CAMPBELL INDUSTRIAL PARK (CIP) GENERATING STATION PROJECT

2019 COMMUNITY BENEFITS PROGRAM

REEF FISHES MONITORING PROGRAM

Prepared For:

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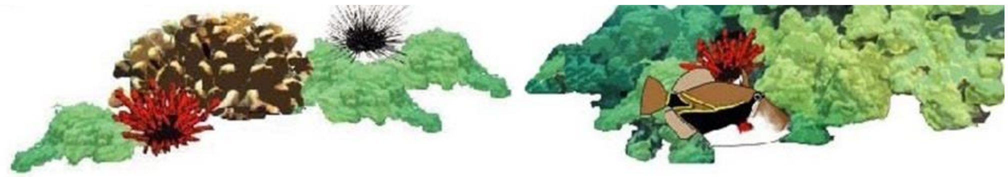

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EXECUTIVE SUMMARY

The quarterly monitoring for Hawaiian Electric's Campbell Industrial Park (CIP) Generating Station Project was initiated to monitor changes in the near-shore biological communities since the startup of the generating station at CIP, Barbers Point, in West Oʻahu in 2010. Eleven annual reports have been submitted between 2007 and 2018. This 2019 report is the twelfth report in this series. The CIP Generating Station's wastewater is permitted to be discharged into two underground injection control (UIC) wells onsite; no effluent discharges to the ocean. The quarterly coral reef fish community monitoring has continued as a commitment and benefit to the local community. Sixteen permanently marked monitoring stations extend from Barbers Point in the southeast to Nanakuli in the northwest, a distance of 7.9 kilometers (4.9 miles). These stations are located in depths between 5 and 12 meters (m). In 2019, the number of monitoring stations was reduced from 16 to 14 based on comparability of biomass (mean standing crop) of fishes, abundance (mean number of individual fish), and mean number of fish species, similarity of habitat, and spatial proximity. Stations were analyzed within four groups (East, Koʻ Olina, Kahe, and Nanakuli) to determine similarities based on all previous historical data. The removal of two monitoring stations, East 2 and Kahe 7D are reflected in this report. Four monitoring events were conducted in 2019: July, August, September, and November with an average reported from the pooled surveys.

Hawaiian Electric has collected data on fish and benthic communities at Kahe Generating Station (KGS) since the mid-1970's. This long-term dataset documented severe changes following storms and hurricanes not related to the operation of KGS. Eight of the KGS monitoring stations (Kahe group) overlap with stations from the CIP Generating Station Project to provide a robust record of trends and patterns in fish community factors and their environmental and meteorological influences.

Shifts in fish communities were observed between 2018 and 2019. During the 2018 fish surveys, the bluestripe snapper, *taʻape,* was dominant in biomass and abundance, comprising nearly half of the individuals present along transects. The yellowstripe goatfish, *weke,* was also high in occurrence. In 2019, the bluestripe snapper and yellowstripe goatfish are within the top ten species for both biomass and abundance, but are not dominant. Instead, the brown surgeonfish, *maʻiʻiʻI,* and saddle wrasse, *hinalea lau wili,* contribute most heavily to the abundance. The biomass along monitoring transects during the 2019 surveys is spread among several species, each representing between 8% to 9.5% of the total estimated biomass: saddle wrasse, brown surgeonfish, whitebar surgeonfish (*maikoiko),* goldring surgeonfish (*kole),* and yellowstripe goatfish. Despite differences in dominant fish species present along transects, the total number of fish species recorded in 2018 is identical to the number recorded in 2019 (110). Trophic regimes remain fairly constant throughout the two years, with herbivores and invertebrate feeders making up the majority of both mean abundance and mean biomass.

Similar to Brock's (2018) findings, the Koʻ Olina group exhibits higher number of fish species, individuals and biomass as compared to the East, Kahe and Nanakuli groups. However, the 2019 data did not show any statistically significant differences or elevated mean number of individuals

or biomass at the East and Nanakuli groups when compared to the Kahe groups with all groups statistically similar in 2019. Brock (2018) also notes high coral community development at Ko‘Olina stations as drivers of high diversity of fish species, abundance and biomass. As in previous years, the KGS discharge pipe (Pipe) station is significantly higher in biomass, abundance and diversity of fishes as compared to the East, Kahe and Nanakuli groups. Although abundance and biomass were significantly higher at the Pipe than at other groups, a statistical difference could not be found between Ko ‘Olina and the Pipe. This is due to low diversity, abundance and biomass of fishes within the East, Kahe and Nanakuli groups, likely resulting from the poorly developed coral communities there and the high variability between fish surveys and years. Although the Pipe transect has significantly lower fish biomass and abundance in 2019 as compared with the previous year, a significantly greater number of fish species was reported. Two of the fourteen transects (East 1 and Kahe 7C) experienced significant declines in fish biomass and abundance between the last two surveys.

Fish populations are heavily influenced by spatial complexity. The topographic relief provided by the KGS Pipe provides protection from predators and habitat complexity that is known to be highly correlated with fish populations. Periodic storms and hurricanes contribute to the lack of spatial relief through breakage and removal of coral colonies and shifting of sands. The poorly developed benthic communities at the Kahe stations are reflected in the lack of fishes as compared to more well-developed benthos as found at the Ko ‘Olina and Pipe stations. The 2019 surveys found no significant change in fish community factors that can be attributed to the KGS or CIP facilities.

INTRODUCTION

Purpose

The Hawaiian Electric Company’s (Hawaiian Electric) Campbell Industrial Park (CIP) Generating Station began service in 2010. The 120 MW combustion turbine and two auxiliary 2 MW diesel engine generators were believed to be the largest commercial generation system designed to be sustainably fueled using biodiesel at that time. CIP Generating Station has allowed Hawaiian Electric and the State of Hawai‘i to move steadily towards their goal of generating 100% renewable energy by 2045. In contrast to the nearby Kahe Generating Station (KGS), CIP Generating Station does not discharge effluent into the ocean. Instead, CIP Generating Station is permitted to discharge effluent (approximately 600 gallons per minute [gpm]) from the production of electricity into two permitted injection wells onsite. This eliminates or greatly reduces any deleterious impacts to the adjacent nearshore marine environment. The development of this electric generating facility initiated an environmental monitoring program with a focus on determining any temporal or spatial changes in fish communities. The spatial extent of the quarterly surveys range from Barbers Point (Kalaeloa) in the southeast direction to Nanakuli in the northwest, a distance of 7.9 kilometers (km) (4.9 miles [mi.]) (Figure 1). Eight of the monitoring stations along this coastline have been surveyed since 2008. The remaining eight stations were established in the 1970s for Hawaiian Electric’s monitoring program. These stations range in depth from 5 meters (m) (16.4 feet [ft]) to 12 m (39.4 ft). Prior to construction of the CIP Generating Station, baseline surveys were conducted in 2008 (Brock 2019), followed by continued monitoring during the construction phase in 2009 (Brock 2019). Quarterly monitoring continued once the plant was fully operational in 2010 and has been consecutively monitored thereafter (Brock 2019). This statistical record of long-term monitoring has increased in value with the onset of acute events including storms, hurricanes, temperature anomalies, flooding, and other stochastic events. This has allowed an understanding of fish community impact and subsequent recovery along this coastline. Reassessments in the Kahe area have increased the value of this database due to comparable surveys conducted by Hawaiian Electric in this region in the 1970s and 1980s, providing over four decades of information on fish community structure. Fish assemblage factors including biomass, abundance, trophic levels, and species composition accurately assess populations and determine spatial and temporal change. Surveys continue as a benefit to the community on the west side of O‘ahu.

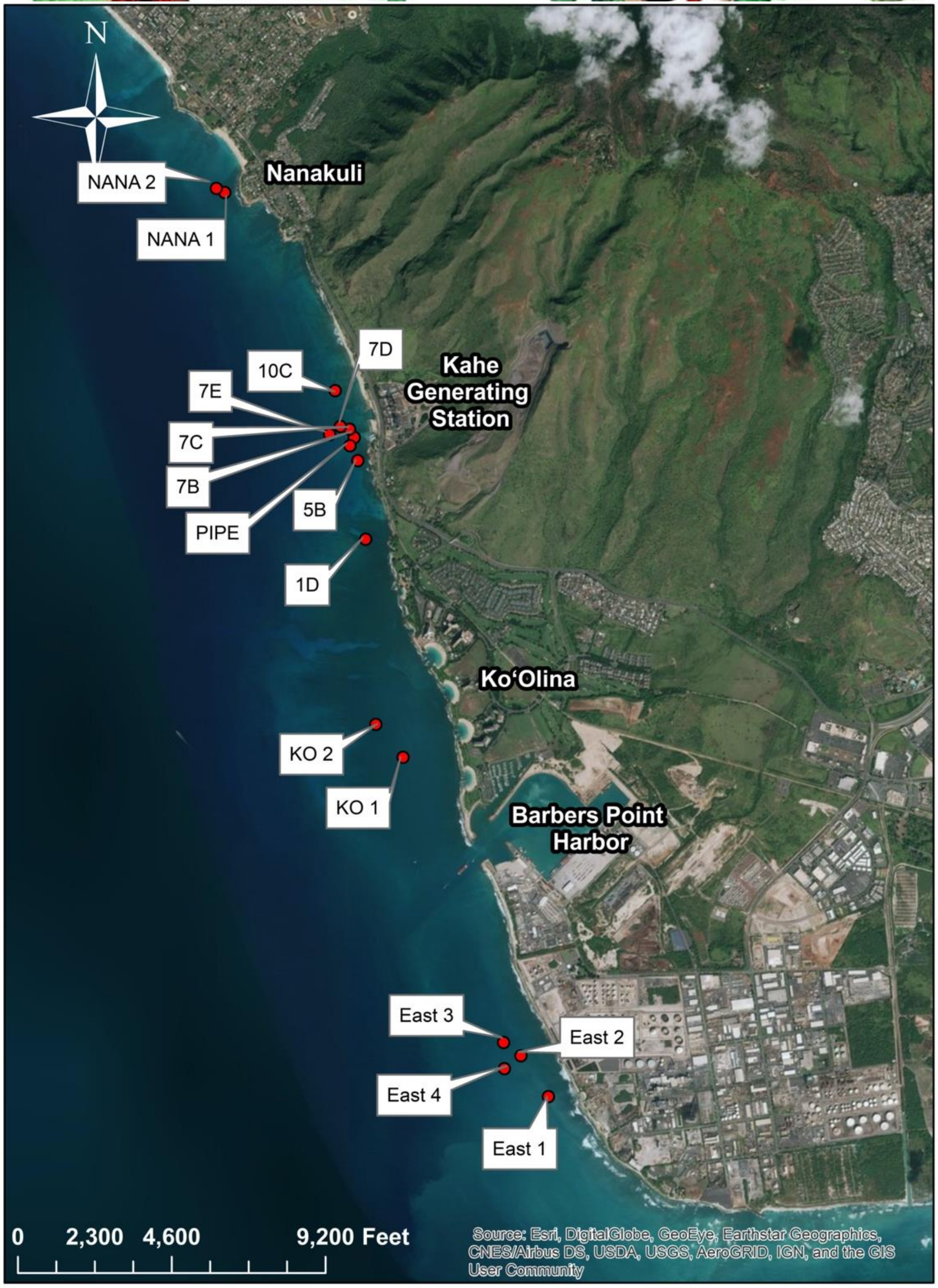


Figure 1. Map showing the southwest coastline of O'ahu from the Barbers Point Harbor to Nanakuli Beach Park depicting locations of each of the sixteen permanently marked stations monitored in this study.

Accuracy in determining fish populations depend on the number and size of transects and whether transect locations are randomly selected, stratified random (e.g. following depth contours), or fixed (returning to the same location over time). Fixed transects may not be representative of the entire community of interest but allow for more accurate repeated measurements and over time increase in statistical power due to a larger sample size. Spatial and

temporal variability of fishes can be extremely high due to mobility and large home ranges. Many fish species are cryptic, rare or transient. There are also diurnal/nocturnal and seasonal sources of variability. To quantify absolute values for fish populations, an extremely large sample size is required, especially for heterogeneous habitats, that are diverse in substrate types, otherwise relative values should be used to determine differences between sites. Surveys repeated consistently over time on a regular basis can also be used to accurately quantify absolute values. The statistical power to detect differences increases over time due to an increase in the sample size. As you increase power, you increase the chances that you will detect an effect if it exists. More samples (more surveys) allow for both large and small effect sizes, regardless of the variability in the data, due to an increase in information.

Numerous methods have been developed for sampling fishes. Method selection depends on the focus of the research and the spatial and temporal scales involved. Comparability of methodology is imperative when making comparisons between and within sites. Calibration between methodologies is vital to assurance of evaluations. Quantitative methodology is vital to any long-term monitoring program.

Qualitative (descriptive, non-numerical data) surveys by subject matter experts are:

- Subject to great surveyor error;
- Can’t be replicated by others or compared to other studies using quantitative methods;
- Only certain information can be obtained (e.g. species presence) doesn’t measure all variables;
- Good for large-scale rapid assessment of an area or general conditions;
- Strongly biased; and
- Observations highly variable.

Quantitative (numerical data) surveys:

- Provide species abundance/biomass, most common species;
- Compare to other sites to determine change (seasonality or environmental changes);
- Provide a stable baseline;
- Can verify statistical differences; and
- Are archivable: to review data or confirm species or repeat with new objective.

To avoid comparability issues with this dataset, the species abundance method (Brock (2019), adapted from the belt transect method (Brock 1954) has continued throughout this long-standing survey. This includes a transect length of 50 m and width of 4 m (area 200 m^2). This methodology records fish species and estimates length and number of individuals. From this data, fish community factors of abundance, biomass, trophic levels, endemism, diversity, evenness, and size class can be derived.

This species abundance method maximizes data and statistical comparability, allows for length to biomass conversions, and avoids limitations inherent in some other methods. This method includes two measures of abundance: numerical (number of fishes) and biomass (weight of fishes). These are both important population parameters that address different aspects of fish

community structure. Unlike the belt transect method, species abundance estimates do not require additional survey time to allow for fish equilibrium to occur. The transect line is spooled out as the survey is conducted to avoid scaring fishes.

Size structure of fish populations can be an informative means of characterizing fish communities both spatially and temporally. Variations in recruitment processes such as production, transport, settlement, and mortality, can be revealed in missing or reduced size classes. Lack of recruitment can limit population size. Variations in size categories can explain variation in site attached fishes. The condition of different size assemblages can provide clues to causal mechanisms and links to environmental factors. Certain anthropogenic impacts can be detected, including the most influential impact of overfishing, by quantifying absence or highly reduced abundance of food fishes in the larger size classes. Absence or overabundance in certain size groups can predict future trophic structure and species composition. Size classes can directly influence competition, predation, and shifts in community structure.

Trophic levels and endemism for fish species are also determined in these surveys. The trophic categories used by Brock (2019) were carnivores, herbivores, planktivores, omnivores, and corallivores. Trophic categories from 2019 forward are herbivores, invertebrate feeders, zooplanktivores, and piscivores. These categories are similar to the functional groups used by Brock (2019) but are now comparable on a Statewide spatial scale over a similar temporal scale. Fish assemblage organization including trophic structure is dependent more on local than regional conditions. Thus, these assemblages are more susceptible to local disturbances of fishing pressure, pollution, eutrophication or sedimentation, which can cause major shifts in trophic levels. Declines in apex predators (piscivores) are the most highly evident when comparing feeding guilds in the Main Hawaiian Islands (MHI) as compared with Papahānaumokuākea in the Northwestern Hawaiian Islands (NWHI). Large apex predators, primarily jacks and sharks, comprise over half of the total biomass in the NWHI (54%), while contributing only a small percentage (3%) in the MHI (Friedlander & DeMartini 2002).
Both terrestrial and marine endemism in the Hawaiian Islands is high compared to the rest of the world, due to geographic isolation that restricts gene flow and favors speciation where species evolve over time. Of the 680 species of fishes in Hawaiʻi, 20% are endemic, found exclusively in Hawaiʻi. The overall marine environment has an average of 25% endemism with an endemism rate of 20% for algae, fishes and mollusks and 40% for crustaceans. There are no endemic echinoderms and very low endemism of pelagics due to their mobility. Endemism is restricted to the species and subspecies level with no endemic families and only three endemic genera. There are no single island endemics and corals are depauperate (lacking in number of species), missing many of the genus found elsewhere in the Pacific. There are few endemic species in a genus, only one or two. In contrast, a terrestrial genus has approximately 100 endemics.
Endemism is a biologically relevant attribute in examining fish assemblages. It relates to conservation of biodiversity, genetic connectivity and spatial patterns of recruitment. Historically, endemic comparisons have been based solely on presence/absence data due to lack of quantitative data. Yet, endemism evaluations are more statistically meaningful when incorporating numerical and biomass densities which allow for inclusion of spatial patterns (Friedlander & DeMartini 2004).

Introduced species have become common on reefs in the MHI. Most snappers occurring in Hawai‘i have historically been highly prized food fishes. *Pristipomoides filamentosus* (‘opakapaka), Crimson jobfish, *Etelis carbunculus* (ehu), Ruby snapper *Etelis coruscans* (onaga), and Long-tailed Red snapper inhabit depths of over 60 m. The Division of Aquatic Resources originally known as the Hawai‘i Fish and Game introduced three shallow water snappers from the South Pacific and Mexico in the mid-1950s and early 1960s in hopes of stimulating the commercial fisheries. These are among the 11 demersal species introduced within a 5-year period. *Lutjanus kasmira* (ta’ape) the Blue-stripe snapper and *L. fulvus* (to’au) the Black-tail snapper have become widely established, while the third species, *L. gibbus*, the Humpback red snapper, is extremely rare. The more common of the non-native snappers, *L. kasmira*, (ta‘ape) was introduced from the Marquesas in 1958, while *L. fulvus* (to‘au) was imported two years earlier in 1956. Although only 3,200 *L. kasmira* (ta‘ape) were released on the island of O‘ahu, they have increased their range to include the entire Hawaiian archipelago. The peacock grouper *Cephalopholis argus* (roi) introduced by the state for commercial purposes in 1956 from Moorea, French Polynesia, originally had more popularity as a food fish than the introduced snappers. Its attractiveness as a food fish rapidly declined as cases of ciguatera poisoning increased. This opportunistic feeder is perceived by many local fishermen as unsafe to consume and in direct competition with them because it preys upon native fish species. Contrary to popular belief, Dierking et al. (2005) found that the majority of roi are relatively safe to consume, with approximately 4% containing levels of toxin high enough to cause ciguatera poisoning. However, 20% of samples contained some level of ciguatoxin. Although a strong site specific correlation occurred with the highest percentage of toxic roi found on the island of Hawai‘i, nearly all of the 28 locations tested on several islands contained fish that tested positive for ciguatoxins. Due to its carnivorous nature and presence of ciguatoxin, numerous efforts to cull this fish from the nearshore reefs have been initiated through community projects including “Kill Roi Day” on Maui, “Roi Round-up” on the island of Hawai‘i, and “Kaua‘i no ka Roi” on Kaua‘i. None of these introduced species has been widely accepted as a food fish among the local population or become successful in the commercial fisheries and the ecological effects of these aliens have only recently been realized. Histological reports from Work et al. (2003) found that nearly half of the *L. kasmira* (ta‘ape) examined from O‘ahu were infected with an apicomplexan protozoan. Furthermore, 26% were infected with an epitheliocystic-like organism with potential transmission to endemic reef fishes. In addition, *L. kasmira* (ta‘ape) from Hilo were found to host the nematode *Spirocamallanus istiblenni* (Font and Rigby 2000). Species of goatfish *Mulloides flavolineatus* (weke) and *Parupeneus porphyreus* (kūmū), Whitesaddle goatfish, popular food fishes, may be displaced by *L. kasmira* (ta‘ape) which has also expanded its range into deeper water where *P. filamentosa* (‘opakapaka) reside. Friedlander and Parrish (1998) looked at patterns of habitat use to determine predation and resource competition between *L. kasmira* (ta‘ape) and several native species within Hanalei Bay, Kaua‘i, but found no strong ecological relationships.

Diversity plays an important role in many ecological and conservation issues. Thus, it is included in this report. It can be a significant factor in assessing the efficacy of management efforts. Reductions in diversity can be indicative of fishing pressure since it can selectively remove

specific species. Other anthropogenic impacts, such as eutrophication and sedimentation, can also result in phase shifts that impact fish diversity. Natural conditions can also determine diversity. Areas sheltered from high wave energy have previously been reported to maintain higher fish populations and exhibited greater species diversity in the Hawaiian Islands (Friedlander & Parrish 1998; Friedlander et al. 2003). This can be attributed to reduced habitat complexity in high-energy environments. Seasonal variability in wave impacts can structure the physiography of reefs, reducing habitat and spatial complexity for fishes through a dominance of encrusting morphologies of corals.

This annual report (Rodgers et al. 2019) includes a quantitative analyses of the fish populations along the Kalaeloa-Kahe-Nanakuli nearshore corridor and a comparison with the prior eleven annual surveys conducted by Brock (Brock 2019).

Natural Events and Anthropogenic Impacts to Hawaiian Coral Reefs

Climate change has increased ocean temperatures and changed the ocean chemistry. This is due to the anthropogenic input of emissions into the atmosphere. The oceans absorb much of the carbon dioxide (CO_2) emitted. These global impacts are the ones most critical to address. But we cannot ignore the local impacts. Local problems that add to the decline of fisheries include invasive species, sedimentation, nutrification, pollution, fishing pressure and others.

Both physical and biological processes control species distribution and abundance and other aspects of community structure. On a large scale, physical factors dominate, while at a local scale, biological interactions may control species composition. Physical processes include environmental stress/disturbance, climate, wave exposure, transport processes (dispersal), depth, temperature, salinity, light and oxygen levels. Biological processes include predator/prey relationships, competition, reproduction, recruitment, consumer/resource interactions and food availability.

<u>Fishing Pressure</u>

An expansion of commercial and recreational fisheries with more effective and efficient methods and increased economic pressure have led to worldwide over-fishing. Nearly 70% of fish stocks are considered to be below sustainable levels. Both pelagic and coastal fish abundance have experienced extensive declines on a global scale. Fishing pressure has also caused severe depletion of fish stocks on a local scale. Recent research provides overwhelming evidence of the impact of overfishing in the MHI (Friedlander et al. 2017). It is based on the largest database of its kind including data from over 25,000 surveys and assembled and analyzed by the Fisheries Ecology Research Laboratory. Among the local pressures impacting our reefs, overfishing is clearly the primary forcing function of fish declines. The link between food fish populations and human population is strongly evident while fishes not targeted for food show no connection with populated areas. Reefs off highly populated regions have only a small fraction of food fishes than at remote reefs in the MHI such as at Niʻihau, Kahoʻolawe, and N. Molokaʻi. Compared with Papahānaumokuākea in the NWHIs, the fish biomass is 10 times higher than off Oʻahu. Total catch is considerably lower even with greater fishing effort. The shift is towards smaller, younger individuals and away from larger, piscivorous fishes. If fishes high on the trophic level are

targeted, it is only sustainable under low fishing pressure. Many coastal fish populations have decreased to levels below the ability to replenish themselves (Friedlander and DeMartini, 2002).

The dynamic nature of coral reefs and associated fish populations keeps the marine environment in a constant state of flux. Changes in species abundance, size structure, and trophic levels occur frequently, causing community shifts. These processes can be a result of long-term impacts or stochastic events. The likelihood of recovery is higher from an acute event than from a chronic event. Chronic cases have only shown recovery of reefs after other anthropogenic or natural stressors ceased and where the physical or biological environments have not been altered (Connell, 1997; Erftemeijer et al., 2012; Philipp and Fabricius, 2003).

<u>Influential Factors Controlling Reef Communities</u>

Stratification of coral reef organisms is controlled principally by depth, topographical complexity, and wave regimes. Accretion, growth, and community structure of most coral reefs in the Hawaiian Islands are primarily under the control of wave forces (Grigg, 1998). The dominant wave regimes show quite different patterns of wave height, wave periodicity, intensity and seasonality (Jokiel, 2006) and slight differences in exposure, and have a profound impact on reef coral development (Storlazzi et al., 2005). Large waves and strong currents in exposed areas flush contaminants from reefs. However, anthropogenic impacts can dominate in environments where wave forces are not the major controlling factor. To develop a measure of reef condition, Rodgers (2005) used 43 different factors in an attempt to understand what the most important factors were that influence coral reef communities. Parametric (multiple regression) and non-parametric statistical analyses (principal components analysis, and non-metric multidimensional scaling) were used to determine which environmental factors were most important in structuring coral and fish assemblages. Coral reefs involve multifaceted interactions and each factor alone is a weak predictor of any of the response variables, however, in combination these factors explained a large percent of the variability. Both natural factors such as spatial complexity, waves, and depth and anthropogenic factors such as human population, silt and organics explained most of the variability in fishes and coral (Figure. 2).

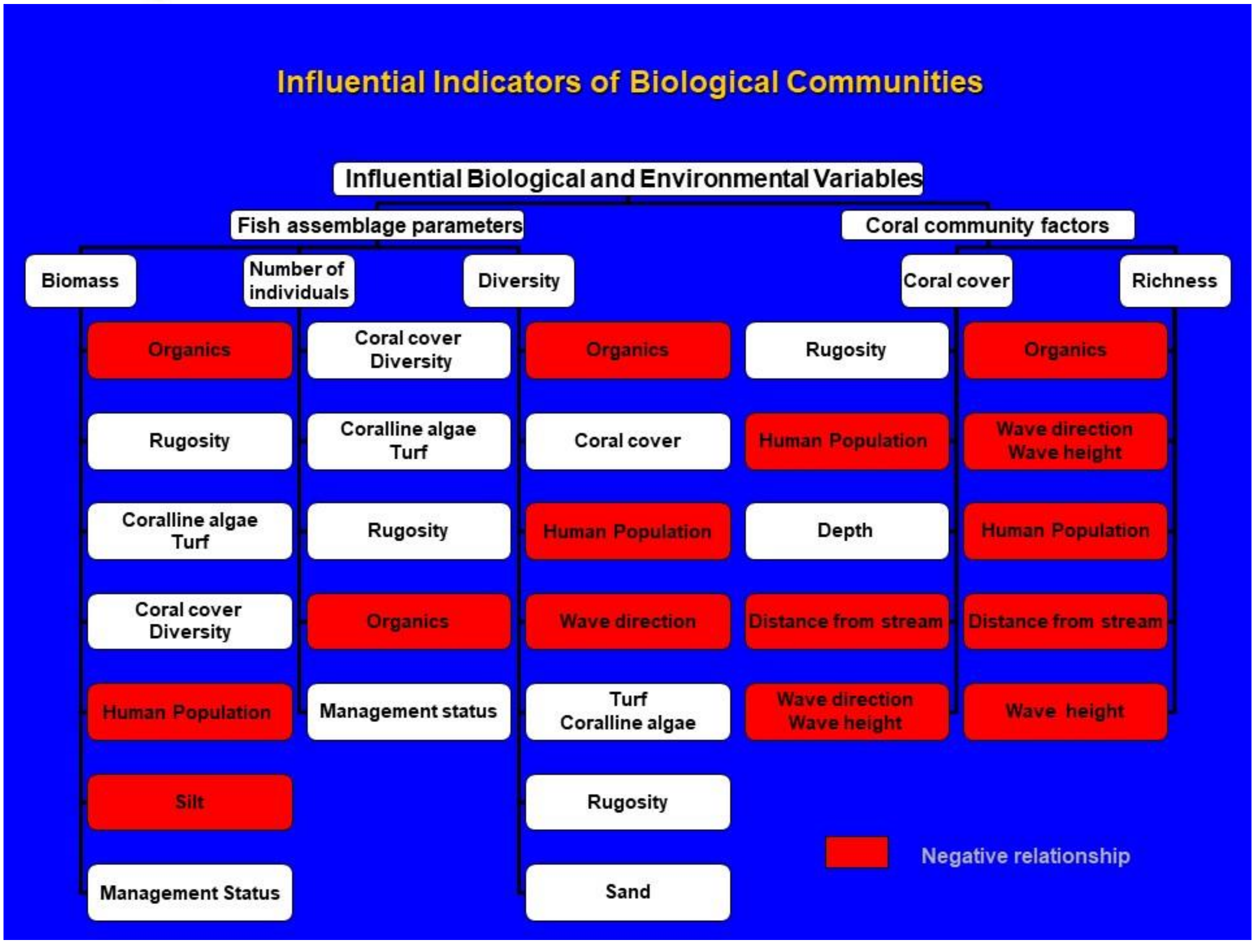


Figure 2. Primary forcing functions driving reef fish biomass, abundance and diversity and coral cover and richness in the main Hawaiian Islands. These top variables of among 43 factors, are most influential to fish and coral populations. Influential factors negatively correlated with fish or coral parameters are colored red. For example, the higher the organics or human population, the lower the fish and coral assemblages.

These influential factors can be less significant when stochastic events occur. Hurricanes have been documented as a major influence on coral reef communities (Heron et al., 2008). Hurricanes can have devastating effects (mechanical breakage, sedimentation, nutrification) but have also been documented to ameliorate coral bleaching (Manzello et al., 2007). Hurricanes absorb energy from the surface and reduce temperatures through evaporative cooling. They can cause upwelling by bringing deeper, cooler waters to shallower depths and a reduction in irradiance levels through cloud shading can decrease temperatures. However, in shallow waters, hurricanes can destroy corals through wave damage and cause mortality of recruits through sand scour. As the frequency and intensity of climate impacts accelerate, we are experiencing more severe and intense storms, hurricanes, and flood events. For example, bleaching events were unknown to science until 1983. The first widespread coral bleaching event in the MHIs occurred in 1996 where although bleaching was extensive, mortality was low because temperatures quickly returned to normal. Then in 2004 and 2006 the corals in Papahānaumokuākea in the

NWHI experienced major bleaching. Hawai‘i then escaped the major bleaching that was occurring in many regions worldwide that devastated many reefs for the next decade due to our geographic location and a downturn of temperature since 1998. It wasn’t until 2014 and 2015 that we experienced another widespread bleaching event where severe mortality occurred. The coral mortality was 50% on the Kona coast and nearly 35% statewide (Kramer et al. 2016). It had been predicted that a bleaching event would impact the Hawaiian Islands once every 25-30 years (Mora et al. 2014). More recent predictive modeling based on the National Oceanic and Atmospheric Administration (NOAA) Coral Watch data is forecasting 6-year intervals between wide spread bleaching events (Eakin et al. 2019). The International Panel on Climate Change, a group of renown scientists from over 40 countries recently announced their predictions based on tens of thousands of scientific papers. Their prediction states that if drastic changes are not made within 11 years, 99% of the world’s coral reefs will be gone within a generation. Many fishes rely on coral reefs to survive. Coral reefs provide protection from predators and food for many species including obligate corallivores. The recovery process following these bleaching, hurricane, and flood events have been well documented. Successional patterns of recovery have been documented globally and in the Hawaiian Islands (Blumenstock et al. 1961, Ball et al. 1967, Perkins and Enos 1968, Stoddard 1969, Maragos et al. 1973, Grigg and Maragos 1974, Ogg and Koslow 1978, Woodley et al. 1981, Walsh 1983, Harmelin-Vivien and Laboute 1986, Done et al. 1991, Dollar and Tribble 1993, Skirving et al. 2019). The CIP and the Kahe Marine Monitoring Projects have provided the opportunity to follow coral recovery subsequent to Hurricanes Iwa and Iniki (Noda 1983, Brock 2019).

Hawaiian Electric’s Biological Communities Monitoring Program

The consistent and continued monitoring of benthic and fish communities provides a comprehensive record of spatial and temporal change during the construction of the Kahe Generating Station. Compliance with the National Pollutant Discharge Elimination System (NPDES) permit to allow thermally elevated seawater discharge for cooling purposes has been strictly adhered to throughout the period of construction and operation. Well-designed benthic and fish surveys within the zone of mixing, adjacent areas, and comparable reference sites allow for comparisons over space and time. The sample size, frequency of monitoring, and duration of surveys makes this program one of the longest and most valuable records in the Hawaiian Islands.

Fish populations are highly variable, requiring numerous transects to quantify absolute values of fish communities. A large sample size is necessary due to the high variability among fish assemblages. Many rare, cryptic or mobile species can be under reported and the power to accurately detect absolute fish abundances can be extremely low. Variation in numbers can be attributed to differences in visibility and natural fluctuations that are typically observed in temporally spaced censuses of highly mobile reef organisms. Although fish populations vary considerably both spatially and temporally, statistical power increases over a time series as additional data is acquired, as with the CIP monitoring dataset. With nearly five decades of survey data, the power to detect differences increased considerably. Data, surveyor, and methodological compatibility were maintained to assure statistical significance and quality assurance and control. In long-term monitoring programs such as this, methodological

consistency is crucial. Coral and fish survey procedures and data assessment have and continue to maintain this consistency annually using uniform methodology. The variation of long-term monitoring of fish surveys was determined through statistical analyses of prior surveys with current surveys (Brock/Stender). In addition, a surveyor with similar expertise as the original surveyor was selected to continue fish community assessments. In order to interpret any environmental changes observed, it is vital to have qualified expertise in each area of the marine field. Low surveyor variation in this long-term monitoring record of nearly half a century is imperative to maintain since annual variability can often obscure trends and patterns.

<u>Historical Surveys to Date</u>

KGS began operation in 1963. The later expansion of the KGS to include six generating units required an environmental impact statement (EIS) compiled by Sterns-Roger, Inc. in 1973. The EIS included prior baseline conditions from reports submitted by Marine Advisors (1964), B.K. Dynamics (1971), and URS Research Co. (1973). During the station expansion and relocation of the shoreline outfall to the present location offshore, numerous NPDES marine monitoring reports described the Kahe physical and biological environment (Coles and McCain, 1973; Coles and Fukuda, 1975, 1983, 1984;
Environmental Department, 1976; McCain, 1977; Coles, 1979, 1980; Coles et al., 1981, 1982, 1985, 1986; Fukuda and Oda, 1987; Hawaiian Electric Environmental Department 1988-2019: 31 reports). Surveys detected a decline of 20% in the coral communities in proximity to the KGS outfall from 1973 to 1977 (Coles 1979). Once full KGS operations commenced, an increase in coral settlement and growth was reported in proximity to the outfall. This led to the assumption that the construction of the outfall and not the plant operations was responsible for the coral mortality. Fish censusing showed no change as a result of construction or plant operation except on peripheral reefs northeast of the KGS outfall where the abundance and number of species declined once the outfall was operating. The number of shoreline intertidal species increased where affected by the thermal outfall (Coles et al. 1985). Fish surveys conducted since the initial offshore outfall operation in 1976, show fish displacement near the outfall (Coles 1979). The fish population decrease from 1976-1978 was minimal relative to the change following the 1980 Kona storm. Coles et al. (1981) found much greater declines in coral cover, fish populations, and sand redistribution attributed to the 1980 storm than in the seven years previous.

With the addition of the KGS' Unit 6 in 1981, the water flow needed for cooling was increased by 33% above the flow rates for Units 1-5. The rate of flow was subsequently 846 million gallons per day (mgd). The benthic thermal impingement was twice the area, but mainly limited to sand areas offshore. This increase in the generating capacity reduced the surface plume to half the area. Coral cover and fish populations both declined from previous surveys likely due to the loss of habitat from the 1980 storm (Coles et al. 1982.)

The CIP Generating Station began construction in 2009. Prior to construction, surveys had been conducted in 2007 and 2008 (Brock 2019). Twelve to fifteen stations were surveyed in 2007 and sixteen stations in 2008. The KGS discharge pipe station was added by the third survey and analyzed separately based on the unusual fauna. The high spatial complexity of the artificial

structure provided habitat and protection for an extensive and well-developed fish community. During the construction phase in 2009, three fish surveys were completed at all sixteen stations. Operation of the new plant began in 2010. Unlike the KGS, the CIP Generating Station has no direct input into the ocean since it is located well inland. Details of quarterly surveying from 2010 through 2018 can be found in Brock (2019). Environmental and meteorological shifts have been apparent since 2014. The most widespread coral bleaching event occurred in the Hawaiian Archipelago in 2014 and 2015. Simultaneously in 2015, an unprecedented fifteen major storms were recorded. Loss of reef structure from coral mortality following severe bleaching events are strongly correlated to fish community factors (Friedlander et al. 1998). Loss of reef structure can have devastating impacts on fish assemblages.

The increase in ocean temperatures is directly related to the increase in carbon emissions. However, other large-scale weather patterns and global phenomena also affect ocean temperatures. The Pacific Decadal Oscillation (PDO) has been described as a long-lived El Niño-like pattern of Pacific climate variability characterized by widespread variations in Pacific Basin and North American climate. During the past century, two major PDO eras have persisted for 20 to 30 years. Cool PDO regimes prevailed from 1890–1924 and again from 1947–1976, while warm PDO regimes occurred from 1977 through the mid-1990s. A downturn of warm seawater temperature off Hawai‘i in 1975 and 1998 was experienced as the PDO reversed. The PDO experienced a temporary reprieve of slight cooling due to a downturn of temperature since 1998 at the end of the last cycle of the PDO. Nevertheless, as the bleaching threshold was approached in 1996, there was a reversal of the warming trend that can be attributed to the PDO. Because of the uncertainty of how the PDO works, it is not possible to predict with certainty what will occur. A decline in warming of Hawaiian waters marked the beginning of a 20 to 30 year-long cool phase. This cooling phase which may be currently switching to a warming phase in Hawaiian waters, only served to moderate the local warming trend during the first part of the PDO cool cycle, but will accelerate warming as the cycle reverses. Temperatures have been steadily increasing over the past several decades and models predict even more severe bleaching events that are projected to increase in frequency and intensity in the coming decade with concomitant decline in Hawaiian corals. The shorter El Nino/La Nina cycles may have an additive or synchronous effect on ocean temperatures as warm water from the western Pacific moves east. The warm water replaces the cold water, warming the air above it and increasing the amount of air rising in the Intertropical Convergence Zone, intensifying cloudiness and rainfall. These weather phenomena increase ocean temperatures and increase storm activity.

Historical Impacts (Storms, Hurricanes Iwa & Iniki)

The monitoring program at Kahe encompasses stochastic storm events (January 1980, November 1982, September 1992, November 2003) and two major hurricanes (Iwa 1982 and Iniki 1992). The major storm in 1980 had a large impact on the shallow benthic coral community due to wave energy of up to 6 m released at shallower depths. Coral cover declined by nearly 19% following this major storm event (Coles and Fukuda 1984). This was attributed to extensive sand scour and deposition resulting in a coral community compositional shift.

Hurricane Iwa, two years later in 1982, had the opposite effect where sand attenuation occurred revealing substrate previously buried by up to five feet of sand. This hurricane with maximum wave heights of 9 m (Noda 1983) destroyed offshore reefs deeper than 6 m, while sparing coral communities closer to shore (Coles et al. 1985). Subsequent surveys in 1983 validated the observations made shortly after the hurricane. Significant declines of coral, algae, and fishes occurred in regions where hurricane force waves were greatest (Coles et al. 1985). Coral cover offshore from the Kahe facility declined 5.4% in addition to the previous declines of 18.7% attributed to the 1980 storm.

The impact waves have on a reef depends on complex interactions between wave direction, topographical relief, and substrate bathymetry (Dollar and Tribble 1993; Storlazzi et al. 2002, 2005). A wave shadow is created in the lee of the islands, blocking waves that can ameliorate the influence of these waves on reefs (Storlazzi et al. 2005). For example, waves are lessened during north Pacific swells on the south shore of Moloka‘i due to island blockage although refraction does occur on the extreme ends of the coast. In contrast, the west side of O‘ahu, where Kahe is located, is vulnerable to waves and refraction from all directions because it does not fall under this wave shadow. Wave direction can be a strong influence on the level of impact occurring during a storm (Table 1).

Table 1. Waves influencing the main Hawaiian Islands (Jokiel 2008).

	Typical			**Extreme**				
	Height		**Period**	**Height**		**Period**	**Direction**	
Wave Type	**(m)**	**(ft)**	**(s)**	**(m)**	**(ft)**	**(s)**	**Mean**	**Range**
NE Trade wind waves	1.2-3.7	4-12	5-8	4.0-5.5	13-18	9-12	NE 45°	0-90°
North Pacific swell	2.4-4.6	8-15	10-17	4.9-7.6	16-25	18-25	NW 315°	282-45°
Southern swell	0.3-1.2	1-4	12-17	1.5-3.1	5-10	14-25	SSW 190°	236-147°
Kona storm waves	0.9-1.5	3-5	8-10	1.8-3.1	6-10	11-14	SW 210°	258-247°

m=meters, ft=feet, s=seconds

Northeast Trade wind waves: Typical trade winds weaken at night and gradually increase throughout the morning with wind speeds at the maximum in the afternoon. This is related to an increase in wind-driven waves. Offshore waves break and dissipate along the north and east shores of all islands. Islands act as a barrier to surface winds but increase in velocity as they funnel through breaks between islands producing sizable wave chop in channels with distinct boundaries. The November 2003 storm was an extremely destructive northeast wave event due to wave heights well above normal. Damage at Pila‘a on the north coast of Kaua‘i resulted in a 43% reduction in coral cover with extensive fragmentation. Similar reductions were reported on the northeast facing shore of O‘ahu at Wawamalu near Sandy Beach (Jokiel and Brown 2004).
North Pacific Swells are generated in the North Pacific by winter storms. These can result in breaking inshore waves of over 15 m. This wave energy limits the coral development on north

shores of islands where species of high skeletal strength and encrusting or lobate morphologies exist (Storlazzi et al. 2005, Rodgers et al. 2003). **Southern Swell** is generated by winter storms in the Antarctic typically reaching the Hawaiian Islands a week following generation, during the Summer and early Fall. These storms weaken due to the spread of energy. This is the reason summer south swells do not typically reach the heights of winter north swells. **Kona Storm Waves** can occur anytime of the year, but commonly develop from October through April. Waves are generated by southerly or southwesterly winds that precede cold north winds. Three-meter wave heights can be generated under extreme conditions. The Kona coast of the island of Hawaiʻi experienced 6 m waves that reduced coral cover from 46% to10% following a Kona storm in 1980 (Dollar and Tribble 1993). **Hurricane Waves** are less frequent and highly unpredictable. To date hurricanes have followed trajectories that have led to direct reef impact on the islands of Kauaʻi and Oʻahu and less of an effect on the other islands (Schroeder 1998). Central Pacific hurricanes typically originate near Central America or southern Mexico. As they move towards Hawaiʻi over cooler water they lose energy or encounter atmospheric conditions unfavorable to further development. Hawaiʻi's hurricane season is from June through November. Hurricane Iniki (1992) generated powerful waves that fragmented and abraded corals on south Kauaʻi. Terrestrial objects swept onto the reefs added to the damage. However, re-colonization and recovery of corals occurred rapidly and within a decade, many reefs had returned to their prior condition. Hurricane Iniki also had an impact in Kona, Hawaiʻi with declines in coral cover from 15% to 11% (Dollar and Tribble 1993) and Mamala Bay on Oʻahu (Brock 1996) with loss of rugosity and shelter for fishes. Storms and hurricanes have been documented to negatively impact fish communities in west Oʻahu (Brock CIP reports) and elsewhere in Hawaiʻi (Walsh 1983). The Kahe dataset is important in separating these stochastic events from other environmental and anthropogenic factors.

METHODOLOGY

Survey Stations

Eight stations were established in the 1970's prior to construction of the CIP Generating Station and an additional eight stations were added in 2008 prior to the preconstruction monitoring surveys. These stations were established to assess the fish communities in proximity to the CIP and Kahe Generating Stations at Kalaeloa and Kahe (Figure.1). Four stations are near the CIP Generating Station at 7-10 m depths and seven stations are adjacent to the Kahe Generating Station with one monitoring station along the KGS pipeline (5-12 m depths). Between these two sets, two stations are located northwest of the Ko ʻOlina and Barber's Point Harbors between the 1st and 3rd KoʻOlina lagoons at 7 and 9 m depths. A reference site outside the KGS zone of mixing was established at Nanakuli (Coles et al. 1985). These two stations act as a control to assess any changes in fish structure at the other stations.

The sixteen survey stations located along the west coast of Oʻahu from Kalaeloa to Nanakuli have been surveyed quarterly since 2008 by a single surveyor (Figure 1). Subsequent to the departure of the original surveyor in 2019, survey stations were reduced to 14 with the removal of stations East 2 (2) and Kahe 7D (11). This was based on an analysis of historical data to determine proximity and site similarities. Elimination criteria included close proximity and similar habitat to other stations, similar fish composition and comparability. Mean standing crop

(biomass), mean number of fishes (abundance), and mean fish species within site groups show within group similarity for each of the four sets of groups (Ko'Olina, CIP, Nanakuli, and Kahe). These spatial similarities by location were the initial foundation for separation and removal of the two stations.

Station East 2 is within the CIP monitoring area and Station 7D is within the Kahe monitoring area (Figure 1). These groupings were based on statistical analyses conducted by Brock (2019) over 40 time periods. Statistics show East 1 and 2 were not significantly different from one another in the mean number of fish species. All four CIP stations are similar in abundance (number of individuals) and biomass (standing crop). East 2, 3 and 4 are in close proximity to each other. This served as the justification for removal of station East 2.

In the 1970s Hawaiian Electric established transect 11, (Kahe Station 7D) within a cluster of stations ((7B (9), C (10), D (11), and E (12)) that are located in close proximity to one another. All transects are 50 m in length with the exception of the transect at Station 11 (7D) and the KGS pipeline (10.5 m). The pipeline has consistently shown higher fish community factors mainly due to the increased spatial complexity and shelter areas for fishes. Station 7D was removed from the Kahe monitoring area due to lack of comparability. Extrapolating the fish data to 50 m requires inference that the fishes on the first 10 m of the transect are identical to the fishes in the next 40 m. Changes in topography, coral cover, depth, and water quality correlate with fish communities and can differ within 50 m. Fishes are highly mobile and rare or cryptic fishes cannot be expect to be found consistently throughout a transect, influencing the number of species found. Thus, for program validity and to allow for the comparability necessary for data analysis which would otherwise compromise the statistical strength of the results, Station 11 (7D) was removed from the group of stations. Station 16 at the discharge pipe must be retained to evaluate the impact or lack of impact on fish communities from the outfall. The difference in fishes along the 10.5 m pipe is so great that the results are consistently significantly different when compared to other transects. With the removal of stations 2 and 11, beginning in 2019, there are currently 14 stations surveyed quarterly. Fish factors from 2019 forward will be standardized by area (grams per square meter (g/m^2,) individuals/m^2)) and reported along with total species, biomass, and individuals to further refine differences.

Survey Methodology

Transect locations were originally stratified by location, proximity to the Kahe and CIP Generating Stations, and hard bottom habitat. The general station location is determined through a Global Positioning System (GPS) navigation to within several meters. A marker float is deployed to account for drift during anchoring of the vessel. On the substrate, exact start location has been marked with either a cinder block, a prominent geologic feature, or surface triangulations. The bearing direction of the transect was predetermined and followed throughout the entire program. A modified visual transect (line/belt/strip) (Brock 1954) (species abundance methodology) is employed to quantify fish communities. The fish surveyor spools out the 50 m transect line while recording, species, size (total length [TL] in centimeters [cm]) and the number of individual fishes to 2 m on each side of the transect line (4 m total width). This eliminates changes in fish behavior and allows fishes to equilibrate from previous activity in contrast to

laying a transect prior to the survey. All transects are parallel to shore with the exception of the Kahe discharge pipe that runs perpendicular to the shoreline and is only 10.5 m in length. The surveyor records on a slate, equip with underwater writing paper, fish species, size in cm, and number of individuals with the use of self-contained underwater breathing apparatus (SCUBA). All fishes within the linear 200 m^2 transect from the benthos to the surface are recorded.

Biomass estimates are derived through total length estimated to the nearest cm in the field and converted to biomass estimates (tons/hectare) using length-weight fitting parameters. In estimating fish biomass from underwater length observations, most fitting parameters are obtained from the Hawai‘i Cooperative Fishery Research Unit (HCFRU) consistent with previous analyses. Additionally, locally unavailable fitting parameters are obtained from Fishbase (www.fishbase.org) whose length-weight relationship is derived from over 1,000 references. Congeners of similar shape within certain genera are used in those rare cases lacking information. Conversions between recorded TL and other length types (e.g. fork length [FL]) contained in databases involve the use of linear regressions and ratios from Fishbase linking length types. The three commonly used measures of fishes are standard length (excludes the caudal fin), total length (from tip of snout to tail tip), and fork length (from tip of snout to deepest notch of the tailfin). A predictive linear regression of logM vs. logL is used in most cases to estimate the fitting parameters of the length-weight relationship. Visual length estimates are converted to weight using the formula $M = a \times L^b$ where M = mass in grams, L = standard length in millimeters (mm) and a and b are fitting parameters. Any anomalous values are detected by calculating a rough estimate for a given body type. The general trend for a 10 cm fish of the common fusiform shape should be approximately 10 g. Any gross deviations are replaced with values from the alternate source.

Trophic levels for fish species have historically been based on reports (Brock 2019). These trophic categories include: herbivores, planktivores, omnivores and carnivores. Herbivorous fishes diet consists primarily of algae, planktivores feed in the water column on detritus and zooplankton, omnivores are described as fishes feeding on a combination of algae and small benthic invertebrates and include corallivores that feed exclusively on corals, and carnivores that eat fish and invertebrates according to Brock (2019). Brock based these functional groups on Hiatt and Strasburg (1960), Hobson (1974), Brock et al. (1979) and Randall (2007). To update the trophic categories and for comparability with other sites throughout the State of Hawai‘i, these categories have been adapted to reflect the trophic levels described in Friedlander et al. (2017). This data is a compilation of over 25 datasets containing greater than 25,000 surveys collected between 2000 and 2018. The Hawai‘i Monitoring and Reporting Collaborative (HIMARC) is a consortium of managers and researchers throughout the Hawaiian Islands that collectively contribute monitoring and assessment data to the largest searchable database for fishes in Hawai‘i. Trophic categories include herbivores, invertebrate feeders, zooplanktivores, and piscivores. These categories are similar to the functional groups used by Brock (2019).

Target fish species were selected to include popular food fishes to determine changes in fishing pressure. The genera selected were Acanthus, Aphareus, Cephalopholis, Caranx, Scarus,

Chlorurus, Seriola, Sargocentron, Priacanthus, Kyphosus, Mullodicthys, Parupeneus and Decapterus.

Statistical Methods

Comparative analysis of mean number of fish species documented per transect, mean number of individual fish censused per transect, and mean estimated standing crop (g/m^2) were performed between 2018 and 2019 data to detect any significant differences which may have developed over the year, using an Independent-sample Mann-Whitney U test. The non-parametric Kruskal-Wallis ANOVA with pairwise comparisons was utilized to detect significant difference between all transects and groupings surveyed in 2019. Transects were grouped according to geographic locations (Table 2) into 5 total groups: East group (East 1, East 3, East 4), Ko‘Olina group (KO 1 and KO 2), Kahe group (1D, 5B, 7B, 7C, 7E, 10C), Nanakuli group (NANA 1 and NANA 2) and Pipe. These groupings differ from Brock (2019) to make groupings more consistent with the location of the transect. The 2018 data from Brock’s appendix was re-grouped and descriptive statistics were performed with new group assignments in order to compare to 2019 data. The four timepoints for quarterly surveys were not found to be statistically different, and therefore, time points were pooled within transects and groups for analyses.

Table 2. Latitude and longitude of sixteen permanently marked fish monitoring stations utilized in this study. Stations 2 & 11 (grey) were not surveyed in 2019.

Station No.	Station Area Name	Grouping	Latitude	Longitude	Remarks
1	East 1	East	21º18.237' N	158º07.024'W	New- offshore CIP
2	East 2		21º18.452'N	158º07.152'W	New - offshore CIP
3	East 3	East	21º18.558'N	158º07.239'W	New - offshore CIP
4	East 4	East	21 º 18.406'N	158º07.285'W	New - offshore CIP
5	Ko‘Olina 1	Ko‘Olina	21º19.724'N	158º07.581'W	New - offshore Ko’Olina
6	Ko‘Olina 2	Ko‘Olina	21º19.904'N	158º07.693'W	New - offshore Ko’Olina
7	Station 1D	Kahe	21º20.763'N	158º07.773'W	Old Hawaiian Electric station
8	Station 5B	Kahe	21º21.145'N	158º07.819'W	Old Hawaiian Electric station
9	Station7B	Kahe	21º21.239'N	158º07.855'W	Old Hawaiian Electric station
10	Station 7C	Kahe	21º21.255'N	158º07.881'W	Old Hawaiian Electric station
11	Station 7D		21º21.268'N	158º07.893'W	Old Hawaiian Electric station
12	Station 7E	Kahe	21º21.272'N	158º07.977'W	Old Hawaiian Electric station
13	Station 10C	Kahe	21º21.522'N	158º07.925'W	Old Hawaiian Electric station
14	Nanakuli Control 1	Nanakuli	21º22.329'N	158º08.440'W	Old Hawaiian Electric station
15	Nanakuli Control 2	Nanakuli	21º22.353'N	158º08.462'W	New control station
16	On Outfall	Pipe	21º21.193'N	158º07.869'W	New north side of outfall

RESULTS AND DISCUSSION

OVERALL

Utilizing data from all 48 surveys performed from 2007 to present (2007-2018 performed by Brock), the number of fish species, the number of fish individuals and the biomass were compared between groups of transects: East (3 transects), Ko‘Olina (2 transects), Kahe (6 transects), Nanakuli (2 transects), and Pipe (1 transect). The number of individuals and number of fish species present differed significantly (Appendix A) between groups, with the exception of East and Kahe groups whose number of fishes and fish species were similar. The greatest number of fish individuals and species was observed at the Pipe, followed by Ko‘Olina, Kahe, East and Nanakuli. When comparing the fish biomass throughout all survey years, all groups were found to be statistically different (Appendix A), with the exception of the Kahe and Nanakuli groups, where biomass was similar. Fish biomass was greatest at the Pipe, followed by Ko‘Olina, East, Kahe and Nanakuli. A similar trend was observed in the 2019 data. Fish biomass at East (p = 0.032, 0.009), Kahe (p = 0.011, 0.004), and Nanakuli (p = 0.014, differs only at Pipe not at Ko‘Olina) groupings is significantly lower than both Ko‘Olina and Pipe groupings (Figure 3a, Appendix A). Fish abundance and number of species are significantly higher at the Pipe when compared to East (p = 0.025, 0.047), Kahe (p = 0.007, 0.002) and Nanakuli (p = 0.002, 0.004) (Figures 3b and 3c). Fish abundance and number of species are also significantly higher at Ko‘olina group transects as compared to Nanakuli (p = 0.018, 0.012) (Figures 3b and 3c). Number of species is also significantly greater at Ko‘olina transects when compared to Kahe (p = 0.004).

A total of 110 fish species were recorded in 2019 surveys combining all 14 transects. The number of species present in 2018 surveys (16 transects) was also 110. This attests to the experience of both surveyors. *Mā‘i‘i‘i* (20.7% individuals, 9.1% biomass, *Acanthurus nigrofuscus*, Brown surgeonfish,) and *hīnālea lauwili* (18.6% individuals, 9.33% biomass, *Thalassoma duperrey*, Saddle wrasse) are the dominant fishes along transects for both number of individuals and biomass (Figures 4a and 4b). The majority of individuals along transects are in the trophic levels of invertebrate feeders (43% abundance, 40% biomass) or herbivores (41% abundance, 46% biomass) (Table 3). However, zooplanktivores (14% abundance, 11% biomass) and piscivores (1% abundance, 2% biomass) are also present (Figure 5a, Table 3).

Table 3. Proportion of fish individuals (A) and (B) biomass contributing to each trophic feeding level. (C) Mean proportion of fish individuals and biomass in each trophic level in Brock’s 2019 report standardized to new trophic categories.

A. 2019 Trophic Levels: Number of Individuals (%)

Transect Group	Herbivores	Invertebrate Feeders	Piscivores	Zooplanktivores
East	31.7	42.4	0.5	25.3
Ko‘Olina	71.1	28.0	0.5	0.5
Kahe	31.8	37.6	0.6	30.0
Nanakuli	50.1	41.8	0.8	7.3
Pipe	15.8	63.2	0.5	20.5

Total	40.1	42.6	0.6	16.7

B. 2019 Trophic Levels: Mean Biomass (%)

Transect Group	Herbivores	Invertebrate Feeders	Piscivores	Zooplanktivores
East	58.4	32.5	5.8	3.3
Ko‘Olina	74.6	22.9	0.9	1.7
Kahe	45.9	43.1	2.4	8.6
Nanakuli	41.3	45.5	2.9	10.3
Pipe	9.9	60.8	2.5	26.8
Total	46.0	41.0	2.9	10.1

C. 2018 Brock

	Herbivores	Invertebrate Feeders	Piscivores	Zooplanktivores
Number of Individuals (%)	44.0	30.1	0.4	25.5
Mean Biomass (%)	54.5	38.5	0.2	6.8

In the 2018 surveys, the dominant trophic levels of fishes are also herbivores (51.5% abundance, 59.8% biomass) and invertebrate feeders (27.2% abundance, 34.6% biomass) (Figure 5b). To compare 2019 trophic levels to those observed in 2018, fishes within Brock’s (2018) appendix were reassigned to four trophic categories: herbivores, invertebrate feeders, piscivores, or zooplanktivores (the herbivore category also includes detritivores and the invertebrate feeders include corallivores, mixed feeders, and sessile invertebrate feeders). To determine whether there are any statistically significant differences among the mean number of fish species per transect, the mean number of individuals fish per transect or the mean estimated standing crop (g/m^2) per transect over time, transects were merged into geographic groups (East, Ko‘Olina, Pipe, Kahe, Nanakuli) and pooled over survey dates at each geographic location (four quarterly surveys). The fourteen stations (Figure 1) were assigned to the five geographic locations beginning in 2019: (1) East: East 1, East 3, East 4, (2) Ko‘Olina : Ko 1 and Ko 2, (3) Kahe: 1D, 5B, 7B, 7C, 7E, 10C, (4) Nanakuli: NANA 1 and NANA 2, (5) Pipe.

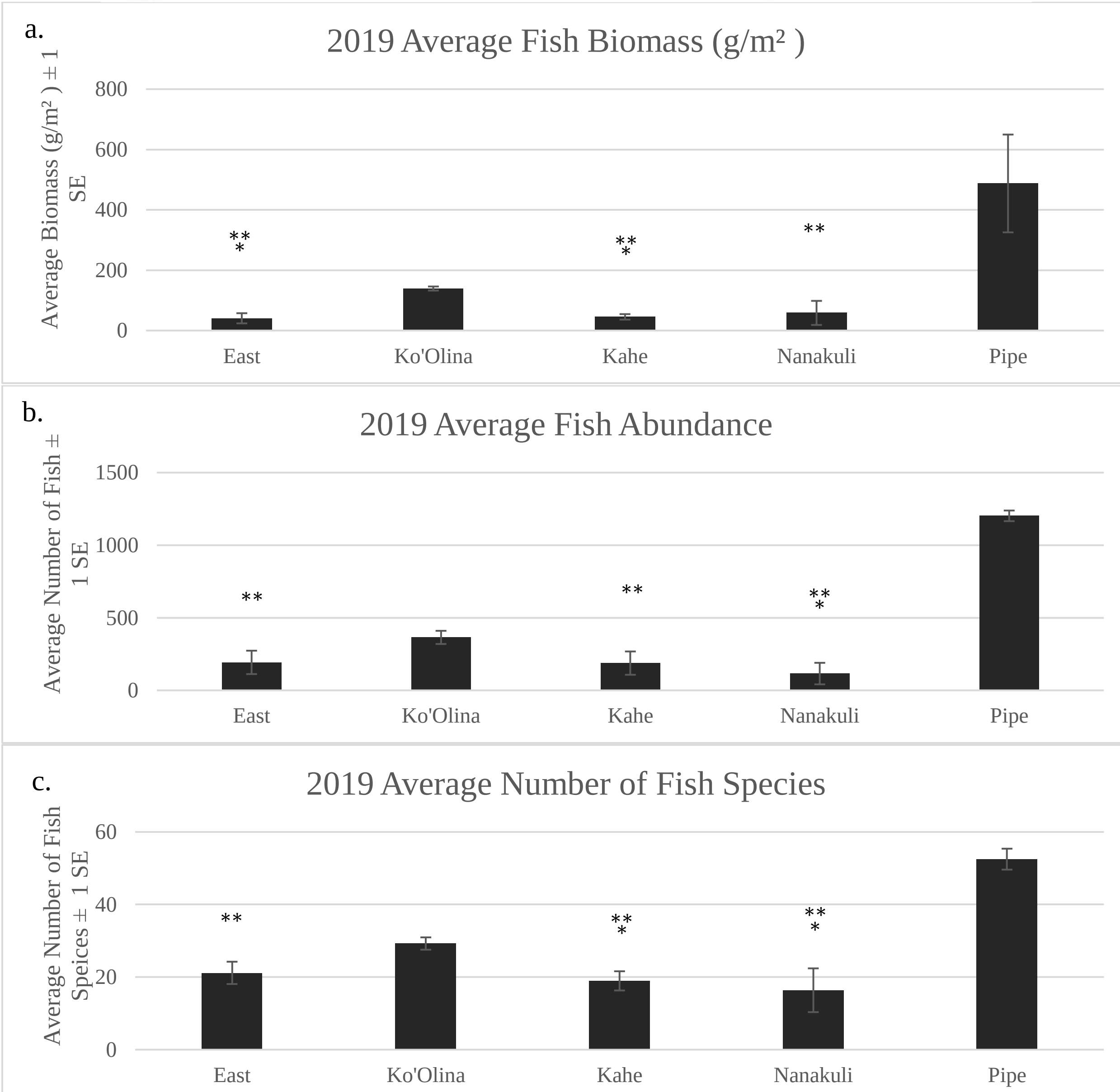


Figure 3. Average fish biomass, abundance and number of species per station grouping for 2019 surveys only. Standard error bars represent ± 1 SE. One asterisk (*) represents significant difference from Ko'Olina grouping, while two asterisk (**) represents a significant difference from Pipe transects. Example: Nanakuli shows both one and two asterix representing significant difference from both Ko 'Olina and the Pipe.

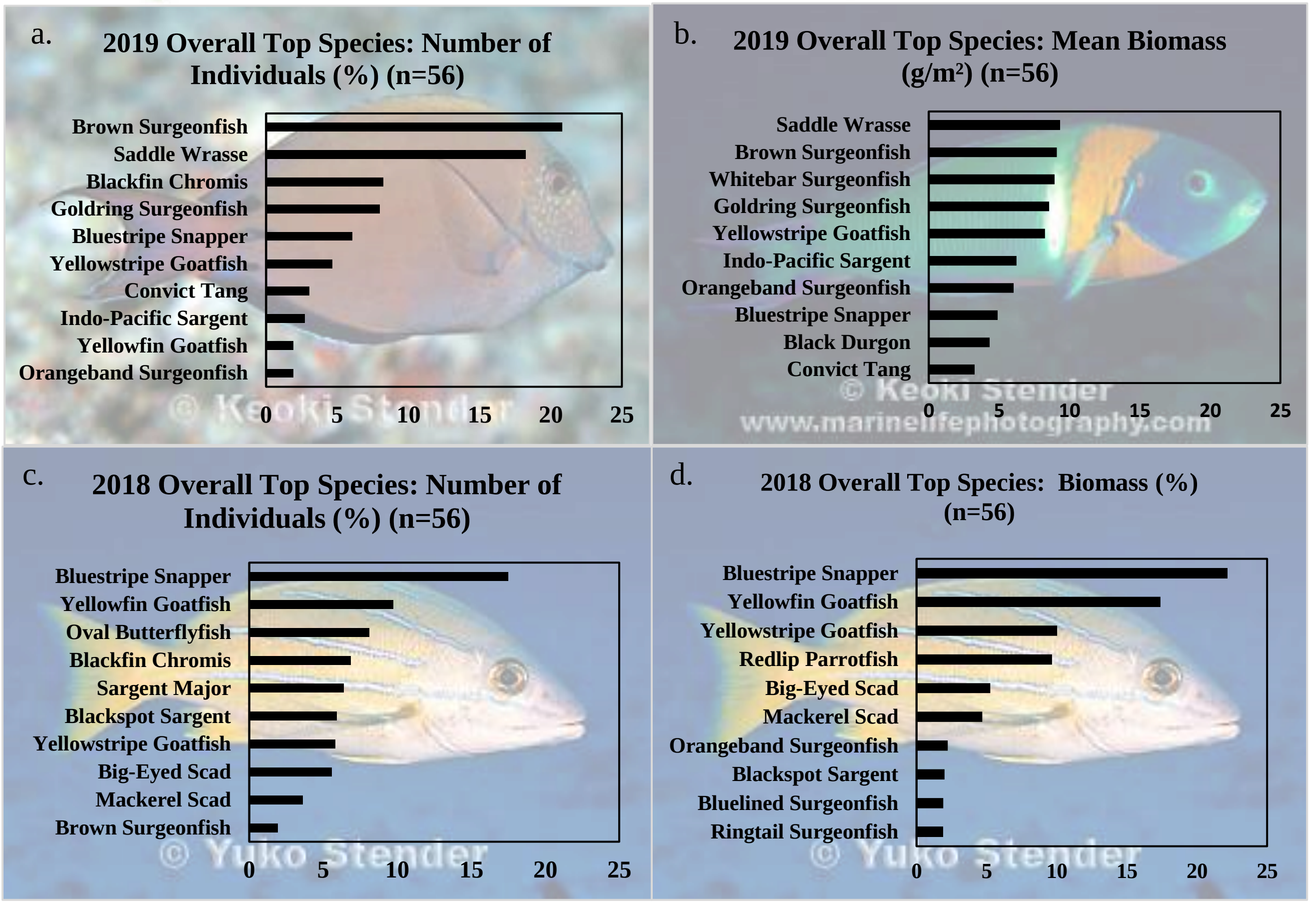


Figure 4. Top ten fish species contributing to number of individual fishes and biomass (g/m^2 or %) for survey years 2019 (a,b) and 2018 (c,d).

The 2019 data are presented herein along with a comparative analysis to the 2018 data. The complete data set from the four 2019 quarterly surveys is given in Appendix B.

Transect surveys were conducted on July 25, August 26, September 13, and November 29, 2019. The number of fish species, number of fish individuals, and biomass did not differ significantly between survey dates and therefore, the four survey dates were pooled for analysis.

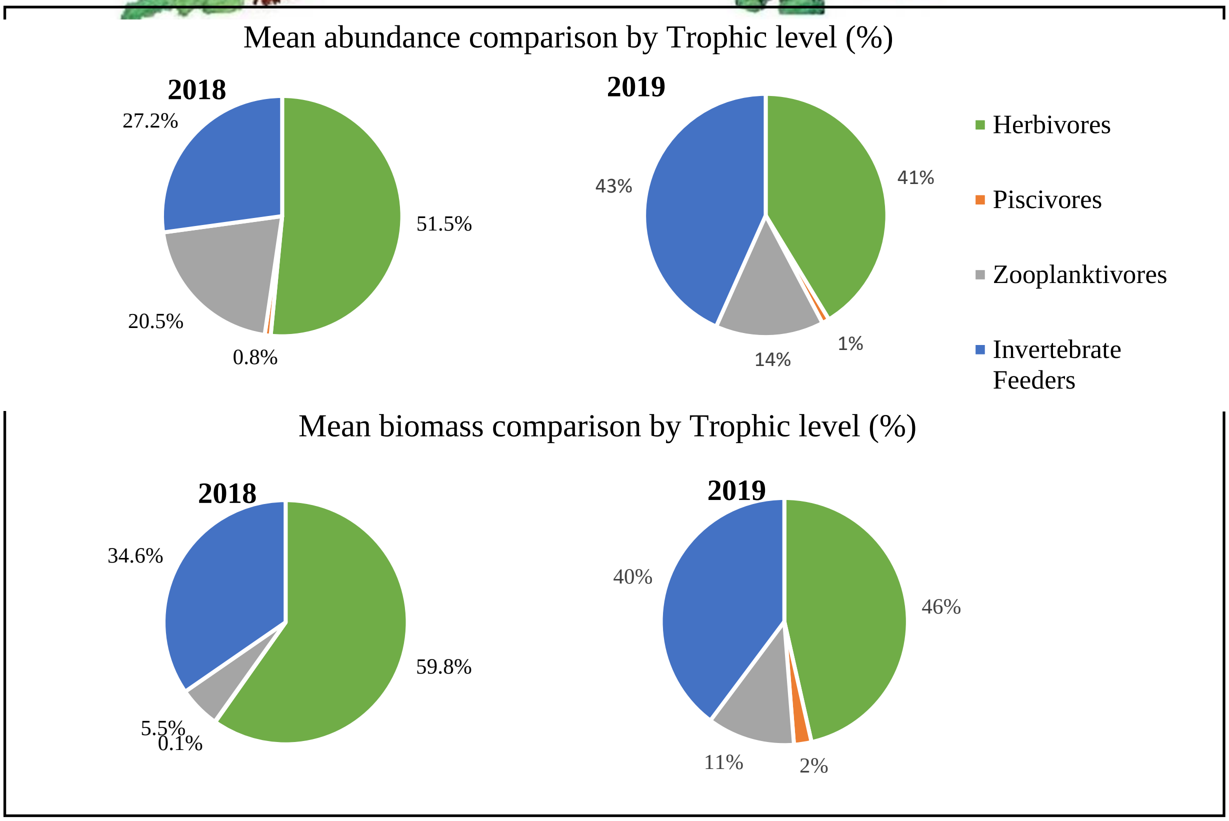
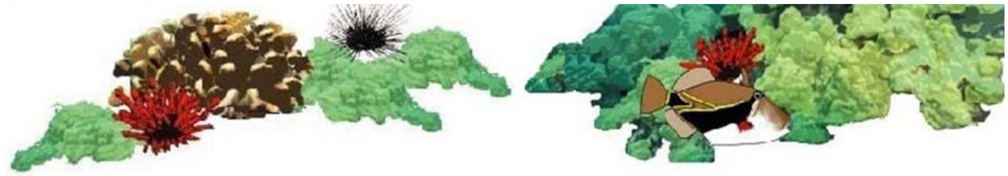


Figure 5. Mean abundance and biomass of each trophic level during 2019 and 2018 surveys.

EAST

In 2019, transects East 1, East, 3 and East 4 were surveyed within the East transect grouping. Prior years included the surveying of East 2. Because East 2 was eliminated from the 2019 surveys, it was also removed from descriptive statistics for year 2018 data comparisons. East 1 transect has an estimated standing crop of 15.8 ± 12.2 g/m^2; this is the lowest of the biomass estimates in the East for 2019 (Figure 6). East 3 has 42.5 ± 25.6 g/m^2, and East 4 has the highest biomass with 63.4 ± 22.9 g/m^2. The East group had significantly lower biomass estimates (p = 0.005) and number of fish species present (p = 0.02) in the 2019 surveys when compared to the 2018 surveys (Biomass: 2018 = 168 ± 47.8 g/m^2, 2019 = 41 ± 16.9 g/m^2; Number of fish species: 2018 = 18 ± 0.7, 2019 = 21 ± 3.1). Number of fishes did not differ significantly between transects. For all East transects, fish abundance is dominated by the Blackfin Chromis (*Chromis vanderbilti*), *hīnālea lauwili* (*T. duperrey*, Saddle wrasse) and *māʻiʻiʻi* (*A. nigrofuscus*, Brown surgeonfish) (Figure 7a). The biomass at East transects was dominated by *na'ena'e* (*A. olivaceus*, orange band surgeonfish*)* (Figure 7b).



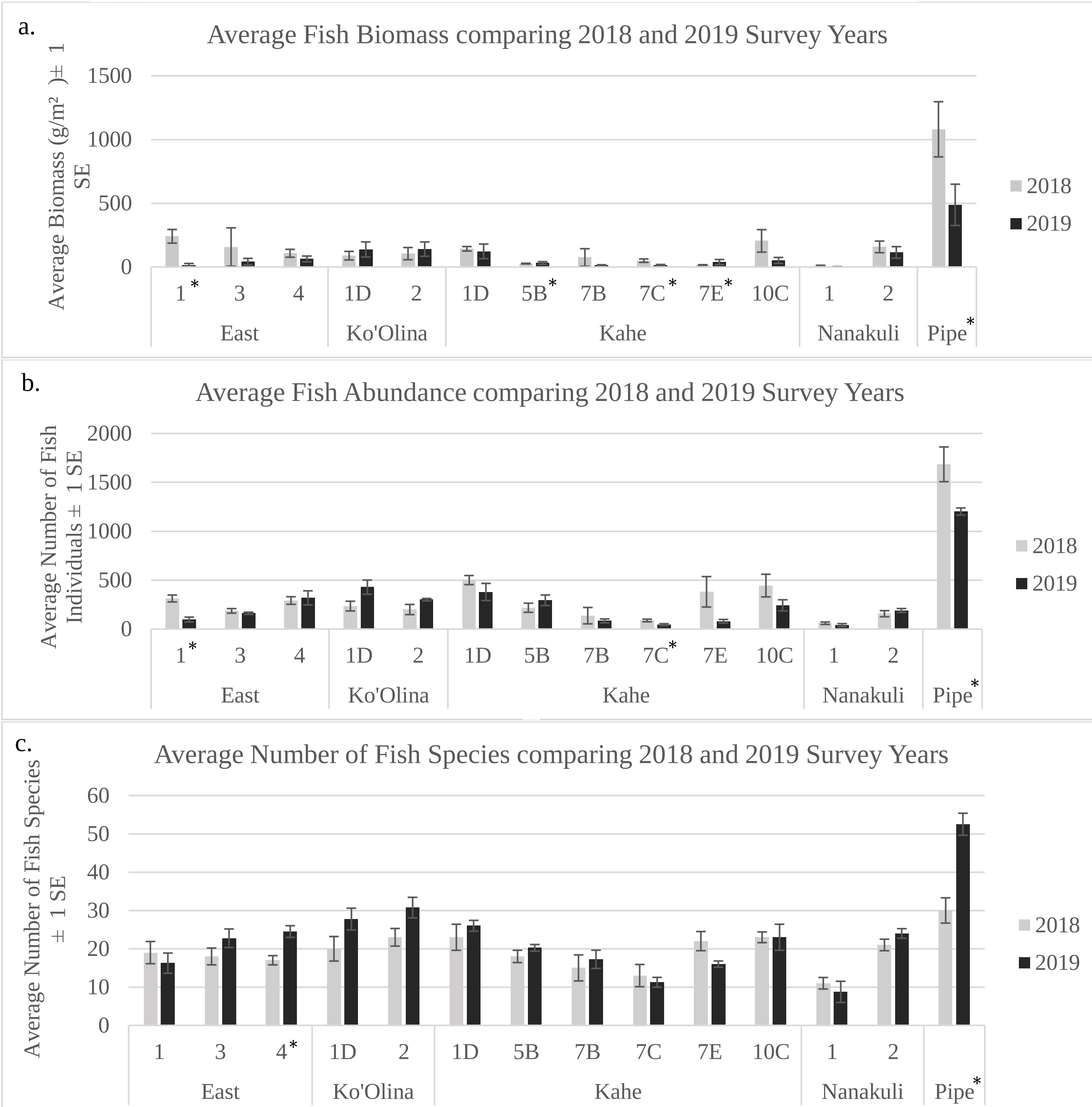


Figure 6. Average fish biomass (a), fish abundance (b) and number of fish species (c) per transect comparing survey years 2018 and 2019. An asterisk (*) after the station name indicates a significant difference between the two survey years.

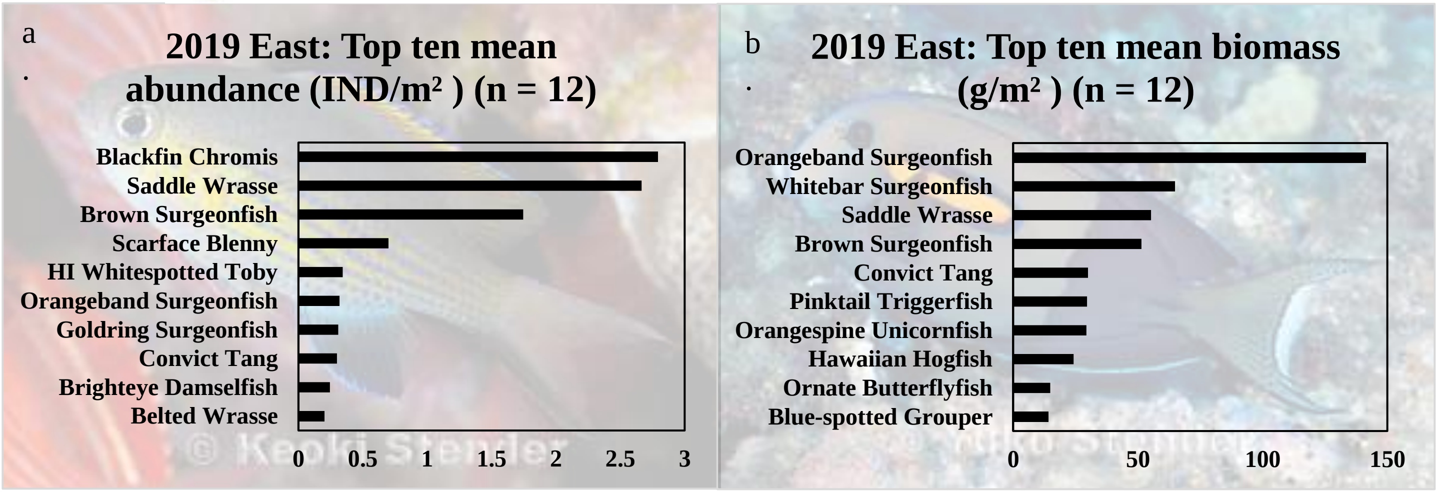


Figure 7. Top ten fish contributing to mean abundance and biomass at East transect grouping in 2019. IND/m^2=individuals per square meter. g/m2=grams per square meter.

East 1: In 2019 along the East 1 transect, an average of 97.5 ± 24.9 individuals of 32 species of fishes were documented. The *hīnālea lauwili* (*T. duperrey*), blackfin chromis (*C. vanderbilti*), *manini* (*Acanthurus triostegus*, convict tang) and scarface blenny (*Cirripectes vanderbilti*) were the most abundant fishes along this transect. The dominant fish species in biomass is different for each survey date reflecting the variability in fish populations. In July 2019, the saddle wrasse was responsible for 24.2% of the biomass, with the *na'ena'e* (16%, *Acanthurus olivaceus*, orangeband surgeonfish), *humuhumunukunukuapua'a* (13.8%, *Rhinecanthus rectangulus*, reef trigger), and *to'au* (12.8%, *Lutjanus fulvus*, black tail snapper) also contributing greatly to the biomass (estimated biomass = 19.2 g/m^2, 135 individuals). In August (5.4 g/m^2, 117 individuals) and September (3.2 g/m^2, 36 individuals) biomass was lower. In August the biomass was dominated by the *mā'i'i'i* (32.8%, *A. nigrofuscus*,) and the black fin chromis (14.9%, *C. vanderbilti*), while in September the *humuhumuhi'ukole* (45.8%, *Melichthys vidua*, pinktail durgon) and the *humuhumunukunukuapua'a* (24.5%, *R. rectangulus*) were dominant. The November survey is the highest in biomass of all four quarters (58.4 g/m^2, 102 individuals). The fishes contributing most to the biomass during November is *na'ena'e (A. olivaceus*, 31.6%), *manini (A. triostegus*, 28.0%) and the *pualu* (15.6%, *Acanthurus blochii*, ringtail surgeonfish).

East 3: The average number of fishes along transect East 3 was 161.8 ± 10.8 individuals of 43 fish species (Figure 6). Along East 3, *hīnālea lauwili* (*T. duperrey*), *mā'i'i'i* (*A. nigrofuscus*), and *kole* (*Ctenochaetus strigosus*, goldring surgeonfish) are the most abundant fishes for all survey timepoints (Appendix B). The July survey counted 167 fishes of 23 species. The four fishes responsible for the majority of the biomass (32.4 g/m^2) during this survey are *roi* (*Cephalopholis argus*, 30%), *hīnālea lauwili* (*T. duperrey*, 25.9%), *'a'awa* (*Bodianus albotaeniatus*, Hawaiian Hogfish (formerly *B. bilunulatus*), 11.4%), and *māi'i'i* (*A. nigrofuscus*, 8.9%). The census in August has the highest biomass (118.0 g/m^2) and number of individual fishes (182 fishes) of all four timepoints. During this survey in August, 24 fish species were observed. *Māikoiko (Acanthurus leucopareius*, whitebar surgeonfish) is responsible for the majority of biomass (55%). Also contributing to the biomass in August is *na'ena'e* (*A. olivaceus*, 14.7%) and *mā'i'i'i*

(*A. nigrofuscus,* 6%). In September, 137 individuals of 17 fish species were identified along transect East 3. The fishes contributing the most to biomass (31.5 g/m^2) are *mā'i'i'i* (*A. nigrofuscus*, 30.1%), *hīnālea lauwili* (*T. duperrey*, 16.8%), *kīkākapu* (*Chaetodon ornatissimus*, ornate butterflyfish, 14.8%) and *na'ena'e* (*A. olivaceus*, 11.4%). In November, 27 species of fishes were identified within 161 individuals. This is the greatest species diversity of all timepoints in the East group. Biomass (31.2 g/m^2) in November is dominated by *kole* (*C. strigosus*, 26.8%), *mā'i'i'i* (*A. nigrofuscus,* 16.9%), *na'ena'e* (*A. olivaceus* 14.2%) and *hīnālea lauwili* (*T. duperrey*, 12.9%).

East 4: In 2019, the East 4 transect is found to have consistently higher biomass, number of individuals, and number of fish species as compared to East 1 and East 3, however, this is not statistically significant (Figure 5). In July, 505 individuals of 28 species were recorded along East 4 transects. The biomass (109.6 g/m^2) is made up of 44.1% *na'ena'e* (*A. olivaceus)* and 9.5% *humuhumuhi'ukole* (*M. vidua*). August census observed a decrease in biomass (73.5 g/m^2), number of individuals (241 fishes) and number of fish species (25 species). The biomass is more evenly distributed between a greater number of fish species with the same dominant species as in July, *na'ena'e* (*A. olivaceus,*32.9%). Other fishes contributing to the biomass in August are *umaumalei* (*Naso lituratus*, orangespine unicornfish, 15.6%), *hīnālea lauwili* (*T. duperrey*, 12.3%) and *mā'i'i'i* (*A. nigrofuscus*, 10.4%). September (63.6 g/m^2, 281 individuals, 22 species) and November (70.3 g/m^2, 249 individuals, 23 species) census exhibits similar parameters of the community surrounding East 4. Both surveys found the biomass to be distributed more evenly between several species of fishes. In September, the biomass is made up of *na'ena'e* (*A. olivaceus*, 28.1%), *mā'i'i'i* (*A. nigrofuscus,* 12.1%), *humuhumu'ele'ele* (*Melichthys niger,* black durgon, 10%) and *hīnālea lauwili* (*T. duperrey*, 9.7%). In November, the species contributing to the majority of biomass differs: *umaumalei* (*N. lituratus*, 16.3%), *'omilu* (*Caranx melampygus*, blue trevally, 14.2%), *manini* (*A. triostegus*, 13.1%), *humuhumuhi'ukole* (*M. vidua*, 12%) and *kala holo* (*Naso hexacanthus*, sleek unicornfish, 9.6%).

KO ʻOLINA

The KoʻOlina group includes transects KO 1 and KO 2. Average standing crop estimates for the KoʻOlina group was significantly lower (p = 0.028) in 2018 (97 ± 19.6 g/m^2) when compared to 2019 (139 ± 6.8 g/m^2) (Figure 6). The KoʻOlina group also saw significantly fewer numbers of fishes (p = 0.028) and species of fishes (p = 0.005) in 2018 (217 ± 116 individuals, 22 ± 1.3 species) as compared to 2019 (365 ± 46 individuals, 29 ± 1.7 species) (Figure 6). Surveys in 2018 showed more variability in biomass and number of fish individuals between the two transects (KO 1 and KO 2) and four survey dates. In the KoʻOlina group, the most abundant fishes are the Orange band Surgeonfish, *na'ena'e* (*A. olivaceus)*, the Goldring Surgeonfish, *kole* (*C. strigosus*) and the Saddle Wrasse, *hinalea lauwili* (*T. duperrey*) (Figure 8a). *Kole* (*C. strigosus*) alone is responsible for over half of the biomass within the KoʻOlina group (Figure 8b).

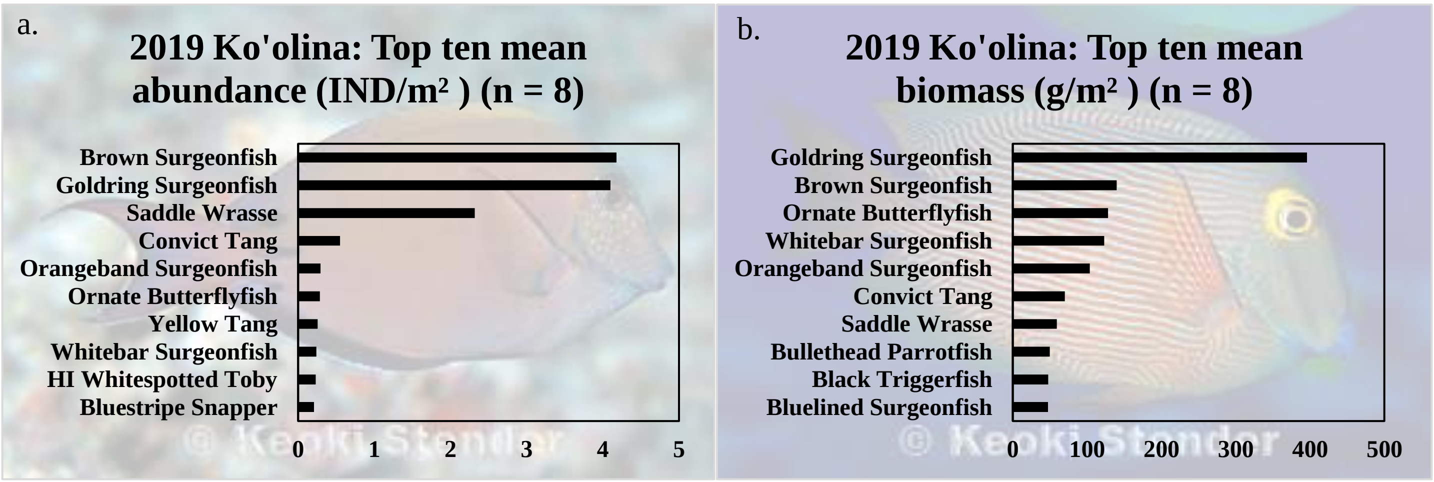


Figure 8. Top ten fishes contributing to mean abundance and biomass at the Ko‘Olina transect grouping in 2019. IND/m^2=individuals per square meter. g/m2=grams per square meter.

Ko ‘Olina 1: In 2019, the KO 1 transect varied in fish biomass over the four survey dates: July = 104 g/m^2, August = 203.5 g/m^2, September = 270.8 g/m^2, November = 116.9 g/m^2. Despite this fluctuation, the fish species contributing the majority of the biomass remained similar. Collectively, *kole* (*C. strigosus*, July: 40.2%, August: 43.7%, September: 37.1%, November: 50.7%) and *mā‘i'i'i* (*A. nigrofuscus*, July: 12.4%, August: 10.9%, September:13.2%, November: 9.0%) are two of the dominant biomass contributors. The September census also found *manini* (*A. triostegus*, 15.6%) and *uhu* (*Chlorurus spilurus* (formerly *C. sordidus*), bullethead parrotfish, 12.2%) to contribute a large portion of the biomass, while *hīnālea lauwili* (*T. duperrey, 11.4%*) is common during the November census. Species contribution to biomass shows the similar patterns for numbers of individuals along KO 1, however, the number of individuals varies between time points (July: 302, August: 479, September: 580, November: 353). The greatest number of species was recorded during the August survey (34) followed by September (28), July (27), and November (22).

Ko ‘Olina 2: Along the KO 2 transect in July, 310 individuals from 35 fish species were present. The total estimated biomass of 168 g/m^2 is dominated by three species: *kole* (*C. strigosus*, 32.1%), *na'ena'e* (*A. olivaceus*, 9.5%), and *humuhumu‘ele‘ele* (*M. niger*, 8.6%). July (35 species) has the highest biodiversity of all four surveys (August: 34 species, September: 25 species, November: 29 species). The biomass estimate (115.6 g/m^2) for 318 fish individuals for the August survey found 29.3% of biomass from *kole* (*C. strigosus*), 13% from *na'ena'e* (*A. olivaceus*), and 11% from *mā‘i'i'i* (*A. nigrofuscus*). The biomass in the September survey (160.5 g/m^2, 270 individuals) is dominated by three surgeonfish species: *mā‘iko‘iko (A. leucopareius*, 37%), *maiko* (*Acanthurus nigoris*, bluelined surgeonfish, 13.4%), and *mā‘i'i'i* (*A. nigrofuscus*, 13.4%). The November survey has the highest estimated biomass of the 2019 surveys (269.7 g/m^2, 306 individuals) The major contributors included *kīkākapu* (*C. ornatissimus*, 38.8%), *na'ena'e* (*A. olivaceus*, 16.2%*)* and *mā‘iko‘iko (A. leucopareius*, 16%). The species highest in

abundance during the 2019 KO 2 surveys are *mā'i'i'i* (*A. nigrofuscus*), *kole* (*C. strigosus*), *hīnālea lauwili* (*T. duperrey*) and *kīkākapu* (*C. ornatissimus*).

KAHE

The Kahe group is comprised of six transects: 1D, 5B, 7B, 7C, 7E and 10C. The Kahe 7D transect was eliminated from the 2019 surveys and therefore was removed from all group averages. At Kahe stations, estimated biomass in 2019 was 45 ± 9.1 g/m^2, while in 2018 estimated biomass was 86 ± 18.5 g/m^2 (Figure 6). No significant difference was found between years due to the high level of variability between surveys. The average number of fishes in 2019 (188 ± 80.4) and 2018 (295 ± 90.8) were also found not to be significantly different. The average number of species was identical for the two years (2018: 19 ± 2.7, 2019: 19 ± 2.6). In 2019, the Orangeband Surgeonfish, *na'ena'e* (*A. olivaceus)* is greatest in both abundance and biomass (Figure 9). The Saddle Wrasse, *hīnālea lauwili* (*T. duperrey*) also contributes significantly to both abundance and biomass. The third highest contributor to the biomass at Kahe group is the Black Triggerfish, *humuhumu'ele'ele* (*M. niger*).

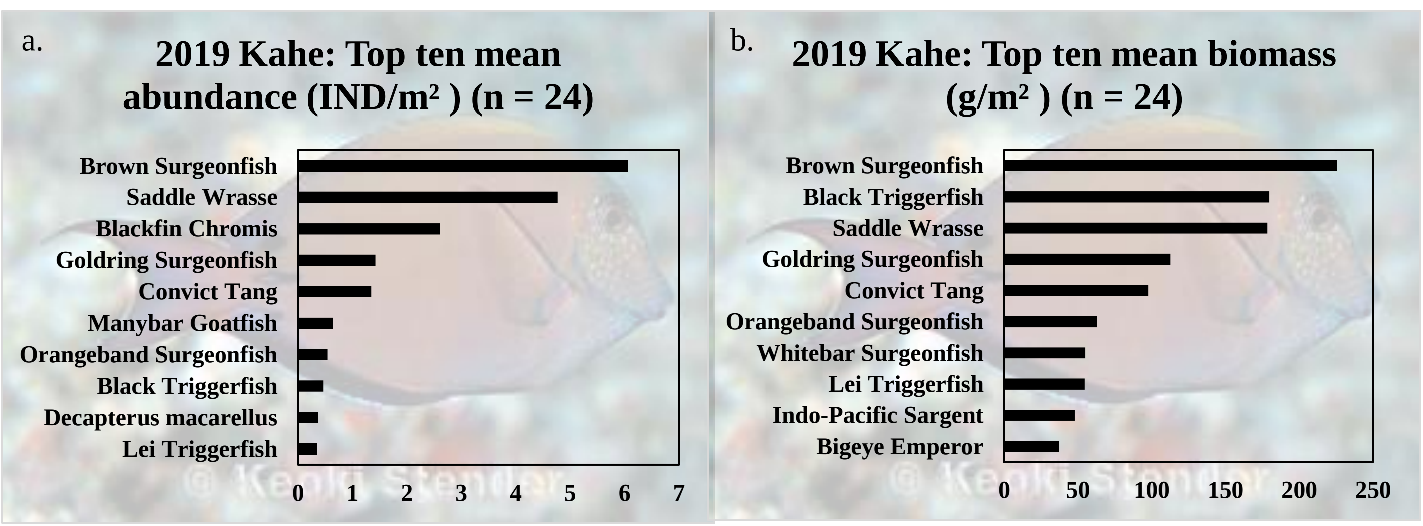


Figure 9. Top ten fishes contributing to mean abundance and biomass at the Kahe transect grouping in 2019 surveys. IND/m^2=individuals per square meter. g/m2=grams per square meter.

Kahe 1D: In 2019, transect 1D fluctuates in biomass, number of individuals, and number of species present along the transect: July: 102 g/m^2, 324 individuals, 27 species, August: 152.1g/m^2, 364 individuals, 24 species. September: 271.4 g/m^2, 593 individuals, 29 species, November: 88.3 g/m^2, 237 individuals, 24 species. The biomass during the July survey is dominated by *humuhumu'ele'ele* (*M. niger*, 22.5%), *hīnālea lauwili* (*T. duperrey*, 19.3%), *mamo* (*Abudefduf vaigiensis*, Indo-Pacific sergeant, 14.3%), and *kole* (*C. strigosus*, 12.7%). In the August survey the largest portion of the biomass also consists of humuhumu'ele'ele (*M. niger*, 36.1%), however, *mā'i'i'i* (*A. nigrofuscus*, 14.5%), *kole* (*C. strigosus*, 14.4%) and *manini* (*A. triostegus*, 12.4%) are also dominant. The September survey has the highest biomass and abundance of fishes of the four surveys. The biomass is less dominated by a few species as in

previous surveys, but split more evenly between several different species: *mā‘i'i'i* (*A. nigrofuscus*, 16.7%), *māikoiko (A. leucopareius*, 15.7%), *kole* (*C. strigosus*, 15.3%), *mu* (*Monotaxis grandoculis*, bigeye emperor, 9.6%), *hīnālea lauwili* (*T. duperrey*, 9.1%), and *humuhumu‘ele‘ele* (*M. niger*, 8.5%). The November survey biomass is heavily dominated by *kole* (*C. strigosus*, 41.1%), with *humuhumu‘ele‘ele* (*M. niger*, 14.5%) and *mā‘i‘i‘i* (*A. nigrofuscus*, 13.4%) also contributing to the biomass. The five most abundant species are identical in each survey [*hīnālea lauwili* (*T. duperrey*), *na'ena'e* (*A. olivaceus), mā‘i'i'i* (*A. nigrofuscus*), *kole* (*C. strigosus*), and *manini* (*A. triostegus*)].

Kahe 5B: 5B exhibits low overall biomass for each quarterly survey, while maintaining high individual fish and species counts: July: 42 g/m^2, 327 individuals, 21 species, August: 34.1 g/m^2, 262 individuals, 21 species, September: 47.7g/m^2, 405 individuals, 21species, November: 33.8g/m^2, 184 individuals, 18 species. Two fish species dominate the biomass estimates in each of the four surveys: *mā‘i'i'i* (*A. nigrofuscus*, July: 32.9%, August: 52.8%, September: 37.4%, November: 38.7%) and *hīnālea lauwili* (*T. duperrey*, July: 30.9%, August: 20.9%, September: 39.5%, November: 11.4%). In the November survey, a school (20 individuals) of large (20 cm) *'opelu* (*Decapterus macarellus*, mackerel scad, 27.8%) is also found to influence the biomass. The three most abundant fishes along all survey dates are *mā‘i‘i‘i* (*A. nigrofuscus*), *hīnālea lauwili* (*T. duperrey*), and the blackfin chromis (*C. vanderbilti*). Chromis are small schooling fishes that can contribute strongly to abundance (number of individuals) but make very little contribution to biomass.

Kahe 7B: In the 2019 surveys, the 7B transect had low estimated biomass, low individual fish counts and low number of species present for all four quarterly surveys: July: 10.2 g/m^2, 36 individuals, 12 species, August: 19.2 g/m^2, 108 individuals, 16 species, September: 16.0 g/m^2, 83 individuals, 20 species, November: 20.4 g/m^2, 108 individuals, 21 species. During the July survey, *na'ena'e* (*A. olivaceus*, 27.7%), *piliko'a* (*Cirrhitops fasciatus*, redbar hawkfish, 20.6%), and *moano* (*Parupeneus multifasciatus*, manybar goatfish, 19.7%) made up the majority of the biomass. In August, the biomass is dominated by the *humuhumulei* (*Sufflamen bursa*, lei triggerfish, 20.5%), *mā‘i'i'i* (*A. nigrofuscus* 19%), *hīnālea lauwili* (*T. duperrey*, 16%), and *malu* (*Parupeneus pleurostigma*, sidespot goatfish, 13.5%). During the September survey, *kihikihi* (*Zanclus cornutus*, Moorish idol, 28%) is the most dominant fish for biomass followed by *mā‘i‘i‘i* (*A. nigrofuscus*, 18.7%), *umaumalei* (*N. lituratus*, 10.1%), and *humuhumulei* (*S. bursa*, 9.8%). The last survey in November, has two fishes responsible for the majority of the biomass: *mā‘i'i'i* (*A. nigrofuscus*, 28.7%) and *humuhumulei* (*S. bursa*, 19.2%). The two most abundant fish species within all quarterly surveys at 7B are the blackfin chromis (*C. vanderbilti*) and *mā‘i'i'i* (*A. nigrofuscus*).

Kahe 7C: Kahe 7C transect has low biomass, low numbers of individual fishes and low numbers of species present throughout the four surveys: July:12.7 g/m^2, 34 individuals, 12 species, August: 7.1 g/m^2, 30 individuals, 8 species, September: 28.9 g/m^2, 58 individuals, 12 species, November: 19.8 g/m^2, 61 individuals, 13 species. July biomass estimates are heavily influenced by *na'ena'e* (*A. olivaceus*, 37.7%), *manini*, (*A. triostegus*, 19.7%), and *humuhumulei* (*S. bursa*, 18.6%). The biomass estimates during August are primarily made up of *humuhumulei* (*S. bursa*, 66.7%), with *moano* (*P. multifasciatus*, 14.3%) and *hīnālea lauwili* (*T. duperrey*, 10.5%) also contributing. During the September surveys, no one fish species dominates the biomass: *na'ena'e* (*A. olivaceus, 30.6%), manini* (*A. triostegus*, 21.3%), *umaumalei* (*N. lituratus*, 15.9%),

humuhumulei (*S. bursa*, 13.6%). During the last survey of the year in November at 7C, *na'ena'e* (*A. olivaceus*, 32.3%), *mā'i'i'i* (*A. nigrofuscus*, 21.2%), and *humuhumulei* (*S. bursa*, 11.9%) dominates the biomass. Among all survey dates the fishes that contribute the most to biomass at station 7C are *na'ena'e* (*A. olivaceus*, 29.3%), *humuhumulei* (*S. bursa*, 19.5%) and *manini* (*A. triostegus*, 12.6%). The *manini* (*A. triostegus*) is also the most abundant species in July and September surveys, while the blackfin chromis (*C. vanderbilti*) is most abundant in August and the *mā'i'i'i* (*A. nigrofuscus*) is most abundant in November.

Kahe 7E: 7E is one of the most variable transects in respect to biomass and number of individuals fishes. The biomass (21.1 g/m^2, 37 individuals, 15 species) for July's survey is dominated by several species of triggerfish *humuhumumimi* (*Sufflamen fraenatus*, bridled triggerfish, 21.2%), *humuhumu'ele'ele* (*M. niger*, 17.4%), *humuhumulei* (*S. bursa*, 11.2%), *humuhumuhi'ukole* (*M. vidua*, 10%) and *'opelu* (*D. macarellus*, 19.2%). The biomass and number of individual fishes in August's survey (40 g/m^2, 112 individuals, 16 species) is double that found in July. While *'opelu* (*D. macarellus*, 47%) still dominates the biomass, two surgeonfish are also found in high biomass, *manini* (*A. triostegus*, 15.4%) and *na'ena'e* (*A. olivaceus*, 13.4%). In September, the biomass more than doubles (94.2 g/m^2), while the number of individual fishes and number of species (91 individuals,18 species) present along transect 7E remains similar to August. This increase in biomass is largely due to *humuhumu'ele'ele* (*M. niger*, 62.3%) and *na'ena'e* (*A. olivaceus*, 11.6%). The biomass in November's survey (38.7g/m^2, 79 individuals, 15 species) shows a large decrease. During this time the biomass is dominated by *mu* (*M. grandoculis*, 28.1%), *na'ena'e* (*A. olivaceus*, 16.9%) and two species of triggerfish, *humuhumuhi'ukole* (*M. vidua*, 10.9%) and *humuhumulei* (*S. bursa*, 10.2%). Overall, the *'opelu* (*D. macarellus*) is most abundant for the first two quarterly surveys (July and Aug.), while the *humuhumu'ele'ele* (*M. niger*) is most abundant in September, and the *moano* (*P. multifasciatus*) is most abundant in November.

Kahe 10C: The last of the Kahe stations, transect 10C, is found to increase in biomass and number of individual fishes throughout the year (July: 43.3 g/m^2, 121 individuals, 15 species, August: 41.9 g/m^2, 203 individuals, 23 species, September: 60.8 g/m^2, 320 individuals, 29 species, November:112.5 g/m^2, 326 individuals, 25 species. In July's survey, transect 10C biomass is largely made up of *hīnālea lauwili* (*T. duperrey*, 36.5%), two species of *mamo* (*A. vaigiensis*, 33.7% and *Abudefduf abdominalis*, sergeant major, 17.1%). Both August and September biomass is dominated by *hīnālea lauwili* (*T. duperrey*, Aug.: 38.9% and Sept.: 20.8%) and *mā'i'i'i* (*A. nigrofuscus*, Aug.: 28.9% and Sept.: 46.3%). The November survey has the highest biomass and number of individual fishes of all four surveys. The fishes contributing most to the estimated biomass is *manini* (*A. triostegus*, 34.2% *mā'i'i'i* (*A. nigrofuscus*, 14.8%), *hīnālea lauwili* (*T. duperrey*, 12.6%), and *mamo* (*A. vaigiensis*, 10.4%). For all 2019 surveys, *hīnālea lauwili* (*T. duperrey*) and *mā'i'i'i* (*A. nigrofuscus*) are the most abundant fishes along transect Kahe 10C.

NANAKULI (Control stations)
Two transects are included in the Nanakuli group: NANA 1 and NANA 2. These sites are the control stations for all other stations. No significant differences were found in biomass, abundance, or number of species between 2018 and 2019. The biomass at the Nanakuli stations in 2018 (83 ± 72.8 g/m^2) and 2019 (58 ± 39.9 g/m^2) were within the range of variability. The average number of fishes (2018: 109 ± 141.4, 2019: 116 ± 74.2), and average number of species also remained similar (2018: 16 ± 4.6, 2019: 16 ± 6) (Figure 6). The most abundant fishes at Nankuli group are the Orange band Surgeonfish, *na'ena'e* (*A. olivaceus),*the Brown Surgeonfish, *māikoiko (A. leucopareius*), and the Saddle Wrasse, *hīnalea lauwili* (*T. duperrey*) (Figure 10a), while the Whitebar Surgeonfish, *māikoiko (A. leucopareius*) alone dominates the biomass (Figure 10b).

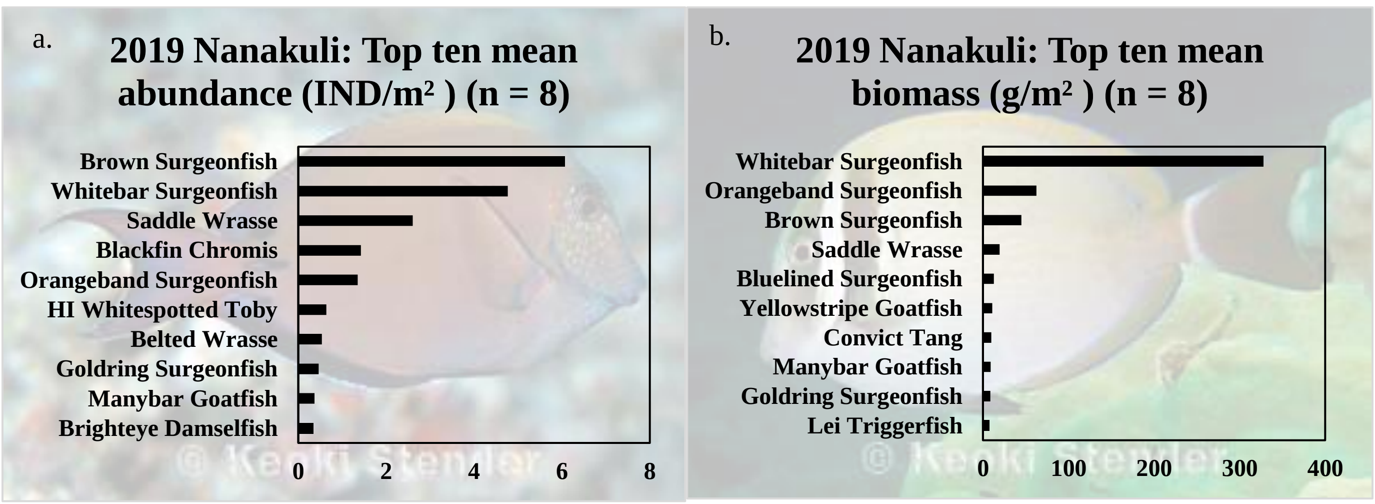


Figure 10. Top ten fishes contributing to mean abundance and biomass at Nanakuli transect grouping. IND/m^2=individuals per square meter. g/m2=grams per square meter.

NANA 1: During the July survey at NANA 1, *humuhumunukunukuapua'a* (*R. rectangulus,* 27.5%), *āwela* (*Thalassoma trilobatum*, Christmas wrasse, 23.2%), and *puhi ōni'o* (*Gymnothorax meleagris*, whitemouth moray, 21.9%) dominates the biomass. Estimated biomass during the August survey is heavily influenced by *hīnālea lauwili* (*T. duperrey,* 30.9%), *'ōmaka* (*S. balteata*, 26.4%), ā*wela* (*T. trilobatum*, 16.5%), and the ambon toby (*Cathigaster amboinensis*, 10.4%). In September, half the number of fish species are present as compared to August, which left the biomass dominated by *humuhumunukunukuapua'a* (*R. rectangulus,* 51.1%) and the schools of blackfin chromis (*C. vanderbilti*, 26.2%). There is a further reduction in the number of species present along NANA 1 transect in November, where the biomass consists of *humuhumulei* (*S. bursa*, 82.9%), *hīnālea lauwili* (*T. duperrey*, 14.8%) and the Hawaiian whitespot (*C. jactator*, 2.3%). Due to the low overall abundance of fishes, the most abundant fishes are not the same for each survey. In July and September, the most abundant fishes at NANA 1 transect are the blackfin chromis (*C. vanderbilti*) and the bright-eye damselfish (*Plectroglyphidodon imparipennis*). During August's survey the *'ōmaka* (*Stethojulis balteata*, belted wrasse) is most abundant. November's survey only documents four fishes.

NANA 2: Despite their geographic similarity, the Nana 2 transect is consistently greater in all fish community factors (July: 107.2 g/m^2, 159 individuals, 22 species, August: 93.4 g/m^2, 213 individuals, 27 species, September: 168.8 g/m^2, 164 individuals, 23 species, November: 203.9 g/m^2, 226 individuals, 24 species. 75.3% 7%) when compared to the Nana 1 transect (July: 5.7 g/m^2, 64 individuals, 14 species, August: 2.3 g/m^2, 54 individuals, 11 species, September: 1.5 g/m^2, 40 individuals, 7 species, November: 0.9 g/m^2, 4 individuals, 3 species (Figure 6). The species responsible for the majority of the biomass at NANA 1 are dissimilar to those contributing to biomass at NANA 2 despite their nearby locations. During July's survey along NANA 2 transect, *na'ena'e* (*A. olivaceus,* 31.8%), *māikoiko (A. leucopareius*, 20.2%), and *weke* (*Mulloidichthys flavolineatus*, yellowstripe goatfish, 10.2%) are responsible for the majority of the calculated biomass. In the August survey the dominant fish responsible for the biomass is *māikoiko (A. leucopareius*, 43.5%). Similarly, in September and November *māikoiko (A. leucopareius,* September: 66.2% and November: 75.3%) are the majority of the estimated biomass at NANA 2. For all 2019 surveys at the NANA 2 transect, three species of surgeonfishes are most abundant: *mā'i'i'i* (*A. nigrofuscus*), *māikoiko (A. leucopareius*), and *na'ena'e* (*A. olivaceus).*

PIPELINE

The KGS Pipe station is the only transect located on an artificial surface. The fish biomass, number of fish individuals and number of species present along the Pipe is consistently greater than the East, Ko'Olina, Kahe, and Nanakuli groups (Figure 6, see Appendix C). The fish biomass in 2018 (1080 ± 216 g/m^2) was twice that estimated in 2019 (488 ± 162 g/m^2) (p = 0.029) (Figure 6). Similarly, the number of fish individuals decreased from 2018 (1685 ± 177.7) to 2019 (1202 ± 36.7) (p = 0.029). However, a significantly greater number of species were recorded (53 ± 2.9) as compared to 2018 (30 ± 3.3) (p = 0.029). Throughout the four 2019 surveys, the Pipe transect remained consistent in biomass, number of fish individuals and number of species present: July: 593.6 g/m^2, 1228 individuals, 45 species, August: 668.3 g/m^2, 1139 individuals, 55 species, September: 510.6 g/m^2,1163 individuals, 55 species, November: 670 g/m^2, 1279 individuals, 55 species. 49% 13.6% 9.8%. Combining all four survey timepoints, the most abundant fish species in number and biomass at Pipe transect are the Bluestripe Snapper, *ta'ape* (*L. kasmira,* invasive), the Saddle Wrasse, *hīnālea lauwili* (*T. duperrey*), the Yellowstipe Goatfish, *weke* (*M. flavolineatus*), the Brown Surgeonfish, *ma'i'i'i* (*A. nigrofuscus),* and the Sargent Major, *mamo* (*A. vaigiensis*).

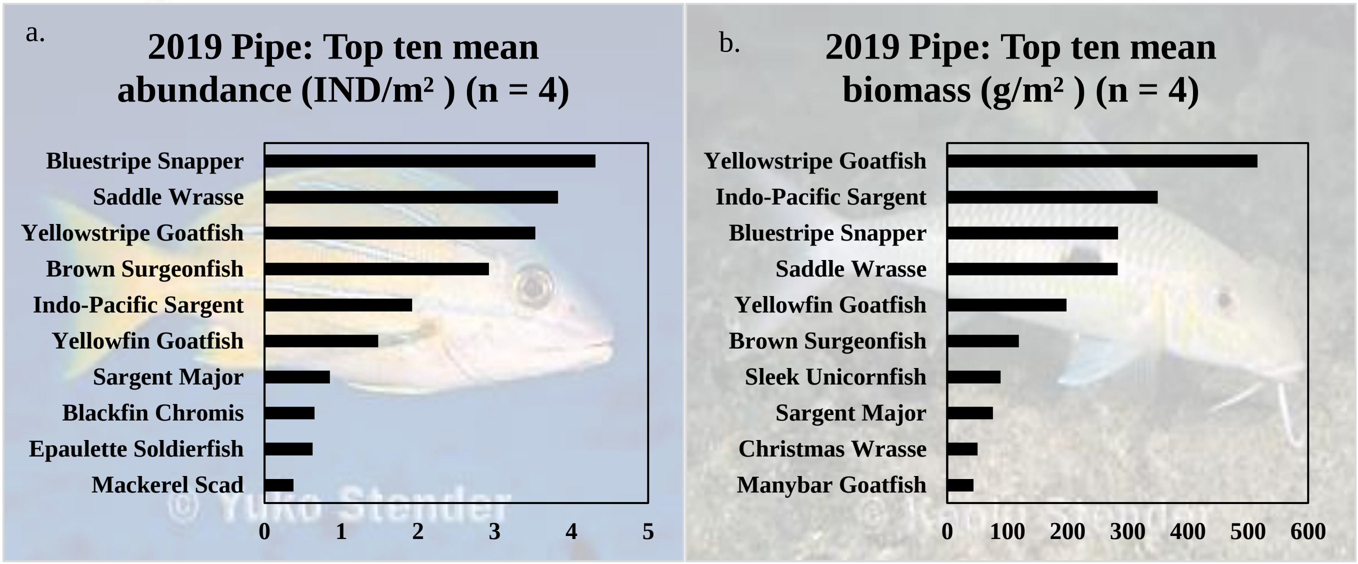


Figure 11. Top ten fish contributing to mean abundance and biomass at Pipe transect grouping. in 2019. IND/m^2=individuals per square meter. g/m2=grams per square meter.

During the July survey, *mamo* (*A. vaigiensis*, 23%), *weke* (*M. flavolineatus*, 21.3%), and *hīnālea lauwili* (*T. duperrey*, 12.6%) are responsible for the majority of the estimated biomass. In August survey at Pipe, the biomass is dominated by *ta'ape* (*Lutjanus kasmira*, bluestripe snapper, 22.4%), *weke 'ula* (*Mulloidichthys vanicolensis*, yellowfin goatfish, 15.1%), *hīnālea lauwili* (*T. duperrey*, 11.8%) and *kala holo* (*N. hexacanthus*, 10.5%). The September survey found *ta'ape* (*L. kasmira*, 16%) to be the most dominant of those contributing to the biomass, with *mamo* (*A. vaigiensis*, 15.3%), *hīnālea lauwili* (*T. duperrey*, 12.6%), and *weke* (*M. flavolineatus*, 11.3%) also contributing greatly to the biomass. Similarly, in November, *weke* (*M. flavolineatus*), *mamo* (*A. vaigiensis*), and *hīnālea lauwili* (*T. duperrey*) are the three top species contributing to the biomass at Pipe transect. Overall, the most abundant species in all 2019 surveys along the Pipe transect are *ta'ape* (*L. kasmira*), *hīnālea lauwili* (*T. duperrey*), *weke* (*M. flavolineatus*), and *mā'i'i'i* (*A. nigrofuscus*).

CONCLUSIONS

- The dominant species observed in 2019 (brown surgeonfish *maʻiʻi* and saddle wrasse *hinalea lau wili*) differed from those in 2018 (bluestripe snapper, *taʻape* and yellowstripe goatfish, *weke*).
- Biomass is contributed mainly by the saddle wrasse, brown surgeonfish, whitebar surgeonfish *maikoiko*, goldring surgeonfish *kole*, and yellowstripe goatfish.
- Identical to 2018, 110 species of fishes were recorded in surveys in 2019. This attests to the similarity of expertise of surveyors.
- No significant shift was found between years in trophic feeding guilds. Herbivores and invertebrate feeders consistently dominate.
- Excluding the Pipe, which has the highest fish abundance and biomass, the Ko ʻOlina group has more developed fish communities than the other groups (East, Kahe, Nanakuli). This can be attributed to high spatial relief associated with well-developed fish communities.
- Two (East 1 and Kahe 7C) of the fourteen transects experienced significant declines in fish biomass and abundance in 2019.
- The 2019 surveys found no significant change in fish communities that can be attributed to Hawaiian Electric's KGS or CIP facilities.

LITERATURE CITED

Ball, M., E. Shinn and K. Stockman. 1967. The geological effects of Hurricane Donna in south Florida. J. Geol. 75:583-597.

Blumenstock, D., F. Fosberg and C. Johnson. 1961. The re-survey of typhoon effects on Jaluit Atoll in the Marshall Islands. Nature 189:618-620.

Brock, V.E. 1954. A preliminary report on a method of estimating reef fish populations. J. Wildlife Mgmt. 18:297-308.

Brock, R.E., C. Lewis and R.C. Wass. 1979. Stability and structure of a fish community on a coral patch reef in Hawaii. Mar. Biol. *54*:281-292.

Brock, R.E. 1996. A study of the impact of Hurricane Iniki on coral communities at selected sites in Mamala Bay, O’ahu, Hawai’i. Project Report PR-96-09. Water Resources Research Center, University of Hawaii, Honolulu. vii+23p.

Brock, R. E. 2019. CIP Generation Project 2018 Community Benefits Program Reef Fish Monitoring Project Year 11 Results. Year 2018 Report. EA. LLC Rep. No. 2019-02. PRIL 2019. Hawaiian Electric Co. Inc., Honolulu.

Dollar SJ, Tribble GW 1993. Recurrent storm disturbance and recovery: a long-term study of coral communities in Hawaii. Coral Reefs 12:223–233.

Done, T., P. Dayton, A. Dayton and R. Steger. 1991. Regional and local variability in recovery of shallow coral communities: Moorea, French Polynesia and central Great Barrier Reef. Coral Reefs 9:183-192.

Eakin CM, Sweatman HPA, Brainard RE. 2019. The 2014-2017 Global-scale Coral Bleaching Event: insights and impacts. Coral Reefs 38: 539-545.

Friedlander A.M. and Parrish, J.D. 1998. Habitat characteristics affecting fish assemblages on a Hawaiian coral reef. Journal of Experimental Marine Biology and Ecology 224:1-30.

Friedlander A. M. and DeMartini, E. E. 2002. Contrasts in density, size, and biomass of reef fishes between the Northwestern and the main Hawaiian Islands: the effects of fishing down apex predators. Marine Ecological Progress Series 230:253-264.

Friedlander A. M. and DeMartini, E. E. 2004. Spatial patterns of endemism in shallow water reef fish populations of the Northwestern Hawaiian Islands. Marine Ecological Progress Series 271:281-296.

Friedlander, A., Brown, E. K, Jokiel, P. L., Smith, W. R., and Rodgers, K.S. 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 AM., Donovan MK, Stamoulis KS, Williams ID, Brown EK, Conklin EJ, DeMartini EE, Rodgers KS, Sparks RT, Walsh WJ. 2017. Human-induced gradients of reef fish declines in the Hawaiian Archipelago viewed through the lens of traditional management boundaries. Aquatic Conservation: Marine and Freshwater Ecosystems. DOI: 10.1002/aqc.2832.

Grigg, R.W. and J.E. Maragos. 1974. Recolonization of hermatypic corals on submerged lava flows in Hawaii. Ecology 55:387-395.

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

Harmelin-Vivien, M. and P. Laboute. 1986. Catastrophic impact of hurricanes on atoll outer reef slopes in the Tuamotu (French Ploynesia). Coral Reefs 5:55-62.Heron S., Eakin CM, Morgan J., and Skirving WJ. 2008. Hurricanes and their Effects on Coral Reefs. https://www.researchgate.net/publication/266558093.

Hiatt, R.W. and D.W. Strasburg. 1960. Ecological relationships of the fish fauna on coral reefs of the Marshall Islands. Ecol. Monogr. *30*:65-127.

Hobson, E.S. 1974. Feeding relationships of teleostean fishes on coral reefs in Kona, Hawaii. Fish. Bull. *72*:915-1031.

Manzello DP, Brandt M, Smith TB, Lirman D, Hendee JC, Nemeth RS 2007. Hurricanes benefit bleached corals. Proceedings of the National Academy of Sciences 104:12035-12039.

Maragos, J., G. Baines and P. Beveridge. 1973. Tropical cyclone Bebe creates a new land formation on Funafuti Atoll. Science 181:1161-1164.

Mora C, Frazier AG, Tong EJ, Longman RJ, Kaiser LR, Dacks RS, Walton MM, Fernandez-Silva I, Stender YO, Anderson JM, Sanchez JJ, Ambrosino CM, Giuseffi LM, Giambelluca TW. 2014. Uncertainties in the timing of unprecedented climates. Nature 511:E5,E6.

Noda, E.K. 1983. Affects of Hurricane Iwa, November 23, 1982 offshore of Kahe Point, Oahu. Unpublished report prepared for Research Corp. of the University of Hawaii.

Ogg, J. and J. Koslow. 1978.The impact of typhoon Pamela 1976. on Guam’s coral reefs and beaches. Pacif. Sci. 32:1056-118.

Randall, J.E. 2007. Reef and shore fishes of the Hawaiian Islands. Sea Grant College Program, University of Hawai'i, Honolulu. xiv+546p.

Rodgers, K.S., C. Newtson, and E.F. Cox. 2003. Mechanical Fracturing of Dominant Hawaiian Corals in Relation to Trampling. Environmental Management vol 31 pp 377-384.

Rodgers, K. S. Evaluation of Nearshore Coral Reef Condition and Identification of Indicators in the Main Hawaiian Islands. 2005. PhD Dissertation. University of Hawai'i, Dept. of Geography. Honolulu, Hawai'i. Pp.203.

Schroeder TA 1998. Hurricanes. In: Juvik S Juvick JO (eds) Atlas of Hawai'i , 3rd edition, University of Hawaii Press, Honolulu , HI, pp 74–75.

Skirving WJ, Heron SF, Marsh BL, Liu G, Dela Cour JL, Geiger EF, and Eakin CM. 2019. The Relentless March of Mass Coral Bleaching: a global perspective of changing heat stress. Coral Reefs 38:547-557.

Stoddart, D. 1969. Post-hurricane changes on the British Honduras reefs and cays: re-survey of 1965. Atoll Res. Bull. 13:1-25.

Storlazzi CD, Field ME, Dykes JD, Jokiel PL, Brown E 2002. Wave control on reef morphology and coral distribution: Molokai , Hawaii. Proc 4th Int Symposium Waves, pp.784–793.

Storlazzi, C. D., M. E. Field, P. L. Jokiel, S. K. Rodgers, E. Brown and J. D. Dykes. 2005. A model for wave control on coral breakage and species distribution: Southern Molokai, Hawaii. Coral Reefs 24:43-55.

Walsh W.J. 1983. Stability of a coral reef fish community following a catastrophic storm. Coral Reefs. 2:49-63.

Woodley, J. et al. 1981. Hurricane Allen's impact on Jamaican coral reefs. Science 214:749-755.