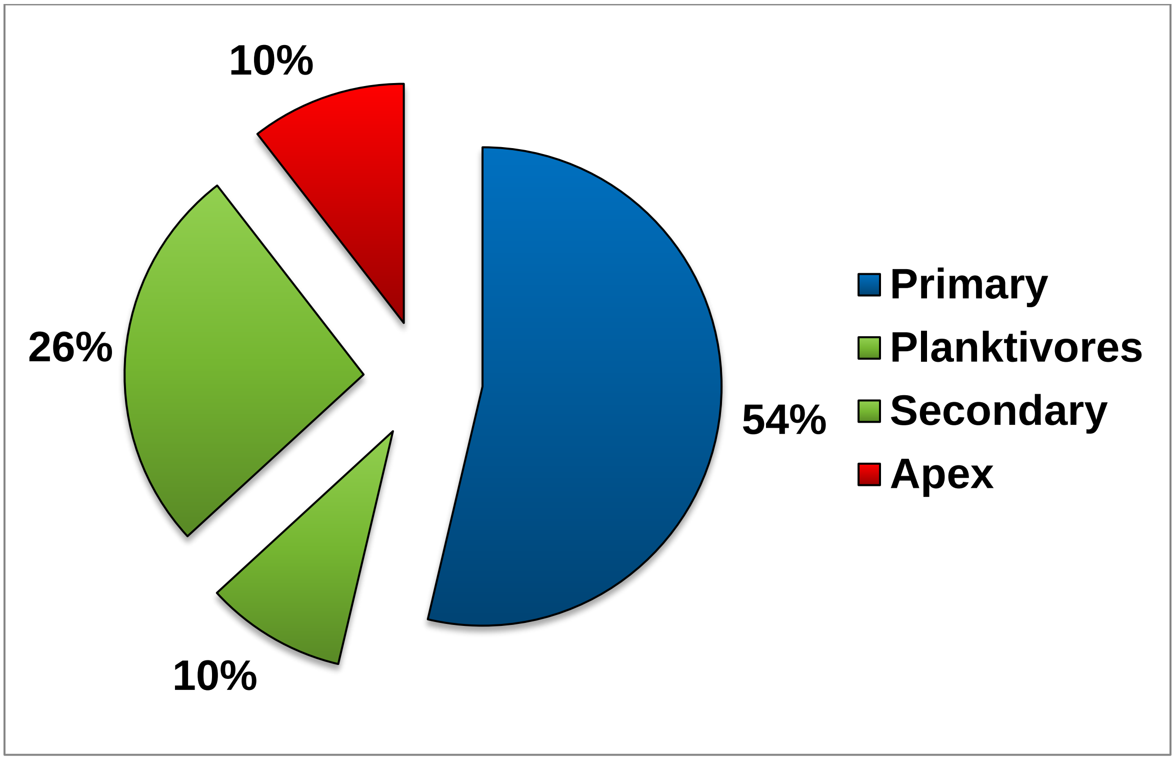

Figure 8. Relative biomass of fish consumer groups at Kalaupapa National Historical Park averaged from 2006-2010. Note that Planktivores (10%) are broken out from the other Secondary Consumers (26%).

Top Ten Fish Species

In terms of density, *Chromis vanderbilti*, a small planktivorous damselfish,was by far the most abundant species found at Kalaupapa from 2006-2010 with 108.2 m^{-2} documented (Table 1). It was seven times more abundant than the next most common species in the park, the primary consumer *Kyphosus* spp. The bulk of the biomass, however, was accounted for by three species: *Kyphosus* spp. (7,435.9 g m^{-2}), the secondary consumer *Bodianus albotaeniatus* (1,830.2 g m^{-2}), and the secondary consumer *Naso hexacanthus* (1,724.9 gm^{-2}). Five of the top ten most abundant species by density were secondary consumers, while five were primary consumers (Table 2). The top ten most abundant species by biomass were composed of five primary consumers, four secondary consumers, and one apex predator (Table 2).

Table 1. Top ten fish species by density (no. m^{-2}) at Kalaupapa National Historical Park averaged over the study period from 2006 to 2010. Common names are from Randall (1996).

Species	Common Name	Hawaiian Name	Consumer Group	Density (no. m^{-2})
Chromis vanderbilti	blackfin chromis	unknown	Secondary (Planktivore)	108.2
Kyphosus spp.	rudderfish	nenue	Primary	14.9
Acanthurus leucopareius	whitebar surgeonfish	māikoiko	Primary	8.4
Thalassoma duperrey	saddle wrasse	hinālea lauwili	Secondary	7.9
Acanthurus nigrofuscus	brown surgeonfish	mā‘i‘i‘i	Primary	7.2
Paracirrhites arcatus	arc-eye hawkfish	piliko‘a	Secondary	7.1
Chromis ovalis	oval chromis	unknown	Secondary (Planktivore)	6.3
Ctenochaetus strigosus	goldring surgeonfish	kole	Secondary	5.9
Acanthurus triostegus	convict surgeonfish	manini	Primary	4.0
Naso hexacanthus	sleek unicornfish	kala holo	Secondary	3.7

Table 2. Top ten fish species by biomass (g m^{-2}) at Kalaupapa National Historical Park averaged over the study period from 2006 to 2010. Common names are from Randall (1996).

Species	Common Name	Hawaiian Name	Consumer Group	Biomass (g m^{-2})
Kyphosus spp.	rudderfish	nenue	Primary	7435.9
Bodianus albotaeniatus	Hawaiian hogfish	‘a‘awa	Secondary	1830.2
Naso hexacanthus	sleek unicornfish	kala holo	Secondary (Planktivore)	1724.9
Acanthurus olivaceus	orangeband surgeonfish	na‘ena‘e	Primary	1596.1
Acanthurus leucopareius	whitebar surgeonfish	māikoiko	Primary	1559.7
Lutjanus kasmira	bluestripe snapper	ta‘ape	Secondary	1437.8
Naso lituratus	orangespine unicornfish	umaumalei	Primary	1337.0
Caranx melampygus	bluefin trevally	‘ōmilu	Apex	1079.3
Naso unicornis	bluespine unicornfish	kala	Primary	957.0
Ctenochaetus strigosus	goldring surgeonfish	kole	Secondary	917.7

Trends in Fish Assemblage Characteristics

For the 30 transects (15 fixed and 15 temporary) surveyed annually, mean fish species richness showed a slight decline from 2006 (27.0 ± 1.2 SE) to 2010 (24.4 ± 1.0 SE, Figure 9). The two-sided trend test indicated that this decline was significant at an $\alpha = 0.05$ level ($t = -2.21$, $p = 0.03$). In comparison, the trend in mean fish density did not change significantly from 2006 to 2010 even though the data suggested a slight decline ($t = -1.88$, $p = 0.14$, Figure 10). In 2006, mean fish density was 1.8 ± 0.2 SE fish m^{-2} , while in 2010 that number was down to 1.3 ± 0.2 SE fish m^{-2}. Mean fish biomass remained relatively stable ($t = -1.10$, $p = 0.28$) from 2006 to

2010 with a surprisingly small range (197.3 ± 22.1 SE g m^{-2} in 2006 to 230.3 ± 42.4 SE g m^{-2}in 2007) of biomass values (Figure 11). Mean fish diversity (H') ranged between 1.92 ± 0.12 SE in 2008 to 2.29 ± 0.09 SE in 2009 with diversity values in between for the other years (Figure 12). Diversity also displayed no significant trend (t = 1.22, p = 0.31) from 2006 to 2010.

Endemic Species

Endemic fish species (N = 32, 24% of the total number of fish species) accounted for 12.4% of the total density with 232.3 individuals m^{-2} documented from 2006 to 2010. The most abundant endemic species was *Thalassoma duperrey* (saddle wrasse) followed by *Chromis ovalis* (oval chromis) (Table 1). *Abudefduf abdominalis* (sergeant major, 1.8 individuals m^{-2}), *Canthigaster jactator* (Hawaiian whitespotted toby, 1.8 individuals m^{-2}), and *Plagiotremus goslinei* (scale-eating blenny, 11.6 individuals m^{-2}) rounded out the endemic species within the top 25 most abundant species overall. Density for most of the endemic species remained consistent over time with the notable exception of *C. ovalis*, which declined dramatically from 2006 to 2010. This species is short-lived and is known to have dramatic recruitment pulses (A. Friedlander, personal communication).

Biomass for endemic species only comprised 7.2% of the total biomass of 32,311 g m^{-2} observed from 2006 to 2010 and was relatively constant over time. These statistics were not surprising since endemics are typically smaller bodied fish compared to non-endemics (DeMartini and Friedlander 2004). *Chlorurus perspicillatus* (spectacled parrotfish) had the highest biomass values of 740 mt km^{-2} (4.9%) followed by the rare *Apolemichthys arcuatus* (bandit angelfish) at 303 mt km^{-2} (2.0 %).

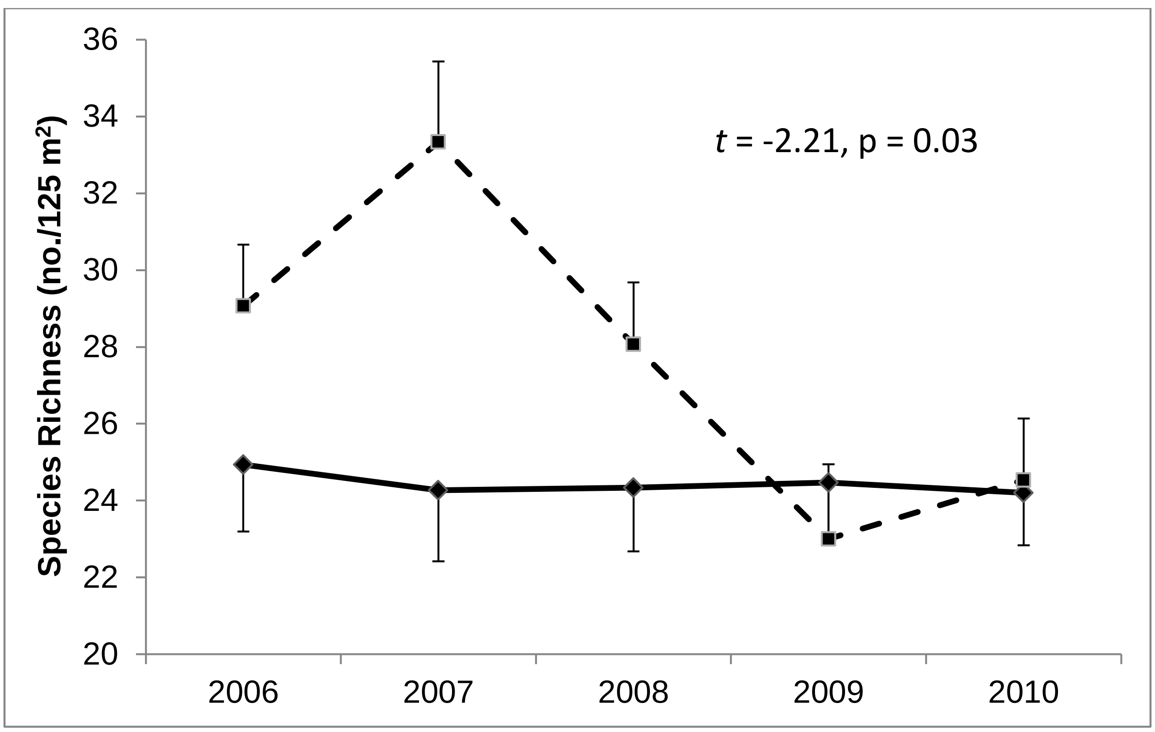

Figure 9. Fish species richness (no.125 m^{-2}) at the 15 fixed sites (solid line) and 15 temporary sites (dashed lines) surveyed in each year at Kalaupapa National Historical Park from 2006-2010. Error bars are one standard error of the mean. Trend analysis *t* statistics are displayed.

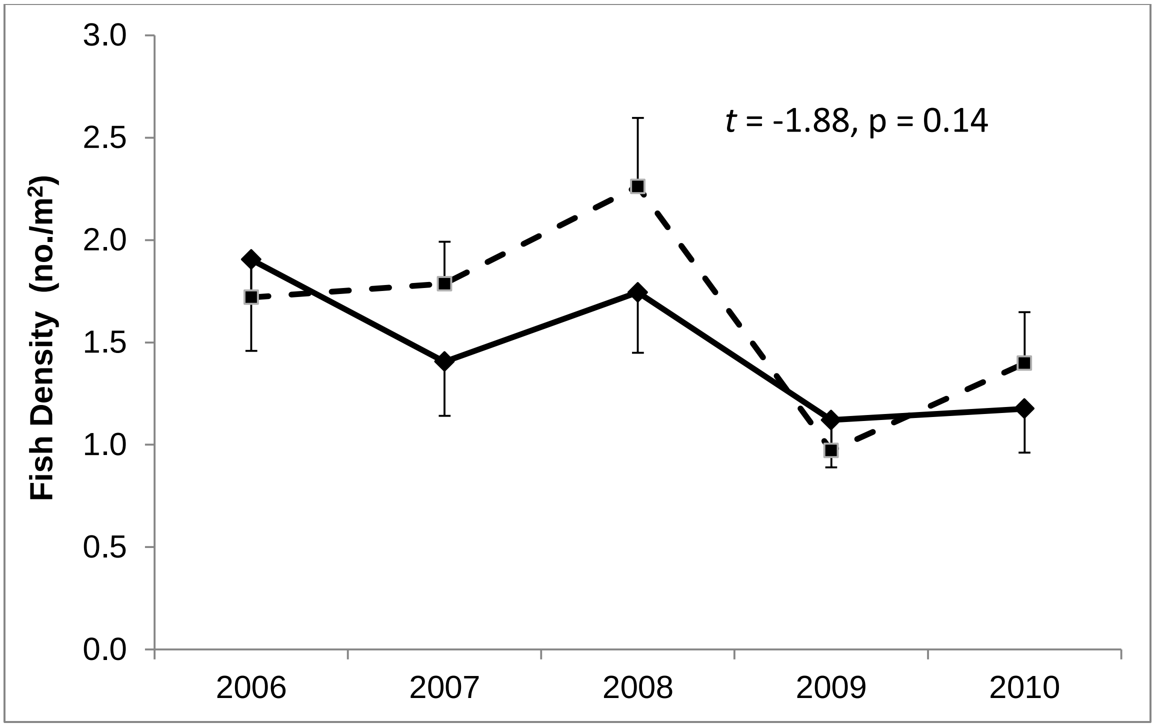

Figure 10. Fish density (no. m^{-2}) at the 15 fixed sites (solid line) and 15 temporary sites (dashed line) surveyed in each year at Kalaupapa National Historical Park from 2006-2010. Error bars are one standard error of the mean. Trend analysis *t* statistics are displayed.

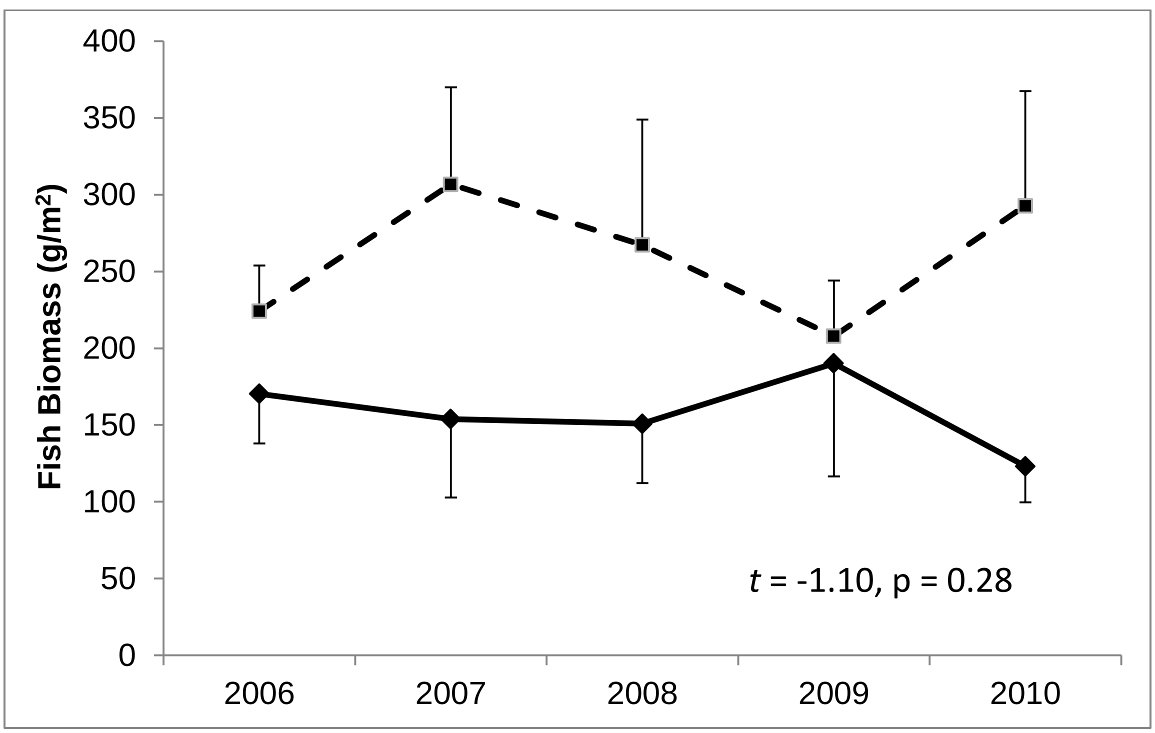

Figure 11. Fish biomass (g m^{-2}) at the 15 fixed sites (solid line) and 15 temporary sites (dashed line) surveyed in each year at Kalaupapa National Historical Park from 2006-2010. Error bars are one standard error of the mean. Trend analysis *t* statistics are displayed.

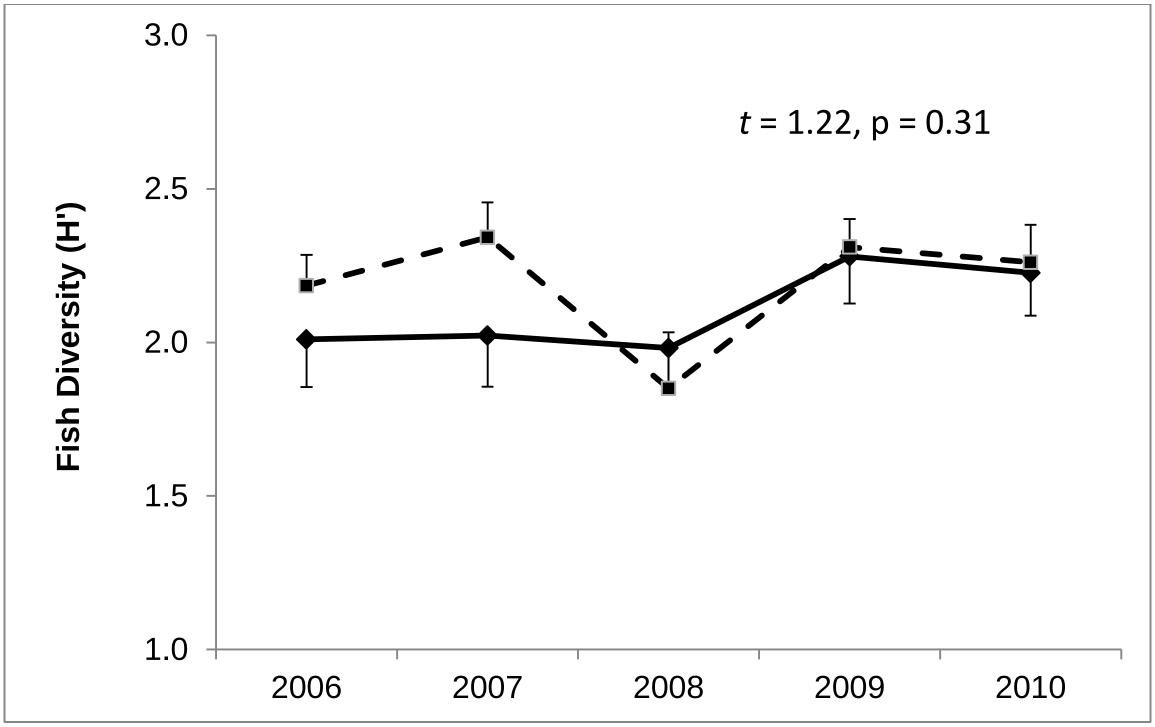

Figure 12. Fish diversity (H') at the 15 fixed sites (solid line) and 15 temporary sites (dashed line) surveyed in each year at Kalaupapa National Historical Park from 2006-2010. Error bars are one standard error of the mean. Trend analysis *t* statistics are displayed.

Invasive Species

Four invasive species (3% of the total number of fish species) accounted for 1.5 % of the total density of 232.3 individuals m^{-2}. The principal invasive species, in terms of density, was *Lutjanus kasmira* (bluestriped snapper) with a total of 2.4 individuals per m^2 documented from 2006 - 2010. This species accounted for 1.2% of total fish density and averaged 0.02 individuals per m^2 on the transect. Over the five year period there did not appear to be any discernable trend in density for this species with values ranging from 0.1 individuals per m^2 in 2008 to 1.1 individuals per m^2 in 2009. Variability was high due to the schooling behavior of this species.

Total biomass for all invasive species was over 7.5% of the total biomass of 32,311 g m^{-2} observed from 2006 to 2010. The two primary invasive species (*L. kasmira* and *Cephalopholis argus* [bluespotted grouper]) accounted for 7.4% (*L. kasmira* – 4.7%, *C. argus* – 2.7%) of the total biomass, with small contributions from *L. fulvus* (0.1%, blacktail snapper) and one recent colonizer, *Abudefduf vaigiensis* (0.06%, Indo-Pacific sergeant). Biomass values fluctuated dramatically for the schooling *L. kasmira* over the years compared to the more solitary *C. argus*, which was observed consistently from year to year. Neither species displayed a trend over the study period, but abundance and distribution of invasive species will be closely monitored as more data are collected.

Discussion

Survey results from 2006 to 2010 indicated that transects with the highest fish species richness values, density, and biomass were concentrated near the northern tip and along the northeastern section of the peninsula coastline (Figures 3, 4, and 5). Fish diversity values, however, were fairly evenly distributed throughout the park (Figure 6). In terms of biomass, three transects fell well outside the range found at all other transects (Figure 5). Fixed transect 6, located along the northwestern coast of the peninsula, had less than half of the biomass found at any other transect, while fixed transect 8, located near the northern tip of the peninsula, had more than four times the biomass found at any other transect (except for temporary transect 3, located on the western coast of the peninsula, which had almost twice the biomass as the remaining transects). Since surveys began in 2006, fixed transect 6 has had the lowest biomass of all transects every year. Several factors such as currents and fishing pressure might influence the spatial distribution of the fish assemblage characteristics at Kalaupapa.

Currents, which are the main mode of dispersal for planktonic 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 13). There did not appear to be a prevailing direction at this location, which would limit larvae coming from outside sources. Additional current meters would need to be installed around the peninsula to clarify the net direction of current flow, especially during the spawning season. Lumpkin (1998) reported that, at a regional scale, the principal surface current flow around the Hawaiian archipelago was from east to west, which suggests that the peninsula would be a convergence zone for currents and ultimately an optimal area for larval recruitment (Figure 14). Abundance patterns for adults and larvae of other species such as corals have revealed a rich biotic zone in the park and support the hypothesis that the northern section of the peninsula is a sink (Brown et al. 2014). Fox et al. (2012), found that on the west coast of Hawaiʻi Island fish recruitment was negatively correlated with eddy formation. In particular, when strong eddies developed that cycled the predominantly east to west currents back towards the coastline, recruitment was poor. In comparison, eddy formation around Kalaupapa could develop on the western side of the peninsula as easterly currents passed by the northern point of the peninsula. At present, however, this pattern has not been documented, although lower fish species richness and density were found on the western side of the peninsula compared to the eastern side (Figures 3 and 4). Fox et al. (2012) also reported that other factors such as the El Niño Southern Oscillation, surface temperature, chlorophyll *a* concentration, sea surface height, and rainfall did not show any relationship with fish recruitment. Ultimately, additional methods (e.g., fish larval traps, tag and release, fish tracking, etc.) would need to be utilized to clarify whether Kalaupapa serves as a source or sink population of fish larvae.

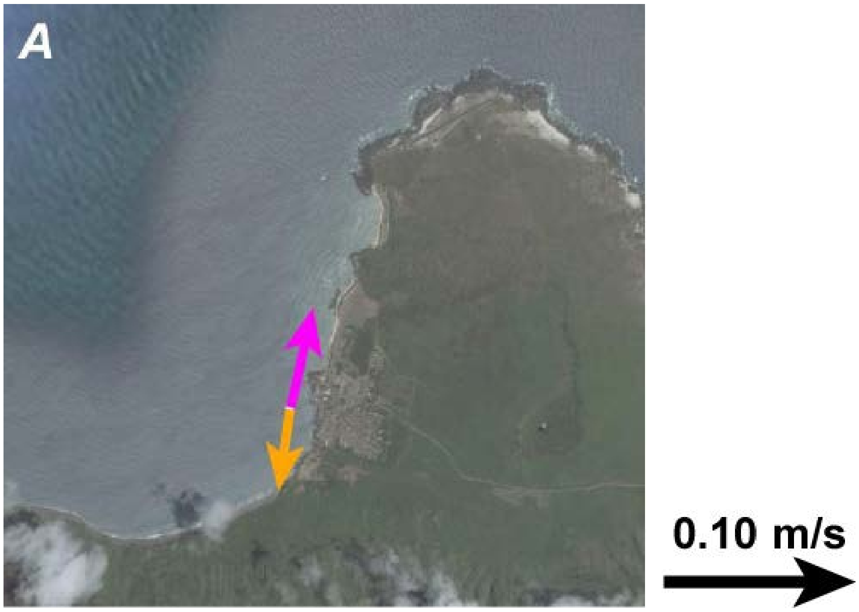

Figure 13. Map showing the relative magnitude and direction of near-surface tidal currents, in meters per second from true north. Magenta is flood tide and orange is ebb tide. A 0.10 m/s vector length is shown for scale. Figure from Storlazzi et al. (2011).

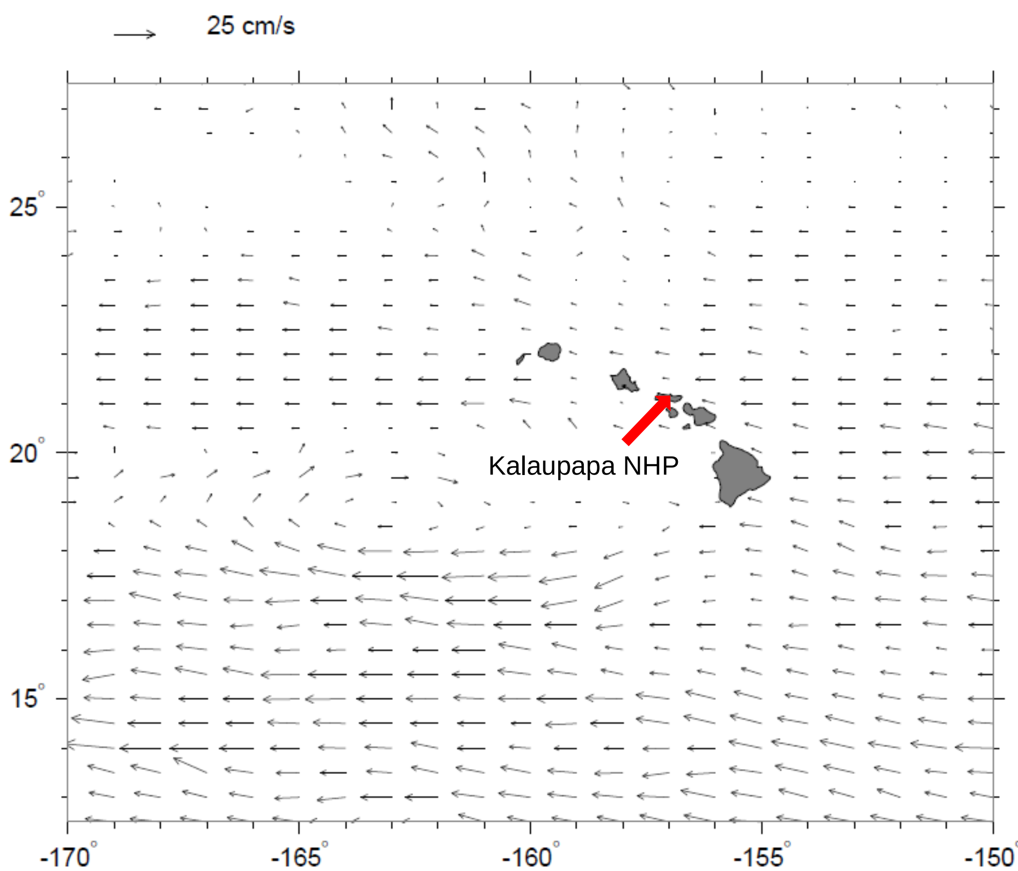

Figure 14. Average direction and strength of surface currents around Hawai'i. Units: cm/s (25 cm/s = 0.5 knot). Figure modified from http://oos.soest.hawaii.edu/pacioos/outreach/oceanatlas/currents.php (2015) and Lumpkin (1998).

Overall fishing pressure within the park is light compared to other areas around Hawaiʻi due to the geographic remoteness and restricted access (Tom 2011). The majority of the fishing activity tends to be concentrated on the western side of the peninsula adjacent to the settlement. Tom (2011) noted, however, that second highest cluster of shoreline segments with fishing pressure existed on the northern section of the peninsula. In most cases, fishing pressure consisted of rod and reel (64% of fishing effort observed) followed by thrownet (10%), surround net (5%), three-prong (5%), and spear gun (1%). In the northern section, the water was generally too rough for in-water fishing techniques such as three-prong spears and spear guns so effort was focused on rod and reel (75%) (Tom 2011). This fishing method has been shown to have the lowest catch per unit effort (CPUE) for reef fishes in Hawaiʻi compared to all other techniques by at least an order of magnitude (McCoy et al. personal communication). Consequently, it is not likely that this inefficient gear type would have a significant impact on fish assemblages off the northern sector of the peninsula, but long-lived species can still be affected if population densities are low and recruitment is limited (Heppell et al. 2005).

The spatial distribution of human activities and settlements have been historically variable along the north shore of Molokaʻi (McCoy 2005, 2007, Flexner 2010). Most of the initial settlements prior to western contact occurred in the major valleys (Hālawa, Wailau, Pelekunu, and Waikolu) on the eastern side of the peninsula. Activities of the early Hawaiians were focused on fishing and taro farming (McCoy 2007). By the time the Hansen's disease settlement was established in 1866 at Kalawao, on the east side of the peninsula, 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 Hālawa, had largely disappeared (Flexner 2010). This shift in human occupation and associated activities, coupled with a decline of over 90% in the recorded human population on the peninsula over the last 100 plus years (Brown et al. 2011a), suggests that concomitant fishing pressure also declined over this time period. These declines would probably have offset any advancement in fishing technology over this time period, allowing the near shore fish assemblages to recover to the present day levels and/or perhaps limiting the initial impact from resource extraction.

In addition to ocean currents and fishing pressure, ecological factors influencing fish assemblages include variations in reproductive output from source populations (Claisse et al. 2009), post-settlement mortality (Hunt and Scheibling 1997), and/or habitat differences (Caselle and Warner 1996). Some of these factors such as human populations at regional scales (Friedlander et al. in review) are currently being investigated that will help explain the existing spatial patterns in fish assemblage structure at Kalaupapa. Habitat factors that could influence the fish assemblage structure around Kalaupapa include the spatial extent of shallow water habitat and complexity of the substrate. For the entire island of Molokaʻi, the spatial extent (161.6 km^2) of shallow water habitat (depth <20 m) that is suitable for coral reef development is less than on Kauaʻi (10% less), Oʻahu (57%), Maui (2%), and Hawaiʻi (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 fish habitat available than the other islands, and this is restricted to a narrow band adjacent to the shoreline (NOAA – NCCOS 2007). This restricted range of suitable habitat should theoretically limit fish populations compared to other wave exposed north shore sites, as well as areas with extensive reef habitat around Hawaiʻi.

The complexity or rugosity of the substrate at Kalaupapa is different than other wave exposed north shore sites around the state. In the park, the substrate consists of large basalt boulders, which have numerous spaces for fish to hide (Figure 15a). In contrast, the more typical north shore coral reefs of Kauaʻi, Oʻahu, and Maui are relatively flat with encrusting coral communities (Jokiel et al. 2004) (Figure 15b). Previous studies (e.g., Friedlander et al. 2007) have shown that complexity of the reef habitat explains a large percentage of the variability in species richness and biomass; higher complexity has higher fish assemblage metrics, although legal protection from fishing pressure also results in higher values for many fish assemblage characteristics (Friedlander et al. 2007). Beets et al. (2010), reported that rugosity at Kalaupapa was higher than values reported at three other national parks (Puʻukoholā Heiau National Historic Site, Kaloko-Honokōhau National Historical Park, Puʻuhonua o Hōnaunau National Historical Park) on Hawaiʻi Island. Friedlander et al. (2003) documented an average rugosity value of 1.60 at 60 sites around the MHI, which was almost identical to the overall mean rugosity index value of 1.62 at Kalaupapa (Brown et al. 2014). Kalaupapa, however, had higher rugosity (1.62 versus 1.44) than other north shore reefs exposed to the northwest swells. The highest mean rugosity values in the MHI were found in sheltered areas such as Kāneʻohe Bay on Oʻahu (1.81) and along wave protected southern shorelines (1.71) (Friedlander et al. 2003). Therefore, even with a limited spatial extent of available habitat, the high complexity of reef habitat at Kalaupapa coupled with the low fishing pressure has resulted in a high density and biomass of reef fish around the park.

Examining rugosity at a finer spatial scale within the park helps explain some of the spatial patterns observed in the fish assemblage (Appendix A). Sites with higher average rugosity, such as the transects on the northern tip (mean rugosity 1.74 ± 0.13 SE) and northeastern section (mean rugosity 1.81 ± 0.07 SE) of the peninsula, generally had higher species richness, higher density, and higher biomass than sites in other parts of the park (e.g., northwestern section of the peninsula, mean 1.66 ± 0.08 SE) with less complex habitats. These results support previous findings that habitat complexity is an important predictor of fish assemblage structure (Friedlander et al. 2007), and suggests that certain areas in the park contain better habitats for fish assemblages than others and serve to attract fishes to areas such as the northern section of the peninsula. The small number of transects within each of these park zones, however, precluded a statistical analysis of rugosity as a predictive factor at this point in time. In future years as more areas are sampled within the park, then habitat complexity can be reassessed to help delineate high quality habitats around the peninsula.

One of the most important metrics to examine from a resource manager's perspective is total fish biomass. In comparison to other locations around the Pacific and Caribbean, total biomass at Kalaupapa approached levels seen in more remote and uninhabited island groups such as the northwestern Hawaiian Islands (NWHI) (Figure 16). These results are encouraging and suggest that fishing pressure at Kalaupapa is relatively light. Indeed, Tom (2011) reported that an "insignificant harvest effect was due to relatively small fishing effort at Kalaupapa". Kaloko-Honokōhau National Historical Park, also in the MHI, had fish biomass levels that were only 38% of the biomass at Kalaupapa NHP even though the benthic habitat has much higher mean coral cover and similar values for rugosity (Beets et al. 2010). It is important to note, however, that biomass of the apex predators was still proportionally lower than levels documented in remote, uninhabited islands indicating some impact from fishing.

In terms of density by species, the planktivore *Chromis vanderbilti* (blacktail chromis) was by far the most abundant species found at Kalaupapa in 2011 (Table 2). The high density of this relatively small (up to about 7 cm, Hoover 2008) species also influenced the relative density versus biomass of the trophic groups. Secondary consumers (including *C. vanderbilti*) accounted for approximately 67% of the individual fish observed in 2011 (Figure 7), yet made up only 46% of the biomass (Figure 8). These results suggest that Kalaupapa has a high abundance of plankton stemming from high primary productivity along the shoreline. Primary consumers accounted for 49% of the biomass (Figure 8), despite representing only 32% of the individual fish observed (Figure 7). This is due, in part, to the *Kyphosus* spp. (rudderfish), which was the third most abundant taxon in the park (Table 2) and attains a relatively large size of to 60 cm (Randall 1996).

a.

b.

Figure 15. Typical substrate profile at Kalaupapa NHP (a) and Hanalei Bay, Kauaʻi (b), which are both northern, wave-exposed coastlines around the MHI. Photos by Sylvester Lee (a) on September 24, 2014 and Eric Brown (b) on May 21, 2010.

Of particular ecological importance are the apex predators. Worldwide, large apex predators have been on the decline with many, including sharks, disappearing at alarming rates (Worm et al. 2006). These (typically) large predators are important to the reef because their absence can cause dramatic shifts in the species composition and dominant taxa of a reef (Sandin et al. 2008). At Kalaupapa in 2011, apex predators accounted for just 1% of individual fish observed (Figure 7), but constituted 5% of the biomass (Figure 8). One of the top ten species by biomass was also an apex predator (*Caranx melampygus*, bluefin trevally, Table 3). This relatively high apex predator biomass for an inhabited island could be partly due to the light fishing pressure at Kalaupapa (Tom 2011). It is important to note that the trophic structure at Kalaupapa more closely resembles fished reefs rather than unfished reefs where biomass is dominated by apex predators and a trophic composition approximates an inverted pyramid (Sandin et al. 2008). Consequently, even with light fishing pressure the impacts were readily discernable.

From 2006 to 2010, the trends in the four main fish assemblage characteristics (species richness, density, biomass, diversity) indicated that the fish assemblage at Kalaupapa was relatively stable over that time period (Figures 9-12). Only species richness showed a slight decline in the last few years that was statistically significant. Some notable fish species not observed in 2010, but documented in all prior years, included *Aulostomus chinensis* (trumpetfish), *Chaetodon miliaris* (milletseed butterflyfish), *Cirrhitus pinnulatus* (stocky hawkfish), *Cirripectes vanderbilti* (scarface blenny), and *Priacanthus meeki* (Hawaiian bigeye). Further monitoring in subsequent years will help us learn if this decline is ecologically significant and a cause for concern, especially for the common species listed above that were not observed in 2010. Of particular note for all of the data sets, was the low variance for each of the metrics across time. This pattern suggested a relatively homogeneous and stable fish assemblage across space and time.

Several factors likely contributed to this stability in fish assemblage structure. First, is the remoteness of the area. There are no roads leading into the settlement and the nearest harbor is more than 50 km from the western boundary of the park. Second, is the low level of human perturbation that occurs in the settlement. The human population at Kalaupapa has declined 92% from a peak of 1,177 in 1900 to 90 in 2010 (U.S. Census Bureau 2013). In addition, the population has been relatively stable for the past decade with light fishing and diving pressure (Tom 2011). There are also no major industries and no evidence of nutrient enrichment in the ocean from human sewage (Kalaupapa unpublished data, presented at 2012 International Coral Reef Symposium, Cairns, Australia). Third, is the seasonal refuge afforded by the strong winter storms (U.S. Naval Oceanographic 2010, NOAA 2015, Stormsurfing 2015), which restricts vessel traffic in the park and limits in-water (e.g., spearfishing), and even shoreline fishing during this time of year. Ultimately, all of these factors likely limit fishing activity in the park.

Endemic and invasive fish species are both significant components of the fish assemblage at Kalaupapa. Values for endemic species, however, were lower than fish assemblage metrics documented from elsewhere around the state. Friedlander et al. (2003) reported that endemics accounted for 35% (12% in this study) of the density and 22% (7% in this study) of the biomass from 60 stations from around the MHI. Their study sampled a wider array of habitats including reef areas dominated by endemic coral species such as *Porites compressa*. This coral species appears to be a preferred substrate for many fish recruits, including *Ctenochaetus strigosus* (goldring surgeonfish), which is endemic to the Hawaiian Islands and Johnston Atoll (DeMartini and Anderson 2007). In comparison, Friedlander et al. (2003) found that invasive species at their study sites around the MHI accounted for <1% (3% in this study) of the total density and <3% (7.5% in this study) of the total biomass. Having similar proportions of endemic and invasive fish species might be a point of concern, but habitat differences and differing levels of resource extraction across the state could explain the observed patterns in the two groups of fishes. Indeed, DeMartini and Friedlander (2004) found that endemics comprised 52% of the total density and 37% of the total biomass in the NWHI, which has substantially different reef habitats than the MHI and no fishing. Invasive species are not an appreciable component of the fish assemblages in the NWHI. With only five years of monitoring, it is too early to comment on the spatial and temporal patterns of endemics and invasive species, but this is one component of the fish assemblage that will be closely monitored in the future. In summary, the proportion of endemic and invasive fish species appears to be more similar than other nearshore habitats around the MHI, which have more pronounced differences between the two fish groups.

It is anticipated that atmospheric changes in climate will have corresponding impacts on ocean temperatures and water chemistry. Sea surface ocean temperatures recorded by the National Marine Fisheries Service (1956–1992) and the Integrated Global Ocean Services System–National Meteorological Center (1992–2014) for Koko Head, Oahu indicate that overall temperatures have increased by more than 0.5° C since 1956 (Figure 17, see Jokiel and Brown 2004). Several brief cooling periods have occurred during the intervening years, but the recent spike in temperatures in 2014 and the associated coral bleaching (Rodgers et al. 2015) indicate that the warming trend is continuing. Over a longer time period, ocean temperatures are expected to continue rising by 1.4 - 2.6 °C due to increased CO_2 emissions and the concomitant increase in atmospheric temperatures (IPCC 2013). Even though the impact of increasing temperature on coral reef fish communities has not been studied as well as temperature impacts on coral reef habitat, there are some recent studies that highlight potential issues. For example, Bellwood et al. (2012) reported that the cryptobenthic fish assemblage in the central Great Barrier Reef failed to recover to pre-bleaching conditions following the 1998 El Niño bleaching event from prolonged high temperatures, despite the fact that the coral community recovered fully.

Ocean chemistry is also expected to change with increasing CO_2 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) projected that by 2050, coral reef ecosystems will reach a tipping point and corals will be unable to calcify and grow. Kalaupapa 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). Potential concerns with elevated CO_2 levels on coral reef fish include direct effects on internal calcifying structures such as otoliths (Ateweberhan et al. 2013), changes in fish predator-prey behavior (Cripps et al. 2011), changes in fish assemblage structure (e.g., loss of biodiversity) associated with declining coral reef habitat (Hixon 2011), and synergistic effects of stressors (Ateweberhan et al. 2013). The most widely studied aspect of these climate change impacts has focused on the negative effects of habitat decline on the related fish assemblage (Graham et al. 2009, Ateweberhan et al. 2013). At present, the short duration of this study has not revealed any patterns in the fish assemblage associated with increasing temperatures or changes in pH, but due the high wave energy environment and low coral cover at Kalaupapa, local impacts may have a greater potential impact to the fish and coral communities in the short to medium time frame (e.g., Graham et al. 2014).

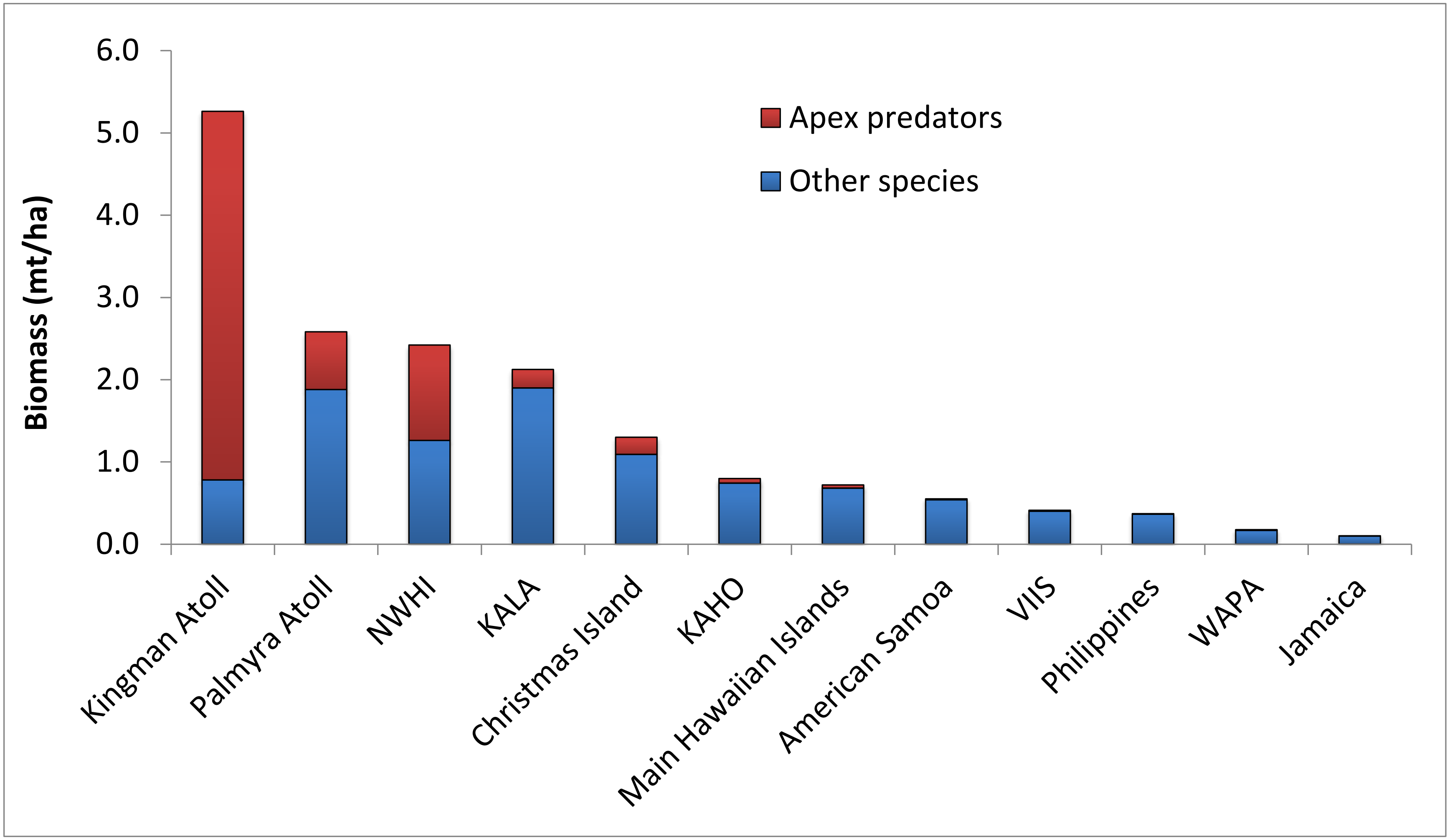

Figure 16. Mean fish biomass (metric tons per hectare: mt ha^{-2}) at various island locations in the Pacific and the Caribbean. Acronyms are as follows: NWHI = Northwestern Hawaiian Islands, KALA = Kalaupapa National Historical Park, KAHO = Kaloko-Honokōhau National Historical Park National Historical Park, VIIS = Virgin Islands National Park, WAPA = War in the Pacific National Historical Park. Modified from Friedlander et al., (2008) and this study.

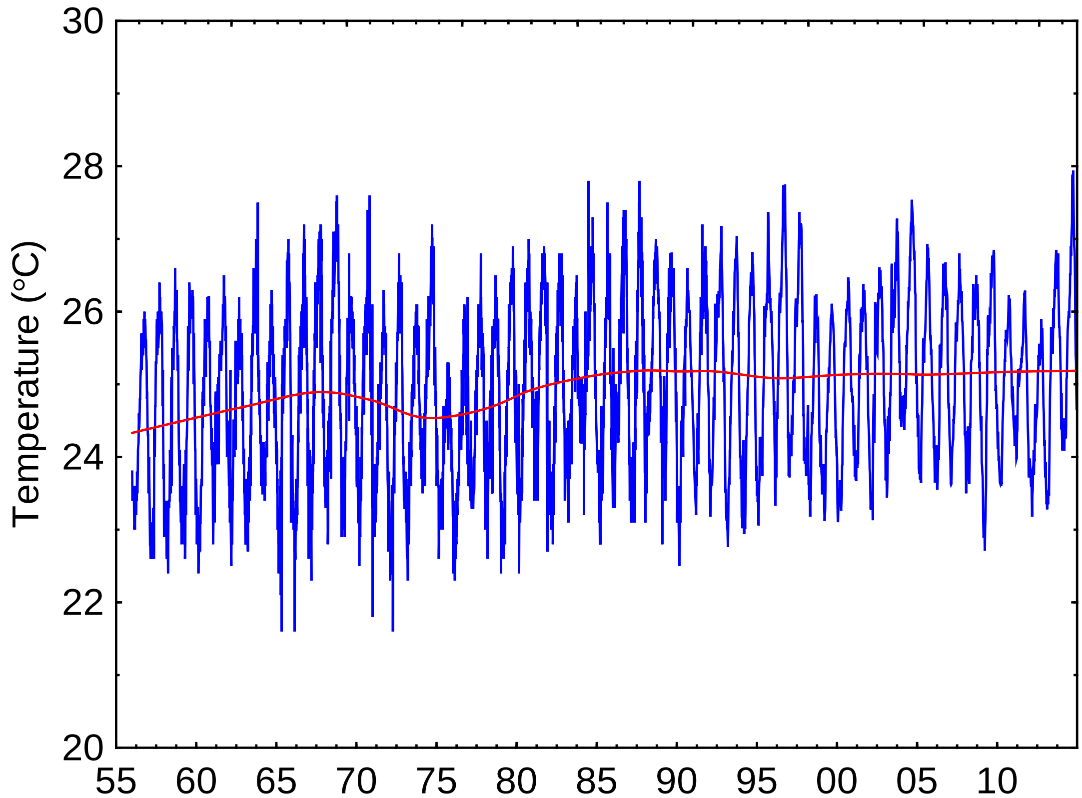

Figure 17. Combined sea surface temperature (SST) record using National Marine Fisheries Service (NMFS) data for Koko Head, Oahu (1956–1992) and corrected Integrated Global Ocean Services System–National Meteorological Center (IGOSS–NMC) temperature data (1992 to 2014; Modified from Jokiel and Brown 2004).The red line indicates a Lowess function fitted to the data.

Further observations will be needed to determine whether these long-term trends of stability in the fish community are real or simply annual fluctuations in fish assemblage characteristics, or measurement error associated with the methodology. Data collection and rigorous statistical analyses in subsequent reports will help us learn if the observed trends are ecologically significant and cause for management concern, as long-term change in the fish taxa or assemblages may be indicative of variation in certain environmental stressors or drivers. For example, a decrease in fish biomass has often been associated with increasing fishing pressure (Friedlander and DeMartini 2002) or a reduction in fish species richness corresponding to a degraded habitat such as high turbidity levels (Bejarano and Appeldoorn 2013). Co-location of this marine fish monitoring protocol with the benthic community monitoring protocol and the water quality monitoring protocol will allow us to determine if any such associations exist at Kalaupapa.

In conclusion, the fish assemblage around Kalaupapa appears to be healthy compared to the rest of the MHI and continued monitoring is needed to see if local, regional, and global factors are affecting these assemblages.

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

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

Survey Date	Transect	Transect Type	Latitude	Longitude	Bearing	Depth (m)	Rugosity
8/2/2006	1	Fixed	21.18705	-157.01559	90	17.8	1.41
8/2/2006	2	Fixed	21.18609	-157.01321	120	12.8	1.45
8/10/2006	3	Fixed	21.19380	-156.98687	0	14.2	1.72
8/2/2006	4	Fixed	21.19911	-156.98765	30	18.4	1.42
8/8/2006	5	Fixed	21.20736	-156.98396	90	11.5	1.43
7/24/2006	6	Fixed	21.20795	-156.98288	30	12.7	1.30
8/10/2006	7	Fixed	21.21069	-156.98184	60	20.7	2.00
7/24/2006	8	Fixed	21.21538	-156.96892	90	14.8	1.94
7/25/2006	9	Fixed	21.21411	-156.96586	120	14.8	1.65
8/1/2006	10	Fixed	21.19950	-156.95477	150	15.6	1.49
8/9/2006	11	Fixed	21.19179	-156.94896	150	15.2	1.62
8/9/2006	12	Fixed	21.18918	-156.94775	180	16.8	1.70
8/8/2006	13	Fixed	21.18428	-156.94775	150	12.8	1.42
8/15/2006	14	Fixed	21.17179	-156.92124	210	13.8	1.44
8/15/2006	15	Fixed	21.17183	-156.91610	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 (continued).

Survey Date	Transect	Transect Type	Latitude	Longitude	Bearing	Depth (m)	Rugosity
8/9/2007	1	Fixed	21.18705	-157.01559	90	17.8	1.49
8/9/2007	2	Fixed	21.18609	-157.01321	120	12.8	1.39
8/9/2007	3	Fixed	21.19380	-156.98687	0	14.2	1.65
8/7/2007	4	Fixed	21.19911	-156.98765	30	18.4	1.43
8/7/2007	5	Fixed	21.20736	-156.98396	90	11.5	1.44
8/2/2007	6	Fixed	21.20795	-156.98288	30	12.7	1.25
8/8/2007	7	Fixed	21.21069	-156.98184	60	20.7	2.16
7/19/2007	8	Fixed	21.21538	-156.96892	90	14.8	1.88
7/19/2007	9	Fixed	21.21411	-156.96586	120	14.8	1.62
7/31/2007	10	Fixed	21.19950	-156.95477	150	15.6	1.49
8/1/2007	11	Fixed	21.19179	-156.94896	150	15.2	1.61
8/1/2007	12	Fixed	21.18918	-156.94775	180	16.8	1.75
8/1/2007	13	Fixed	21.18428	-156.94775	150	12.8	1.42
8/7/2007	14	Fixed	21.17179	-156.92124	210	13.8	1.43
8/7/2007	15	Fixed	21.17183	-156.91610	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 (continued).

Survey Date	Transect	Transect Type	Latitude	Longitude	Bearing	Depth (m)	Rugosity
7/21/2008	1	Fixed	21.18705	-157.01559	90	17.5	1.46
7/22/2008	2	Fixed	21.18609	-157.01321	120	12.9	1.43
8/27/2008	3	Fixed	21.19380	-156.98687	0	14.2	1.63
7/22/2008	4	Fixed	21.19911	-156.98765	30	18.5	1.43
7/23/2008	5	Fixed	21.20736	-156.98396	90	11.2	1.52
7/22/2008	6	Fixed	21.20795	-156.98288	30	12.7	1.27
7/23/2008	7	Fixed	21.21069	-156.98184	60	20.9	2.20
8/19/2008	8	Fixed	21.21538	-156.96892	90	15.0	2.04
8/19/2008	9	Fixed	21.21411	-156.96586	120	15.9	1.69
8/27/2008	10	Fixed	21.19950	-156.95477	150	16.3	1.51
8/26/2008	11	Fixed	21.19179	-156.94896	150	15.3	1.68
8/26/2008	12	Fixed	21.18918	-156.94775	180	17.3	1.64
8/26/2008	13	Fixed	21.18428	-156.94775	150	13.6	1.47
8/20/2008	14	Fixed	21.17179	-156.92124	210	14.3	1.45
8/20/2008	15	Fixed	21.17183	-156.91610	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 (continued).

Survey Date	Transect	Transect Type	Latitude	Longitude	Bearing	Depth (m)	Rugosity
7/13/2009	1	Fixed	21.18705	-157.01559	90	17.6	1.57
7/13/2009	2	Fixed	21.18609	-157.01321	120	12.6	1.50
8/3/2009	3	Fixed	21.19380	-156.98687	0	14.1	1.64
7/17/2009	4	Fixed	21.19911	-156.98765	30	19.1	1.60
7/13/2009	5	Fixed	21.20736	-156.98396	90	11.4	1.51
8/5/2009	6	Fixed	21.20795	-156.98288	30	13.3	1.28
7/17/2009	7	Fixed	21.21069	-156.98184	60	21.2	2.19
7/15/2009	8	Fixed	21.21538	-156.96892	90	15.4	2.04
7/15/2009	9	Fixed	21.21411	-156.96586	120	15.8	1.62
7/16/2009	10	Fixed	21.19950	-156.95477	150	15.8	1.55
8/5/2009	11	Fixed	21.19179	-156.94896	150	14.7	1.90
7/16/2009	12	Fixed	21.18918	-156.94775	180	17.4	1.66
7/16/2009	13	Fixed	21.18428	-156.94775	150	13.2	1.52
8/5/2009	14	Fixed	21.17179	-156.92124	210	14.0	1.45
7/14/2009	15	Fixed	21.17183	-156.91610	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 (continued).

Survey Date	Transect	Transect Type	Latitude	Longitude	Bearing	Depth (m)	Rugosity
8/2/2010	1	Fixed	21.18705	-157.01559	90	17.6	No Rug
8/3/2010	2	Fixed	21.18609	-157.01321	120	12.6	No Rug
8/12/2010	3	Fixed	21.19380	-156.98687	0	14.1	No Rug
8/4/2010	4	Fixed	21.19911	-156.98765	30	19.1	No Rug
8/4/2010	5	Fixed	21.20736	-156.98396	90	11.4	No Rug
8/3/2010	6	Fixed	21.20795	-156.98288	30	13.3	No Rug
8/4/2010	7	Fixed	21.21069	-156.98184	60	21.2	No Rug
8/11/2010	8	Fixed	21.21538	-156.96892	90	15.4	No Rug
8/12/2010	9	Fixed	21.21411	-156.96586	120	15.8	No Rug
8/11/2010	10	Fixed	21.19950	-156.95477	150	15.8	No Rug
8/10/2010	11	Fixed	21.19179	-156.94896	150	14.7	No Rug
8/11/2010	12	Fixed	21.18918	-156.94775	180	17.4	No Rug
8/5/2010	13	Fixed	21.18428	-156.94775	150	13.2	No Rug
8/10/2010	14	Fixed	21.17179	-156.92124	210	14.0	No Rug
8/5/2010	15	Fixed	21.17183	-156.91610	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	Database Query
Fish species richness	Fish_Summary_Status_Maps	qs_j043_Fish_Summary_totals_per_transect
Fish density	Fish_Summary_Status_Maps	qs_j043_Fish_Summary_totals_per_transect
Fish biomass	Fish_Summary_Status_Maps	qs_j043_Fish_Summary_totals_per_transect
Fish diversity	Fish_Summary_Status_Maps	qs_j043_Fish_Summary_totals_per_transect

Trophic Composition Graphs

Data	Excel File	Database Query
Trophic composition by density	Fish_Trophic_Chart	qs_j153_Fish_Consumer_Abundance_per_park_xtab
Trophic composition by biomass	Fish_Trophic_Chart	qs_j173_Fish_Consumer_Biomass_per_park_xtab

Trend Line Graphs

Data	Excel File	Database Query
Fish species richness	Fish_SpRichness_Trends	qs_j253_Fish_Trend_Stat_Setup
Fish density	Fish_Density_Trends	qs_j253_Fish_Trend_Stat_Setup
Fish biomass	Fish_Biomass_Trends	qs_j253_Fish_Trend_Stat_Setup
Fish diversity	Fish_Diversity_Trends	qs_j253_Fish_Trend_Stat_Setup

Tables

Data	Excel File	Database Query
Metadata	KALA_Metadata	qs_x015_Metadata_by_transect
Fish top ten species by density	Fish_Top_Ten_Density	qs_j093_Fish_Top_25_Density_per_park
Fish top ten species by biomass	Fish_Top_Ten_Biomass	qs_j113_Fish_Top_25_Biomass_per_park

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