CAMPBELL INDUSTRIAL PARK (CIP) GENERATING STATION PROJECT

2020 COMMUNITY BENEFITS PROGRAM

REEF FISHES MONITORING PROGRAM

Prepared For:

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EXECUTIVE SUMMARY

The instigation of quarterly ecological monitoring for Hawaiian Electric Company, Inc.'s (Hawaiian Electric's) Campbell Industrial Park (CIP) Generating Station Project was initiated to monitor changes in biological communities with the startup of the generating facility at CIP, Barbers Point in West Oʻahu in 2010. Twelve annual reports have been submitted between 2007 and 2019. The current 2020 report is the thirteenth 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 are permitted. The quarterly coral reef fish community monitoring has continued as a commitment and benefit to the West Oʻahu 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 monitoring stations are located in depths between 5 meters (m) and 12 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), mean number of fish species, similarity of habitat, and spatial proximity. Stations were analyzed within four groups (East, KoʻOlina, Kahe, and Nanakuli) to determine similarities based on 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 2020: 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.

Fish community composition and biomass remained similar from the 2019 to 2020 surveys. In both 2019 and 2020, the brown surgeonfish *maʻiʻiʻi,* and saddle wrasse *hīnālea lau wili,* contribute most heavily to the abundance, with no single species dominating the biomass. The biomass along transects during both survey years is spread among several species, each representing between 6.0%-9.5% of the total estimated biomass: brown surgeonfish *maʻiʻiʻi*, the bluestripe snapper *taʻape,* orangeband surgeonfish *naʻenaʻe*, whitebar surgeonfish *maikoiko*, saddle wrasse *hīnālea lau wili*, Indo-Pacific , and goldring surgeonfish *kole*. The total number of fish species recorded in 2019 (110 species) is similar to the number recorded in 2020 (118 species). 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 the past two annual reports, the KoʻOlina group exhibits a higher number of fish species, individuals and biomass as compared to the Kahe group of stations. However, the 2020 data also shows significantly higher values at KoʻOlina when compared to East and Nanakuli in all three parameters. In 2020, East group did not differ from KoʻOlina group in fish abundance, biomass, or number of species, while Nanakuli only differs from KoʻOlina group with
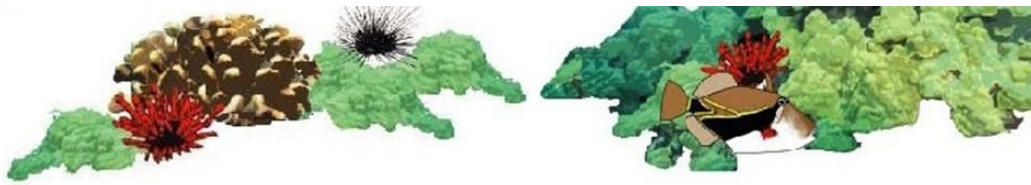
significanlty less fish individuals present along transects. Brock (2018) notes high coral community development at Koʻolina stations as drivers of high diversity of fish species, abundance, and biomass. As in previous years, the KGS discharge pipe (Pipe) station is significantly higher in biomass, abundance and diversity of fishes as compared to the East, Kahe and Nanakuli groups. Although abundance and biomass are significantly higher at the Pipe than at other groups, a statistical difference is not found between Koʻolina 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. Despite significantly higher fish biomass compared to most transects, Pipe transect has significantly lower fish biomass in 2020 as compared with the previous year. The total number of individual fishes and number of species at Pipe transect did not differ between 2019 and 2020 surveys. Pipe transect was the only transect of all fourteen transects to experience a significant decline in fish biomass 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 Koʻolina and Pipe stations. The 2020 surveys found no significant change in fish community factors which can be attributed to the operation of KGS or CIP facilities.

Key Points

- The dominant species observed in 2019 were identical to those reported in 2020: brown surgeonfish (*māʻiʻi'i*, *A. nigrofuscus*) and saddle wrasse (*hīnālea lauwili*, *T. duperrey*).
- Biomass is contributed mainly by the brown surgeonfish (*māi'i'i*, *A. nigrofuscus*), bluestripe snapper (*ta'ape, L. kasmira,* invasive), orangeband surgeonfish (*na'ena'e, A. olivaceus*), whitebar surgeonfish (*māikoiko, A. leucopareius*), saddle wrasse (*hīnālea lauwili*, *T. duperrey*), goldring surgeonfish (*kole, C. strigosus*), and Indo-Pacific sergeant (*mamo, A. vaigiensis*).
- The number of species of fishes recorded in 2020 surveys (118 species) was similar to that of 2019 (110 species).
- No significant shift was found between years in trophic feeding guilds. Herbivores and invertebrate feeders consistently dominate. Herbivores experienced a shift in biomass from 47% dominance in 2019 to 60% dominance in 2020.
- 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.
- Of the fourteen transects only the KGS Pipe experienced a significant decline in fish biomass since 2019.
- The 2020 surveys found no significant change in fish communities that can be attributed to the Hawaiian Electric's KGS or CIP facilities.
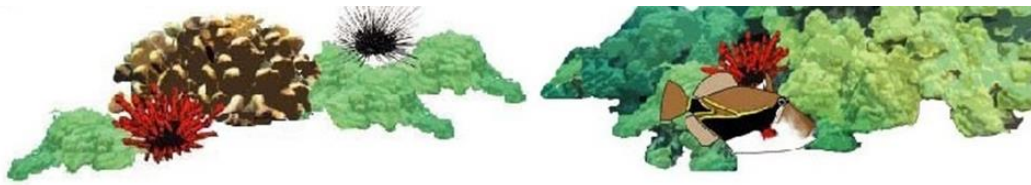
INTRODUCTION

Purpose

The Hawaiian Electric Company, Inc. (Hawaiian Electric) Campbell Industrial Park (CIP) Generating Station began service in 2010 with a 120 megawatt (MW) combustion turbine and two auxiliary 2 MW diesel engine generators. In contrast to the nearby Kahe Generating Station (KGS), the CIP Generating Station does not discharge effluent into the ocean. Instead, the 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 ranges 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 KGS 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 2007 (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 of previous monitoring stations 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 Oʻahu.
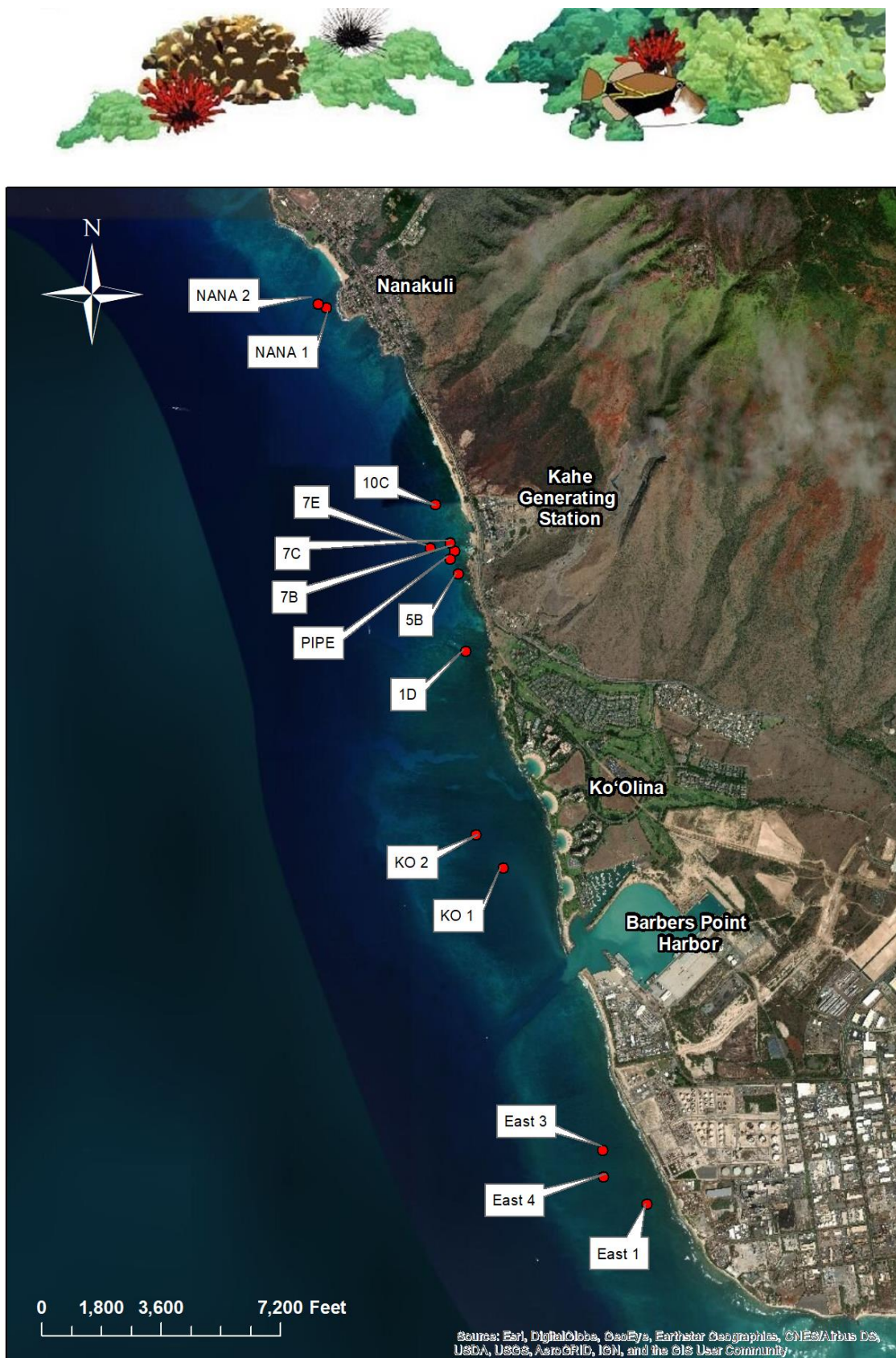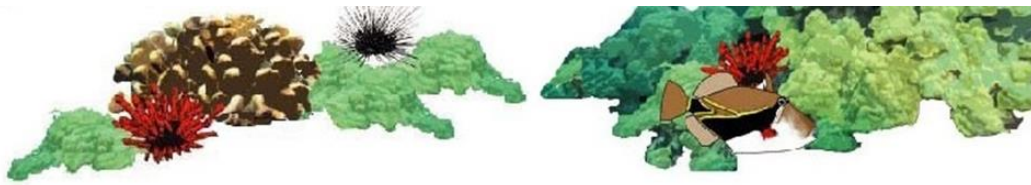
Figure 1. Map showing the southwest coastline of Oʻahu from the Barbers Point Harbor to Nanakuli Beach Park depicting locations of each of the fourteen permanently marked stations monitored in this study.

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 the power increases, the chances of detecting an effect if it exists increases. 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 significant surveyor differences;
• Cannot be replicated by others or compared to other studies using quantitative methods;
• Can obtain only certain information (e.g. species presence) and doesn't measure all variables;
• Are good for large-scale rapid assessment of an area or general conditions;
• Are strongly biased; and
• Result in highly variable observations.

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 square meters [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 away 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 Hawai'i, 20% are endemic, found exclusively in Hawai'i. 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. Pink snapper, *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* (bluestripe snapper, 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 (peacock grouper) 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 the island of Maui, "Roi Round-up" on the island of Hawai'i, and "Kaua'i no ka Roi" on the island of 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), Yellowstripe goatfish and *Parupeneus porphyreus* (kūmū), Whitesaddle goatfish, popular food fishes, may be displaced by *L. kasmira* (ta'ape), Bluestripe snapper which has also expanded its range into deeper water where *P. filamentosa* ('opakapaka), Pink snapper reside. Friedlander and Parrish (1998) looked at patterns of habitat use to determine predation and resource competition between *L. kasmira* (ta'ape), bluestripe snapper 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. 2020) includes a quantitative analyses of the fish populations along the Kalaeloa-Kahe-Nanakuli nearshore corridor and a comparison with the prior twelve annual surveys conducted by Brock (Brock 2019).
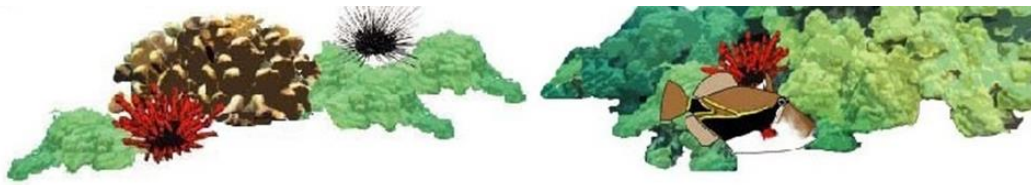
Natural Events and Anthropogenic Impacts to Hawaiian Coral Reefs
Climate change has increased ocean temperatures and changed the ocean chemistry. This is due to the anthropogenic input of emissions into the atmosphere. The oceans absorb much of the carbon dioxide (CO_2) emitted. These global impacts are the ones most critical to address. But the impacts affecting the MHI cannot be ignored. These 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.

Fishing Pressure
An expansion of commercial and recreational fisheries with more effective and efficient methods and increased economic pressure have led to worldwide overfishing. 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 Hawai'i's 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 Ni'ihau, Kaho'olawe, and N. Moloka'i. Compared with Papahānaumokuākea in the NWHIs, the fish biomass is 10 times higher than off

O'ahu. 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).

Influential Factors Controlling Reef Communities
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).
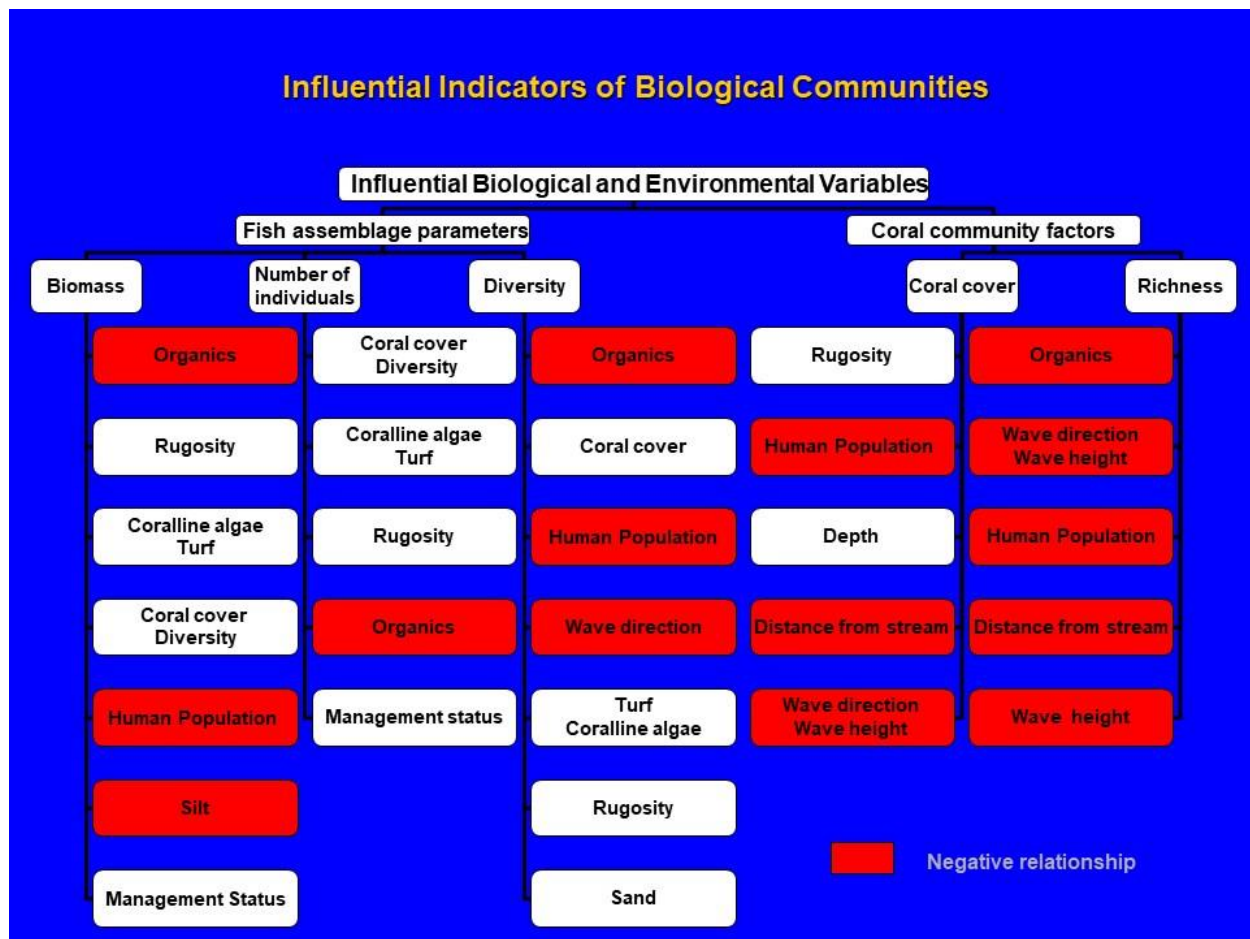
Figure 2. Primary forcing functions driving reef fish biomass, abundance and diversity and coral cover and richness in the main Hawaiian Islands. These top variables are most influential to fish and coral populations. Influential factors negatively correlated with fish or coral parameters are colored 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, Hawai'i is 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 Hawai'i 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 program, 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
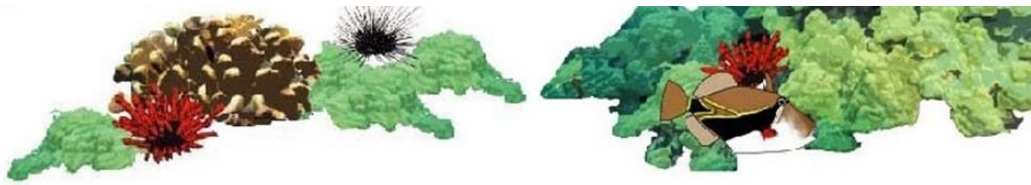
current surveys (Brock/Stender). In addition, a surveyor with similar expertise as the original surveyor was selected to continue fish community assessments. To interpret any environmental changes observed, it is vital to have qualified expertise in each area of the marine field. Low surveyor variation 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. 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).
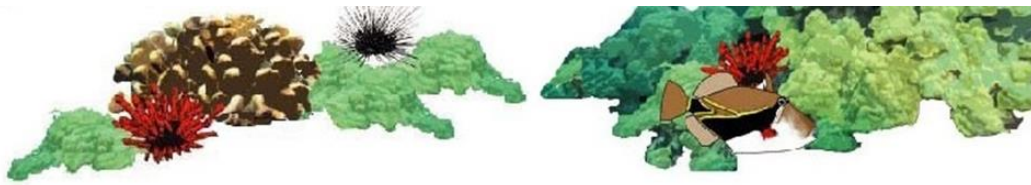
Table 1. Waves influencing the main Hawaiian Islands (Jokiel 2008).

	Typical			Extreme			Direction	
	Height		Period	Height		Period		
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

Hawai'i experienced 6 m waves that reduced coral cover from 46% to 10% 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 Kaua'i and O'ahu 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 Hawai'i over cooler water they lose energy or encounter atmospheric conditions unfavorable to further development. Hawai'i's hurricane season is from June through November. Hurricane Iniki (1992) generated powerful waves that fragmented and abraded corals on south Kaua'i. 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, Hawai'i with declines in coral cover from 15% to 11% (Dollar and Tribble 1993) and Mamala Bay on O'ahu (Brock 1996) with loss of rugosity and shelter for fishes. Storms and hurricanes have been documented to negatively impact fish communities in west O'ahu (Brock CIP reports) and elsewhere in Hawai'i (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 1970s 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 (Figure1). 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 m -12 m depths). Between these two sets, two stations are located northwest of the Ko 'Olina and Barber's Point Harbors between the 1st and 3rd Ko'Olina lagoons at 7 m and 9 m depths. A reference site outside the KGS zone of mixing was established at Nanakuli (Coles et al. 1985). These two monitoring 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 O'ahu 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
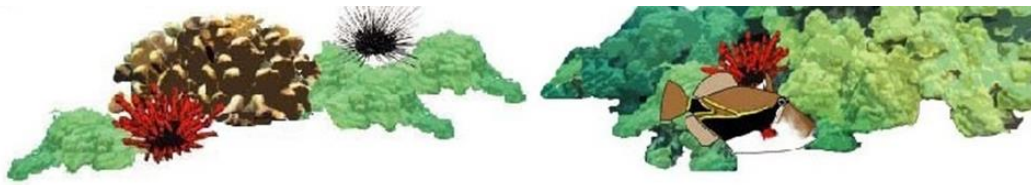
(number of individuals) and biomass (standing crop). East 2, 3 and 4 are in close proximity to each other. This served as the justification for removal of station East 2.

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, equipped 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 2019 and 2020 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 2020. Transects were grouped according to geographic locations (Table 2) into 5 total groups: East group (East 1, East 3, East 4), KoʻOlina 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 location of 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. Each transect was surveyed four times throughout the year with the exception of East 1, which, was not surveyed in November due to poor water visibility. The four timepoints for the 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 and 2020.

Station No.	Station Area Name	Grouping	Latitude	Longitude	Remarks
1	East 1	East	21°18.237' N	158°07.024'W	New- offshore CIP
2	East 2	East	21°18.452'N	158°07.152'W	New - offshore CIP
3	East 3	East	21°18.558'N	158°07.239'W	New - offshore CIP
4	East 4	East	21 ° 18.406'N	158°07.285'W	New - offshore CIP
5	KoʻOlina 1	KoʻOlina	21°19.724'N	158°07.581'W	New - offshore Ko'Olina
6	KoʻOlina 2	KoʻOlina	21°19.904'N	158°07.693'W	New - offshore Ko'Olina
7	Station 1D	Kahe	21°20.763'N	158°07.773'W	Old Hawaiian Electric station
8	Station 5B	Kahe	21°21.145'N	158°07.819'W	Old Hawaiian Electric station
9	Station7B	Kahe	21°21.239'N	158°07.855'W	Old Hawaiian Electric station
10	Station 7C	Kahe	21°21.255'N	158°07.881'W	Old Hawaiian Electric station
11	Station 7D	Kahe	21°21.268'N	158°07.893'W	Old Hawaiian Electric station
12	Station 7E	Kahe	21°21.272'N	158°07.977'W	Old Hawaiian Electric station
13	Station 10C	Kahe	21°21.522'N	158°07.925'W	Old Hawaiian Electric station
14	Nanakuli Control 1	Nanakuli	21°22.329'N	158°08.440'W	Old Hawaiian Electric station
15	Nanakuli Control 2	Nanakuli	21°22.353'N	158°08.462'W	New control station
16	On Outfall	Pipe	21°21.193'N	158°07.869'W	New north side of outfall

RESULTS AND DISCUSSION

The 2020 data are presented herein along with a comparative analysis to the 2019 data. The complete data set from the four 2020 surveys is given in Appendices A and B.

Transect surveys were performed on July 23, September 16, October 5, and November 20, 2020. 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.

Overall

Utilizing data from all 52 surveys performed from 2007 to present (Appendix A, 2007-2018 performed by Brock), the number of fish species, the number of fish individuals and the biomass was compared between groups of transects: East (3 transects), KoʻOlina (2 transects), Kahe (6 transects), Nanakuli (2 transects), and Pipe (1 transect). The number of individuals and number of fish species differed significantly between groups, with the exception of East and Kahe groups whose number of fishes and fish species were similar throughout time. The greatest number of fish individuals and species was observed at Pipe, followed by KoʻOlina, East, Kahe, and Nanakuli. When comparing the fish biomass throughout all survey years, all groups were statistically different from one another with the exception of the Kahe and Nanakuli groups, where biomass was similar. Fish biomass was greatest at Pipe, followed by KoʻOlina, East,

Kahe, and Nanakuli. A similar trend was observed in 2020 data when analyzed exclusively. Fish biomass at East ($p = 0.012$), Kahe ($p = 0.011$), and Nanakuli ($p = 0.037$) groupings were significantly lower than at Pipe transect in 2020 (Figure 3a). Fish biomass at Kahe ($p < 0.001$) groupings was also significantly lower than that at Ko'Olina groupings. Fish abundance and number of species were significantly higher at Pipe when compared to East ($p = 0.029, 0.029$), Kahe ($p < 0.001, 0.001$) and Nanakuli ($p = 0.008, 0.035$) (Figures 3b and 3c). The number of species was also significantly higher at Ko'Olina group when compared to Kahe ($p = 0.002$), with both Kahe ($p = 0.48$) and Nanakuli ($p = 0.044$) groups exhibiting a marginally significant lower number of fish individuals as compared to Ko'Olina (Figures 3b and 3c). In summary, Pipe transect had significanlty higher numbers of species, individual fishes and biomass when compared to East, Kahe, and Nanakuli. Ko'Olina exhibited significantly greater numbers of species, individual fishes and biomass when compared to Kahe, in addition to significnatly higher numbers of individual fishes when compared to Nanakuli.

A total of 118 fish species were recorded in 2020 surveys combining all 14 transects. The number of species present in 2019 surveys was 110. *Māʻiʻiʻi* (20.8% individuals, 9.1% biomass, *Acanthurus nigrofuscus,* Brown surgeonfish,) and *hīnālea lauwili* (18.3% individuals, 9.3% biomass, *Thalassoma duperrey*, Saddle wrasse) were the dominant fishes along transects for both number of individuals and biomass in 2019 (Figure 4c and 4d). In 2020, *māʻiʻiʻi* (19.5%, brown surgeonfish) and *hīnālea lauwili* (14.6%, saddle wrasse) remained the most abundant fishes along transects, while the biomass was a composition of many fish species: *māʻiʻiʻi* (9.3%, *A. nigrofuscus,* brown surgeonfish), *taʻape* (9.2%, *Lutjanus kasmira,* bluestripe snapper), and *naʻenaʻe* (8.8%, *Acanthurus olivaceus*, orangeband surgeonfish). The majority of individual fishes along transects were herbivores (45% abundance, 60% biomass) or invertebrate feeders (38% abundance, 30% biomass) (Table 3). However, zooplanktivores (15% abundance, 8.7% biomass) and piscivores (0.8% abundance, 1.3% biomass) were also present (Figure 5a, Table 3). In 2019, the dominant trophic level of fishes was also herbivores (40% abundance, 47% biomass) and invertebrate feeders (43% abundance, 39% biomass) (Figure 5b). To determine if there were 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 biomass (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 surveys). The fourteen sites (Figure 1) were assigned to five geographic locations: (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, and (5) Pipe.

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

A. 2020 Trophic Levels: Number of Individuals (%)

Transect Group	Herbivores	Invertebrate Feeders	Piscivores	Zooplanktivores
East	46.7	29.6	1.3	22.4
Ko'Olina	66.3	31.3	0.5	1.9
Kahe	39.8	37.0	0.6	22.5
Nanakuli	61.1	28.0	1.2	9.7
Pipe	13.1	65.3	0.6	21.1
Total	45.4	38.2	0.8	15.5

B. 2020 Trophic Levels: Mean Biomass (%)

Transect Group	Herbivores	Invertebrate Feeders	Piscivores	Zooplanktivores
East	74.0	21.1	3.8	1.1
Ko'Olina	73.7	25.5	0.5	0.2
Kahe	50.7	33.9	0.8	14.6
Nanakuli	85.0	13.9	1.0	0.2
Pipe	16.2	55.7	0.6	27.5
Total	59.9	30.0	1.3	8.7

C. 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	0.5	0.5
Kahe	31.8	37.6	0.6	30
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

D. 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	41	2.9	10.1

a. 2020 Average Fish Biomass (g/m²)

b. 2020 Average Fish Abundance
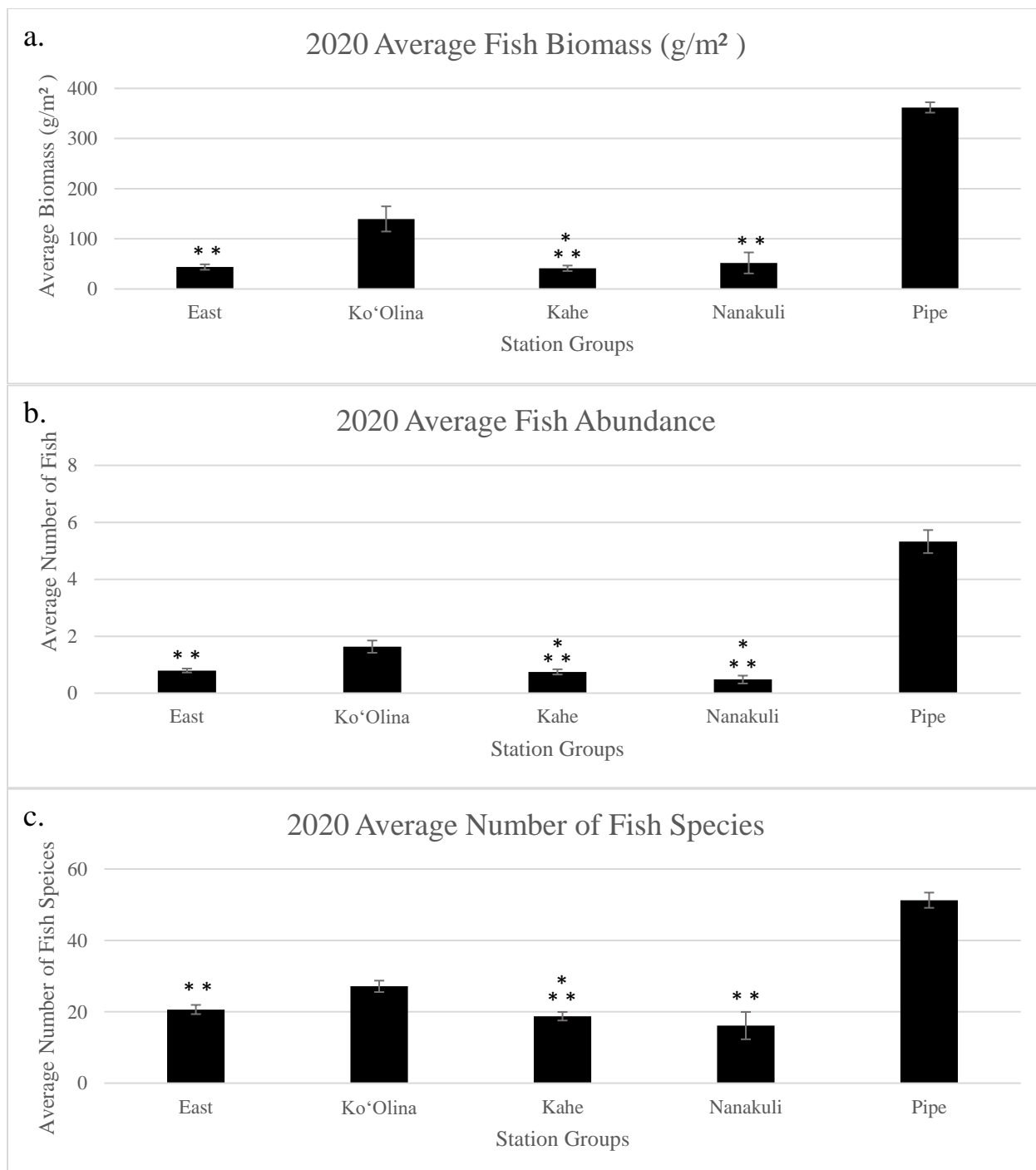
c. 2020 Average Number of Fish Species

Figure 3. Average fish biomass, abundance and number of species per station grouping for 2020 surveys only. Standard error (SE) bars represent $\pm$ 1 SE. Three asterisks (*) represents significant difference from Ko'Olina grouping, while two asterisks (**) represent a significant

difference from Pipe transects. Example: Kahe shows both three asterisks representing a significant difference from both the Ko 'Olina grouping and the Pipe.
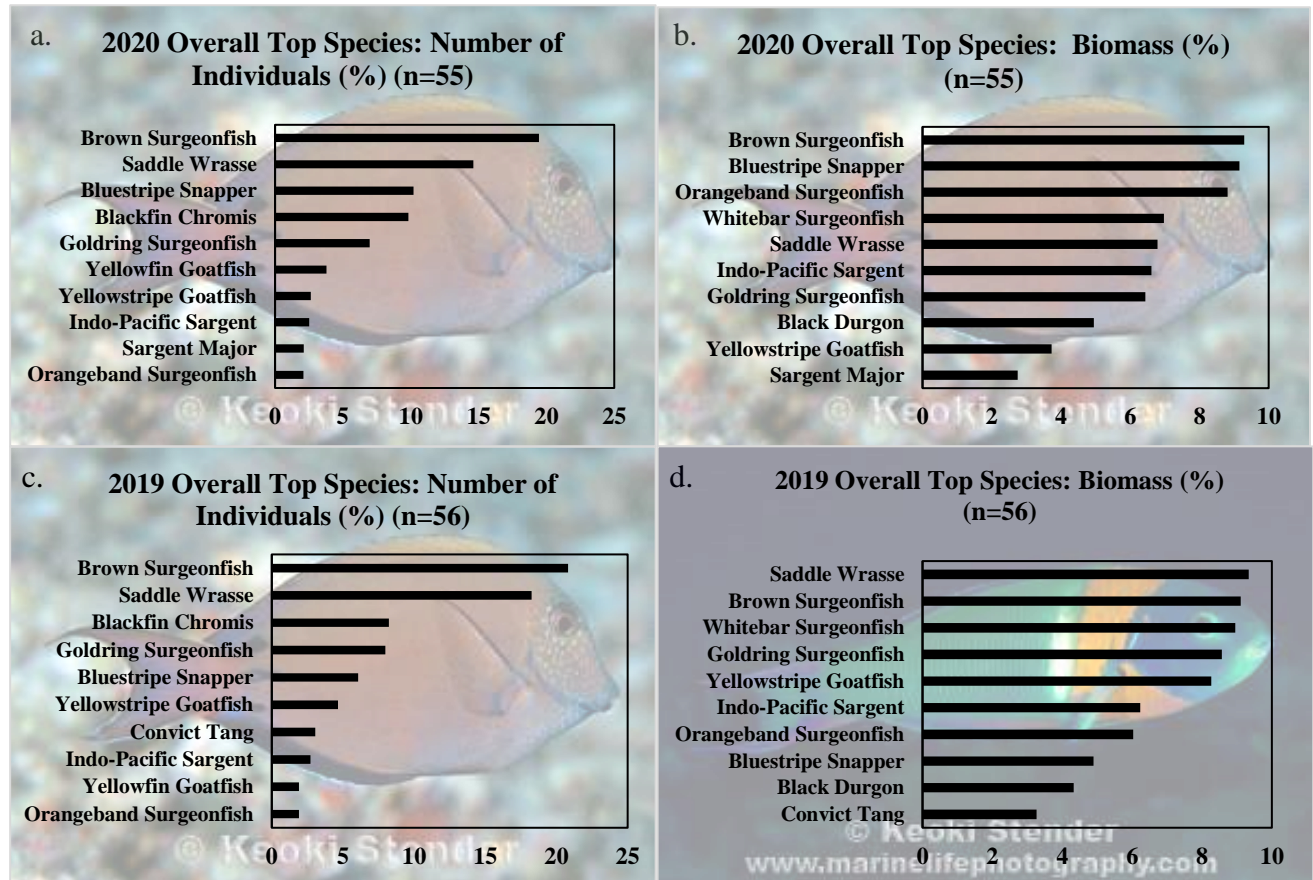

Figure 4. Top ten fish species contributing to number of individual fishes and biomass (%) for survey year 2020 (a, b) and 2019 (c, d).
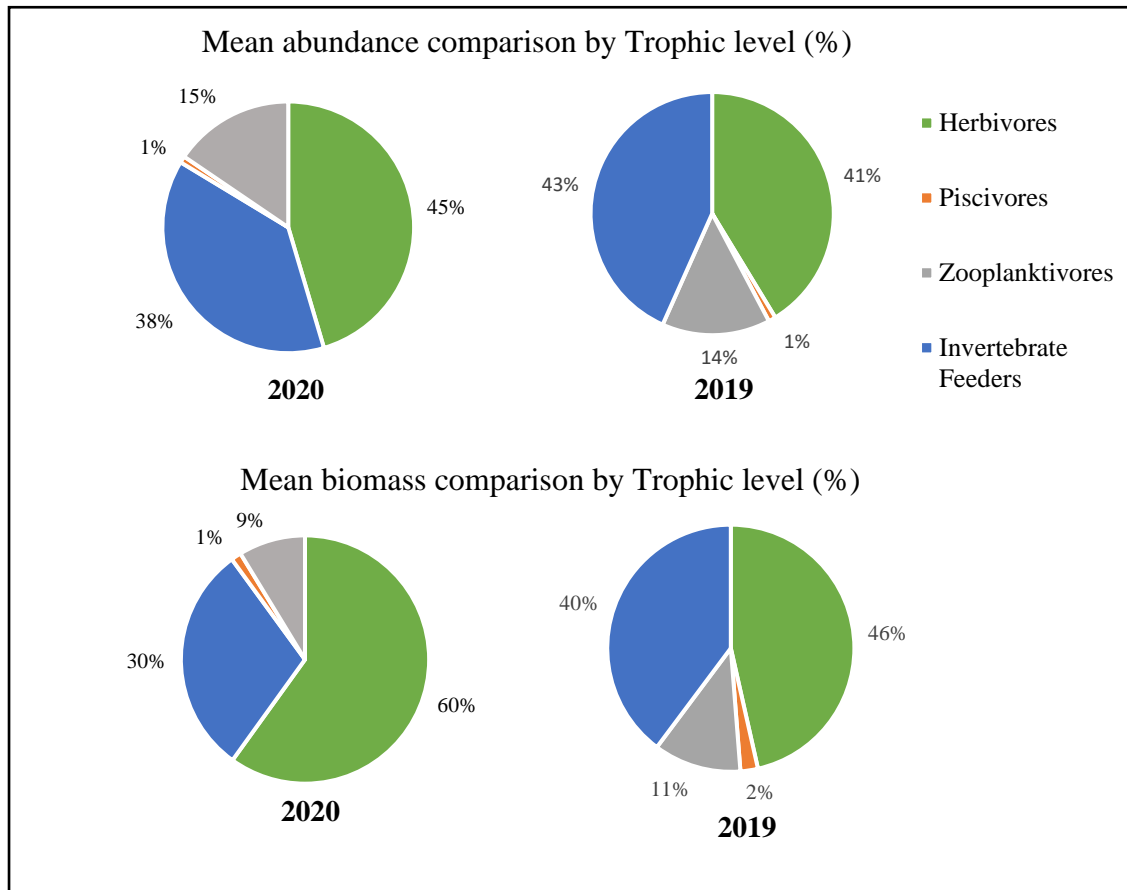
Figure 5. Mean abundance and biomass of each trophic level during 2020 and 2019 surveys.

EAST

In 2019 and 2020, transects East 1, East, 3 and East 4 were surveyed within the East transect grouping. In 2020, East 1 transect had the highest estimated standing crop of all East transects with 59.1 ± 8.0 g/m^2 (Figure 6). East 3 had the lowest biomass in 2020 (18.7 ± 7.1 g/m^2). East 4 had intermediate biomass with 50.9 ± 1.0 g/m^2. East group had similar mean biomass estimates (2019 = 51.4 ± 14.9 g/m^2, 2020 = 42.9 ± 5.4 g/m^2), fish abundance (2019 = 0.96 ± 0.16 individuals/m^2, 2020 = 0.75 ± 0.12 individuals/m^2), and number of fish species (2019 = 21.5 ± 1.7, 2020 = 19.0 ± 2.1) present in the 2020 surveys when compared to the 2019 surveys. Consistent with 2019 surveys, fish abundance at all East transects was dominated by the Blackfin Chromis (*Chromis vanderbilti*), *māʻiʻiʻi* (*A. nigrofuscus,* Brown surgeonfish), and *hīnālea lauwili* (*T. duperrey*, Saddle wrasse) (Figure 7a). The biomass at East transects was dominated by *naʻenaʻe* (*A. olivaceus*, orange band surgeonfish*)* (Figure 7b)
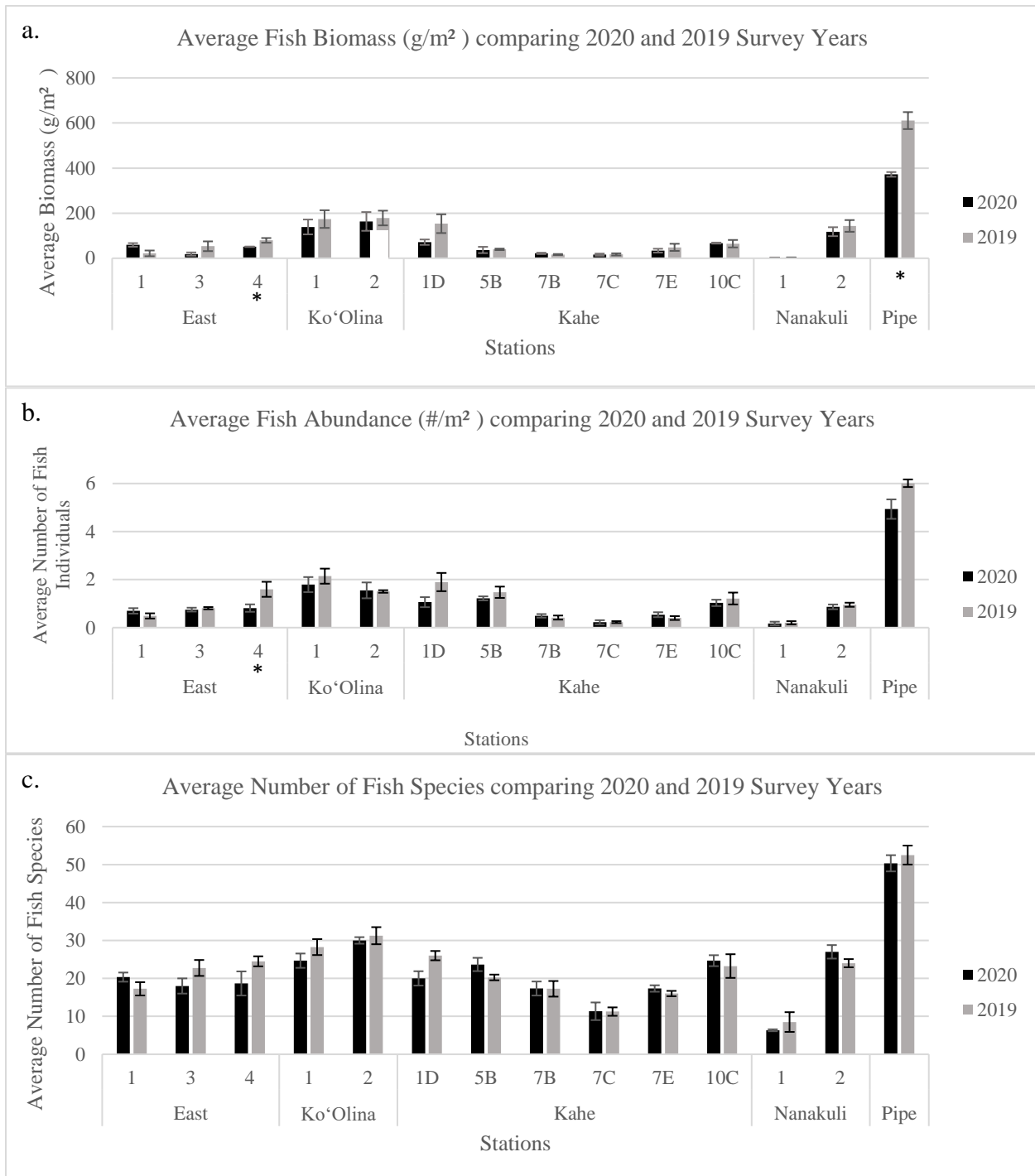
Figure 6. Average fish biomass (a), fish abundance (b) and number of fish species (c) per transect comparing survey years 2020 and 2019. Standard error (SE) bars represent ± 1 SE. An asterisk (*) after the station name indicates a significant difference between the two survey years.
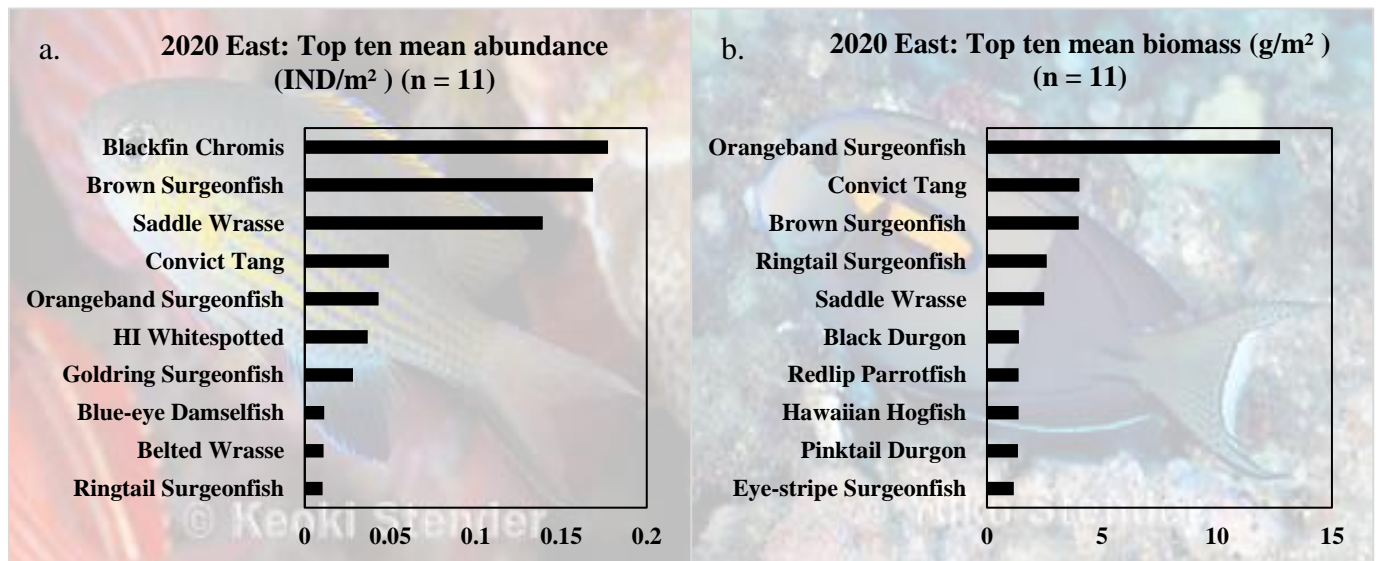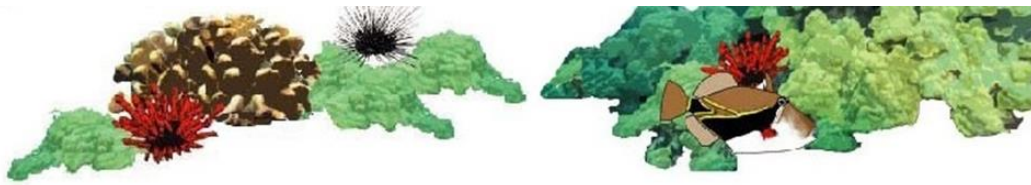
Figure 7. Top ten fish contributing to mean abundance and biomass at East transect grouping in 2020. IND/m^2=individuals per square meter, g/m2=grams per square meter.

East 1: In 2020, East 1 transect had an average of 139 ± 22.8 fish individuals documented, encompassing a total of 35 species of fishes. The *manini* (*Acanthurus triostegus*, convict tang), blackfin chromis (*C. vanderbilti*), *hīnālea lauwili* (*T. duperrey*, saddle wrasse), and *māʻiʻiʻi* (*A. nigrofuscus*, brown surgeonfish) were the most abundant fishes along this transect. The dominant fish species in biomass was different for each survey date, reflecting the variability in fish populations at this site. In July, *manini* (30.0%, *A. triostegus*, convict tang) and *pualu* (20.1%, *Acanthurus blochii*, ringtail surgeonfish) were responsible for half of the biomass (biomass = 47.8 g/m^2, 166 individuals). In September (55.1 g/m^2, 94 individuals) and October (74.5 g/m^2, 158 individuals) biomass was less than reported in July surveys. In September the biomass was dominated by the *pālukaluka* (25.1%, *Scarus rubroviolaceus*, redlip parrotfish) and the *pualu* (19.6%, *A. blochii*, ringtail surgeonfish), while in October the *manini* (27.5%, *A. triostegus,*convict tang), *naʻenaʻe* (20.7%, *A. olivaceus*, orangeband surgeonfish) and *pualu* (19.2%, *A. blochii*, ringtail surgeonfish) were dominant. The November survey was not conducted due to poor water visibility that would compromise survey accuracy.

East 3: The average number of fishes along transect East 3 was 150.0 ± 16.0 individuals of 37 fish species (Figure 6). Along East 3, *māʻiʻiʻi* (*A. nigrofuscus*, brown surgeonfish) and *hīnālea lauwili* (*T. duperrey*, saddle wrasse), were the most abundant fishes for all survey timepoints (Appendix A). In July, the survey documented 173 fishes of 18 species. The four fishes responsible for the majority of the biomass (25.2 g/m^2) during July's survey were the *māʻiʻiʻi* (27.4%, *A. nigrofuscus*, brown surgeonfish), *hīnālea lauwili* (16.1%, *T. duperrey*, saddlewrasse), the *kole* (13.9%, *Ctenochaetus strigosus*, goldring surgeonfish) and the *kīkākapu* (12.0%, *Chaetodon ornatissimus*, ornate butterflyfish). The census in September had the lowest biomass (12.9 g/m^2) and number of individual fishes (105 fishes) of all four timepoints. During this

survey, 18 fish species were observed. *Māʻiʻi* (26.7%, *A. nigrofuscus*, brown surgeonfish) and *hīnālea lauwili* (21.7%, *T. duperrey*, saddle wrasse) encompassed a large portion of the biomass. In October, 172 individuals of 18 fish species were identified along transect East 3. The fishes contributing the most to biomass (18.1 g/m^2) were *māʻiʻi* (41.6%, *A. nigrofuscus,*brown surgeonfish), *kole* (15.1%, *C. strigosus*, goldring surgeonfish), *kīkākapu* (12.1%, *Chaetodon ornatissimus*, ornate butterflyfish) and *hīnālea lauwili* (11.5%, *T. duperrey*, saddle wrasse). In November, 26 species of fishes were identified within 157 individuals. This was the greatest species diversity of all timepoints in the East group. Biomass (45.4 g/m^2) in November was also the highest of all timepoints and was dominated by *naʻenaʻe* (43.0%, *A. olivaceus*, orangeband surgeonfish) and *māʻiʻi* (12.6%, *A. nigrofuscus*, brown surgeonfish).

East 4: Despite a significant decrease in fish abundance (p = 0.029) and biomass (p = 0.029) when compared to 2019 surveys, the number of fish species (18.7 ± 3.2), number of fish (162.7 ± 31.0) present along transects at each survey date, and biomass (50.9 ± 1.0 g/m^2) of East 4 remained consistent throughout the four timepoints in 2020. In July, 213 individuals of 15 species were recorded along East 4 transects. The biomass (48.5 g/m^2) was made up of 38.8% *naʻenaʻe* (*A. olivaceus*, orangeband surgeonfish*)* and 17.7% *pūhi paka* (*Gymnothorax flavimarginatus*, yellowmargin moray). September census observed a biomass of 53.5 g/m^2 encompassing 22 species of fishes, and a decrease in overall number of individual fishes (94 fishes). The biomass continued to be dominated by a *naʻenaʻe* (48.8%, *A. olivaceus*, orangeband surgeonfish) and *humuhumuʻeleʻele* (10.3%, *Melichthys niger,* black durgon). In October (50.6 g/m^2, 181 individuals, 19 species) and November (50.2 g/m^2, 235 individuals, 30 species) the biomass was dominated by *naʻenaʻe* (October: 64.6%, September: 31.1%, *A. olivaceus*, orangeband surgeonfish) and either the *humuhumuhiʻukole* (12.5%, *Melichthys vidua*, pinktail durgon) in October or the *humuhumuʻeleʻele* (10.9%, *M. niger,* black durgon) in September.

KO ʻOLINA

The Koʻolina group includes transects KO 1 and KO 2. Average biomass, abundance and number of fish species for the Koʻolina group were similiar in 2019 (139 ± 6.8 g/m^2, 365 ± 46 individuals, 29 ± 1.7 species) when compared to 2020 (140 ± 25.0 g/m^2, 365 ± 64.3 individuals, 27.1 ± 1.6 species)(Figure 6). Surveys in 2019 showed more variability number of fish individuals between the two transects (KO 1 and KO 2) and four survey dates when compared to 2020. In Koʻolina group, the most abundant fishes were *kole* (*C. strigosus*, goldring surgeonfish) and *māʻiʻi* (*A. nigrofuscus*, brown surgeonfish)(Figure 8a). *Kole* (*C. strigosus*, goldring surgeonfish), *naʻenaʻe* (*A. olivaceus*, orangeband surgeonfish), and *taʻape* (*Lutjanus kasmira*, bluestripe snapper) were responsible for the majority of the biomass (Figure 8b).
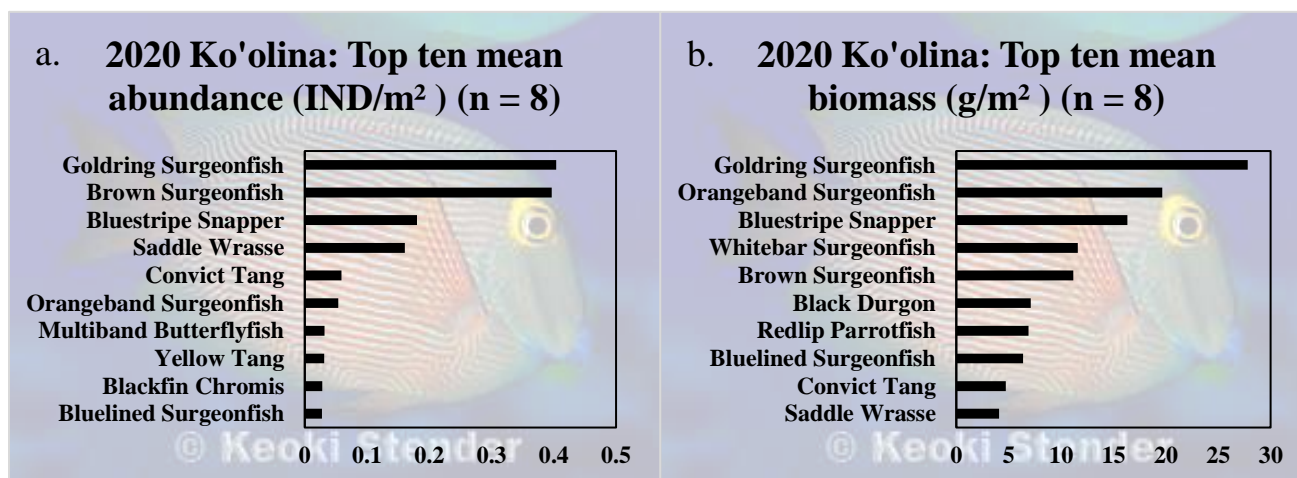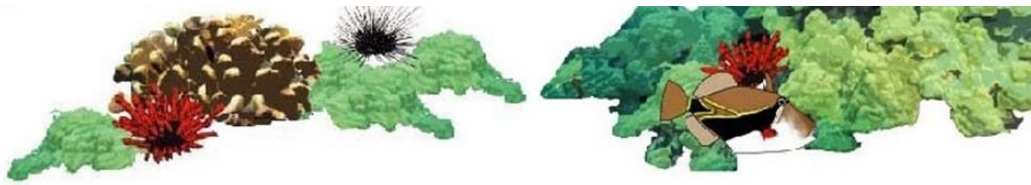
a. 2020 Ko'olina: Top ten mean abundance (IND/m²) (n = 8)

Goldring Surgeonfish
Brown Surgeonfish
Bluestripe Snapper
Saddle Wrasse
Convict Tang
Orangeband Surgeonfish
Multiband Butterflyfish
Yellow Tang
Blackfin Chromis
Bluelined Surgeonfish

0   0.1   0.2   0.3   0.4   0.5

b. 2020 Ko'olina: Top ten mean biomass (g/m²) (n = 8)

Goldring Surgeonfish
Orangeband Surgeonfish
Bluestripe Snapper
Whitebar Surgeonfish
Brown Surgeonfish
Black Durgon
Redlip Parrotfish
Bluelined Surgeonfish
Convict Tang
Saddle Wrasse

0   5   10   15   20   25   30

Figure 8. Top ten fish contributing to mean abundance and biomass at Ko'Olina transect grouping in 2020.

Ko 'Olina 1: In 2020, KO 1 transect varied in fish biomass over the four survey dates: July = 184.2 g/m², September = 179.8 g/m², October = 52.9 g/m², November = 88.7 g/m². Despite this fluctuation, the fish species contributing the majority of the biomass remained similar. Collectively, *kole* (July: 20.1%, September: 11.1%, October: 29.3%, November: 44.5%, *C. strigosus*, goldring surgeonfish) and *ta'ape* (July: 44.3%, September: 15.8%, October:1.6%, November: 21.5%, *L. kasmira*, bluestripe snapper) were two of the dominant biomass contributors. The September census also found *na'ena'e* (24.2%, *A. olivaceus*, orangeband surgeonfish) to contribute a large portion of the biomass, while *uhu* (19.8%, *Chlorurus spilurus* (formerly *C. sordidus*), bullethead parrotfish) was a contributor during the October census. Species contribution to biomass showed the similar patterns for numbers of individuals along KO 1, however, the number of individuals varied between time points (July: 489 individuals (inds.), September: 395 inds., October: 191 inds., November: 329 inds.). The greatest number of species was recorded during the September survey (29) followed by October (24), July (21), and November (21).

Ko 'Olina 2: KO 2 transect in July had the highest biomass (277.4 g/m²) and number of individual fishes (494 individuals) of all timepoints (Appendix A). The biomass was dominated by three species: *na'ena'e* (24.6%, *A. olivaceus*, orangeband surgeonfish), *mā'iko'iko* (19.5%, *Acanthurus leuopareius*, whitebar surgeonfish), and *kole* (19.4%, *C. strigosus*, goldring surgeonfish). July and November (32 species) had the highest biodiversity of all four surveys followed by Septemeber and October (29 species). The biomass (105.6 g/m²) for 240 fish individuals in the September survey found 29.0% of biomass from *kole* (*C. strigosus*, goldring surgeongish), 14.6% from *humuhumu'ele'ele* (14.6%, *M. niger*, black durgon), and 14.2% from *na'ena'e* (*A. olivaceus*, orangeband surgeonfish). In October, the biomass (106.8 g/m², 197 individuals) was dominated by three surgeonfish species: *mā'iko'iko* (26.2%, *A. leucopareius*, whitebar surgeonfish), *maiko* (14.6%, *Acanthurus nigoris*, bluelined surgeonfish), and *na'ena'e* (14.3%, *A. olivaceus*, orangeband surgeonfish). In November, the major contributors to the biomass (122.5 g/m²) were diversified between several species: *na'ena'e* (15.1%, *A. olivaceus*,

orangeband surgeonfish), *kole* (12.8%, *C. strigosus*, goldring surgeonfish), *pālukaluka* (11.3%, *S. rubroviolaceus*, redlip parrotfish), *humuhumuʻeleʻele* (10.5%, *M. niger*, black durgon), and *māʻiʻi'i* (9.4%, *A. nigrofuscus*, brown surgeonfish). The species highest in abundance (277 total individuals) during 2020 KO 2 surveys were *māʻiʻi'i* (*A. nigrofuscus*, brown surgeonfish), *kole* (*C. strigosus*, goldring surgeonfish), and *hīnālea lauwili* (*T. duperrey*, saddle wrasse).

KAHE

The Kahe group encompasses six transects: 1D, 5B, 7B, 7C, 7E and 10C. Kahe 7D transect was eliminated from surveys after 2018 and therefore was removed from all group averages. At Kahe stations estimated biomass in 2020 was 41.3 ± 5.4 g/m^2, while in 2019 estimated biomass was 45 ± 9.1 g/m^2 (Figure 6). No significant difference was found between years. The average number of fishes in 2019 (188 ± 80.4) and 2020 (152.0 ± 22.8) were also found not to be significantly different. The average number of species was similar for the two years (2019: 19 ± 2.6, 2020: 19 ± 2.0). In 2020, *māʻiʻi'i* (*A. nigrofuscus*, brown surgeonfish) dominated in both abundance and biomass (Figure 9). This differed from 2019 surveys where *na'ena'e* (*A. olivaceus*, orangeband) was greatest in both abundance and biomass. In both years, *hīnālea lauwili* (*T. duperrey*, saddle wrasse) also contributed significantly to abundance and biomass.
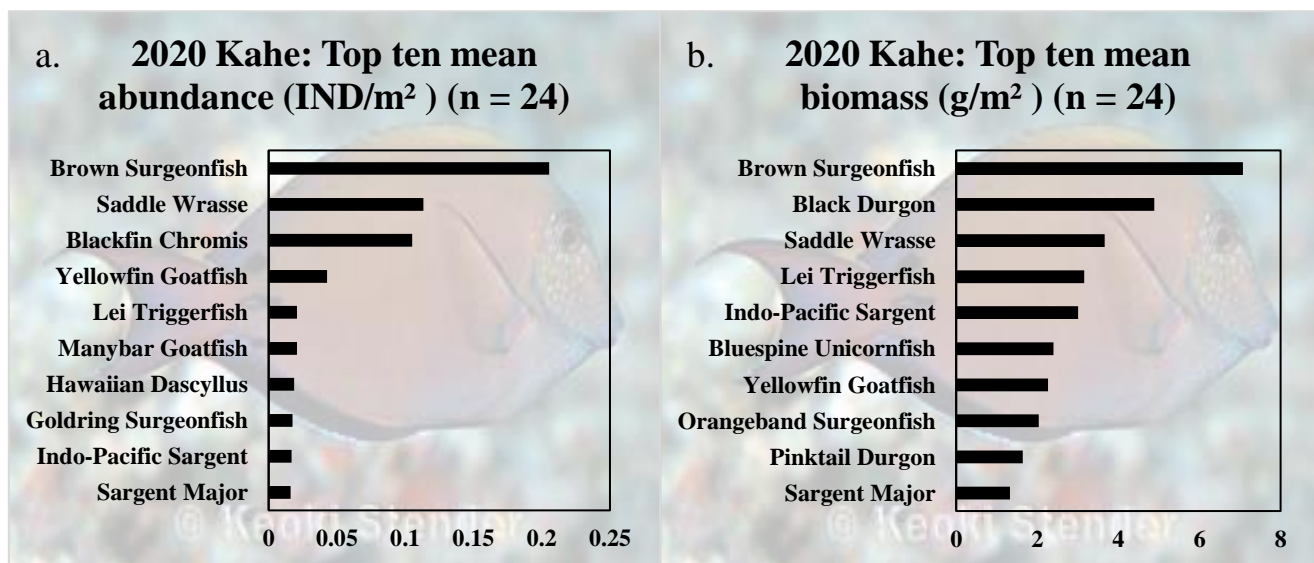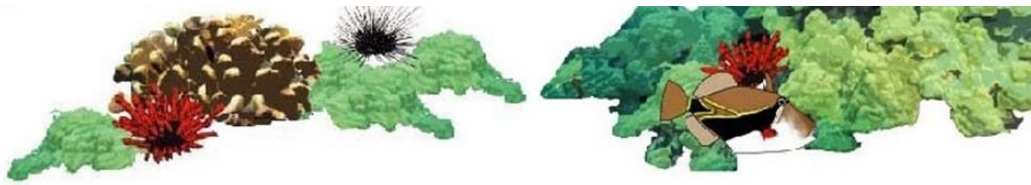

Figure 9. Top ten fish contributing to mean abundance and biomass at Kahe transect grouping in 2020 surveys.

Kahe 1D: In 2020, transect 1D fluctuates in biomass, number of individuals, and number of species present along the transect: July: 104.4 g/m^2, 322 individuals, 24 species, September: 55.4 g/m^2, 129 individuals, 24 species. October: 54.0 g/m^2, 185 individuals, 21 species, November: 61.2 g/m^2, 250 individuals, 19 species. The biomass during July and September was dominated by *humuhumuʻeleʻele* (July: 26.3%, September: 33.1%, *M. niger*, black durgon) and *māʻiʻi'i* (July: 25.2%, September: 21.9%, *A. nigrofuscus*, brown surgeonfish). However, in July, *kole* (17.4%, *C. strigosus*, goldring surgeonfish) also contibuted to the biomass. In October and
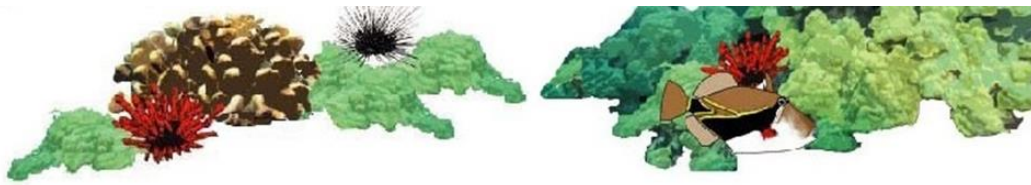
November, the biomass was dominated by *māʻiʻiʻi* (October: 33.3%, November: 35.0%, *A. nigrofuscus*, brown surgeonfish) and *hīnālea lauwili* (October: 20.0%, November: 14.7%, *T. duperrey*, saddle wrasse). Other significant contributors to the biomass were *humuhumuʻeleʻele* (October: 13.6%, November: 12.0%, *M. niger*, black durgon) in October and November, and *kole* (12.2%, *C. strigosus*, goldring surgeonfish) in November. The two most abundant species in all surveys were the *māʻiʻiʻi* (*A. nigrofuscus*, brown surgeonfish) and *hīnālea lauwili* (*T. duperrey*, saddle wrasse).

Kahe 5B: 5B transect remained realitively stable for first three quarterly survey, while the fourth survey saw a large increase in biomass: July: 32.4 g/m^2, 259 individuals, 23 species, September: 41.2 g/m^2, 243 individuals, 20 species, October: 36.6 g/m^2, 229 individuals, 28 species, November: 91.8 g/m^2, 182 individuals, 26 species. *Māʻiʻiʻi* (July: 32.7%, September: 57.8%, October: 35.3%, November.: 7.8%, *A. nigrofuscus*, brown surgeonfish) dominated the biomass in the first three surveys. In July, *hīnālea lauwili* (31.1%, *T. duperrey*, saddle wrasse) was also a significant contributor to the fish biomass, while in October *ʻopelu* (13.9%, *Decapterus macarellus*, mackerel scad) contributed to the biomass. The November survey had the largest increase in biomass, despite a decrease in fish abundance due to a school of *kala* (59.7%, *Naso unicornis,* Bluespine Unicornfish) along the transect. The three most abundant fishes along all survey dates were *māʻiʻiʻi* (*A. nigrofuscus*, brown surgeonfish), blackfin chromis (*C. vanderbilti*), and *hīnālea lauwili* (*T. duperrey*, saddle wrasse). Chromis are small schooling fishes that can contribute strongly to abundance (number of individuals) but make very little contribution to biomass.

Kahe 7B: In 2020 surveys, 7B transect had low estimated biomass, individual fish counts, and number of species present for all four quarterly surveys: July: 16.5 g/m^2, 80 individuals, 13 species, September: 29.2 g/m^2, 138 individuals, 21 species, October: 18.7 g/m^2, 76 individuals, 18 species, November: 16.1 g/m^2, 82 individuals, 14 species. During the July survey, *humuhumulei* (28.5%, *Sufflamen bursa*, lei triggerfish), *hīnālea lauwili* (22.6%, *T. duperrey*, saddle wrasse), *māʻiʻiʻi* (21.6%, *A. nigrofuscus*, brown surgeonfish), and *moano* (10.2%, *Parupeneus multifasciatus*, manybar goatfish) made up the majority of fish biomass along the transect. September surveys were dominated by only two species of fish, *māʻiʻiʻi* (20.5%, *A. nigrofuscus*, brown surgeonfish) and *humuhumulei* (18.8%, *S. bursa*, lei triggerfish). In October, the fish contibuting the most to biomass were the *umaumalei* (27.7%, *Naso lituratus*, orangespine unicornfish) and, again, the *humuhumulei* (25.2%, *S. bursa*, lei triggerfish). Over half of the biomass (57.2%) in November was made up of three species of damselfish: *mamo* (28.2%, *Abudefduf vaigiensis*, Indo-Pacific sergeant), *ʻaloʻiloʻi* (14.7%, *Dascyllus albisella*, Hawaiian Dascyllus), and *mamo* (14.3%, *Abudefduf abdominalis*, sergeant major). *Humuhumulei* (24.4%, *S. bursa*, lei tiggerfish) also contibuted signifincatly to the biomass in November. The two most abundant fish species within all quarterly surveys at 7B in years 2019 and 2020 were the blackfin chromis (*C. vanderbilti*) and *māʻiʻiʻi* (*A. nigrofuscus*, brown surgeonfish).

Kahe 7C: Kahe 7C transect had lowest biomass, numbers of individual fishes and numbers of species present throughout the four surveys when compared to all other Kahe transects: July: 25.6 g/m^2, 86 individuals, 16 species, September: 5.5 g/m^2, 14 individuals, 6 species, October: 16.7 g/m^2, 34 individuals, 12 species, November: 6.7 g/m^2, 13 individuals, 7 species. July biomass estimates were heavily influenced by *humuhumuʻeleʻele* (24.8%, *M. vidua*, pinktail durgon*)*, *naʻenaʻe* (22.9%, *A. olivaceus*, orangeband surgeonfish)*, humuhumulei* (15.4%, *S. bursa*, lei triggerfish), and *māʻiʻiʻi* (14.0%, *A. nigrofuscus*, brown surgeonfish). The biomass

during September was dominated by a single fish species: *humuhumulei* (86.1%, *S. bursa*, lei triggerfish). During the October survey, no one fish species dominated the biomass: *na'ena'e* (21.5%, *A. olivaceus*, orangeband surgeonfish*)*, *humuhumulei* (18.9%, *S. bursa*, lei triggerfish), *umaumalei* (15.8%, *N. lituratus*, orangespine surgeonfish), and *manini* (13.8%, *A. triostegus*, convict tang). During the last survey of the year, *na'ena'e* (35.6%, *A. olivaceus*, orangeband surgeonfish), a single *'o'opu okala* (31.5%, *Diodon holocathus*, spiny puffer), and *humuhumulei* (23.4%, *S. bursa*, lei triggerfish) dominated the biomass. Among all survey dates the fishes that contributed the most to biomass at station 7C were blackfin chromis (*C. vanderbilti*), *mā'i'i'i* (*A. nigrofuscus*, brown surgeonfish), *humuhumulei* (*S. bursa*, lei triggerfish) and *na'ena'e* (*A. olivaceus,* orangeband surgeonfish).

Kahe 7E: Kahe 7E was highly variable in fish biomass and number of individuals throughout the four surveys. July had the highest biomass and total number of fishes (53.2 g/m^2, 146 individuals, 15 species) present along transects when compared to other survey dates and was dominated by two speices of fish: *humuhumu'ele'ele* (41.3%, *M. niger*, black durgon) and *hīnālea lauwili* (17.3%, *T. duperrey*, saddle wrasse). The biomass in September (17.4 g/m^2, 89 individuals, 19 species) was the lowest of all four surveys (October: 30.6 g/m^2, 88 individuals, 18 species; November: 17.5 g/m^2, 47 individuals, 17 species). Surveys conducted from September through November at 7E were dominated by three species of triggerfish: *humuhumuhi'ukole* (September: 24.3%, October: 13.8%, November: 24.1%, *M. vidua*, pinktail durgon), *humuhumu'ele'ele* (September: 21.1%, October: 18.0%, November: 21.0%, *M. niger*, black durgon), and *humuhumulei* (September: 13.4%, October: 15.4%, November: 18.0%, *S. bursa*, lei triggerfish). *Na'ena'e* (28.4%, *A. olivaceus*, orangband surgeonfish) also contibuted greatly to the biomass in October. Overall, *hīnālea lauwili* (*T. duperrey*, saddlewrasse) was the most abundance species along 7E transect in July, while the Blackfin Chromis (*C. vanderbilti*) and *moano* (*P. multifasciatus*, manybar goatfish) was most abundant in September and October surveys, and the *moano* (*P. multifasciatus*, manybar goatfish) and *pili ko'a* (*Paracirrhites aractus*, arc-eye hawkfish) were most abundant in November.

Kahe 10C: Kahe station 10C had the highest average biomass, number of individuals and number of species in 2020 when compared to other Kahe transects (July: 66.2 g/m^2, 261 individuals, 21 species, September.: 64.3 g/m^2, 160 individuals, 25 species, October: 70.9 g/m^2, 197 individuals, 28 species, November:59.9 g/m^2, 272 individuals, 24 species. In all four surveys, *weke'ula* (*Mulloidichthys vanicolensis*, yellowfin goatfish) encompassed a significant portion of the biomass along 10C transect (July: 29.1%, September: 25.0%, October: 12.7, November: 16.3%). In July's survey, other contributors to the biomass were *ta'ape* (16.4%, *Lutjanus kasmira*, bluestripe snapper), *mamo* (11.9%, *A. Abdominalis*, sergeant major), and *humuhumu'ele'ele* (11.1%, *M. niger*, black durgon). In September (17.0%), October (32.0%), and November (30.3%), *mamo* (*A. vaigiensis*, Indo-Pacific sergeant) were also significant contibutors to the biomass. In November, another species of damselfish, *A. abdominalis* (15.3%, *mamo*, sergeant major), contributed greatly to the biomass. The fishes contributing most to fish abundance was *weke'ula* (*M. vanicolensis*, yellowfin goatfish), *hīnālea lauwili* (*T. duperrey*, saddle wrasse), and *mā'i'i'i* (*A. nigrofuscus*, brown surgeonfish).

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 2019 and 2020. The biomass at Nanakuli stations in 2019 (58 ± 39.9 g/m^2) and 2020 (52.0 ± 21.0 g/m^2) were within the range of variability. The average number of fishes (2019: 116 ± 74.2, 2020: 103.8 ± 17.2), and average number of species also remained similar (2018: 16 ± 4.6, 2019: 16.1 ± 3.8) (Figure 6). Similar to that of 2019 surveys, the most abundant fishes at Nanakuli group in 2020 were *māʻiʻi* (*A. nigrofuscus*, brown surgeonfish), *hīnālea lauwili* (*T. duperrey*, saddlewrasse), and *māikoiko (A. leucopareius*, whitebar surgeonfish) (Figure 10a), while *māikoiko (A. leucopareius*, whitebar surgeonfish) alone dominated the biomass (Figure 10b).
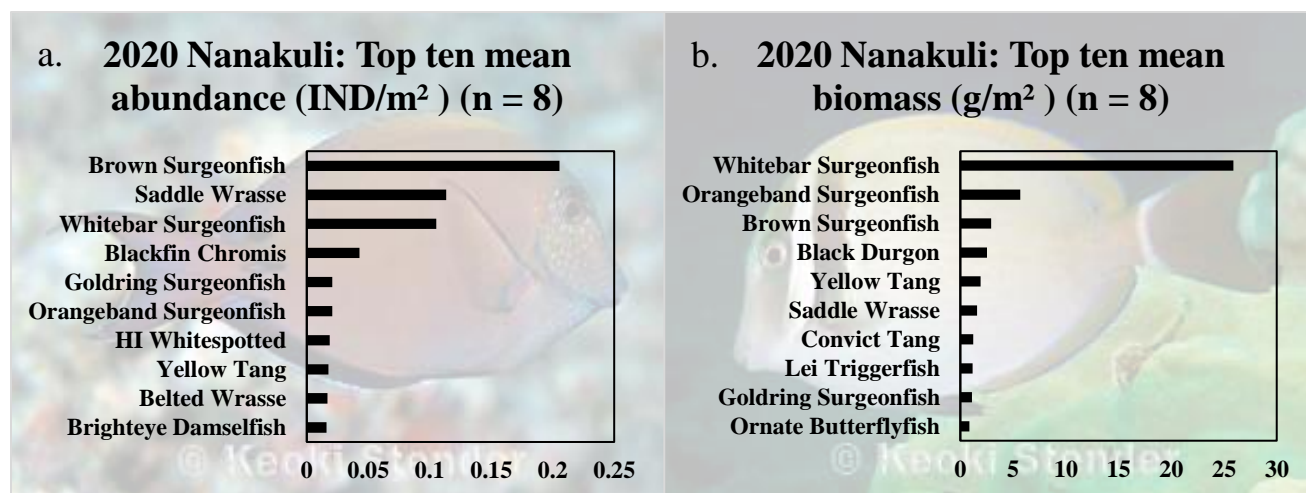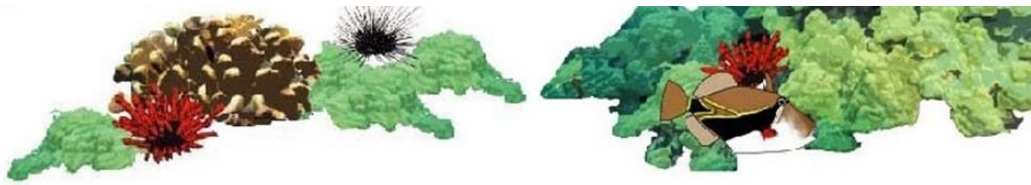

Figure 10. Top ten fish contributing to mean abundance and biomass at Nanakuli transect grouping in 2020 surveys.

NANA 1: Biomass, abundance and number of speices was lowest at NANA 1 transect when compared to all other transects surveyed but was not signifiacntly lower than surveys in 2019. During the July survey at NANA 1 (1.7 g/m^2, 73 individuals, 6 species), several species dominated the biomass: *hīnālea lauwili* (32.6%, *T. duperrey*, saddlewrasse), *ʻōmaka* (24.1%, *Stethojulis balteata*, belted wrasse), *moano* (19.9%, *P. multifasciatus*, manybar goatfish), and blackfin chromis (17.6%, *C. vanderbilti*). In September, biomass (3.4 g/m^2, 19 individuals, 6 species) was composed of *humuhumunukunukuapuaʻa* (46.6%, *Rhinecanthus rectangulus,* reef triggerfish), *hīnālea lauwili* (23.6%, *T. duperrey*, saddle wrasse) and *māʻiʻi* (17.0%, *A. nigrofuscus*, brown surgeonfish). Similarly, *humuhumunukunukuapuaʻa* (83.8%, *R. rectangulus*, reef triggerfish) and *hīnālea lauwili* (11.3%, *T. duperrey*, saddle wrasse) dominated the biomass in October surveys (2.8 g/m^2, 13 individuals, 6 species). November had the lowest biomass (0.46 g/m^2, 13 individuals, 6 species) of all quarterly surveys, which was dominated by *hīnālea lauwili* (37.9%, *T. duperrey*, saddle wrassse), Ambon Toby (30.1%, *Canthigaster amboinensis*), and *ʻōmaka* (19.8%, *S. balteata*, belted wrasse). In July, the most abundant fishes at NANA 1 transect were the blackfin chromis (*C. vanderbilti*). The bright-eye damselfish

(*Plectroglyphidodon imparipennis*) was common along September, October, and November surveys. Due to the low overall abundance of fishes, the most abundant fishes were not the same for each survey.

NANA 2: Despite their geographic similarity, the Nana 2 transect is consistently greater in all fish community factors (July: 129.5 g/m^2, 209 individuals, 23 species, September: 85.2 g/m^2, 130 individuals, 28 species, October: 138.9 g/m^2, 180 individuals, 30 species, November: 54.2 g/m^2, 128 individuals, 23 species. 75.3% 7%) when compared to the Nana 1 transect (Figure 6). NANA 2 transect did not differ in fish biomass, abundance or species diversity between survey years 2019 and 2020. The species responsible for the majority of the biomass at NANA 1 were dissimilar to those contributing to biomass at NANA 2. The biomass on all quarterly surveys was dominated by *māikoiko* (July: 64.7%, September: 38.1%, October: 50.3%, November: 38.9%, *A. leucopareius*, whitebar surgeonfish). In September (21.7%), October (12.6%), and November (12.1%), *na'ena'e* (*A. olivaceus*, orangeband surgeonfish) also significantly contributed to the biomass at NANA 2. The most abundant fishes along all transects were *māʻiʻi* (*A. nigrofuscus*, brown surgeongish), *māikoiko* (*A. leucopareius*, whitebar surgeonfish), *hīnālea lauwili* (*T. duperrey*, saddle wrasse), and *kole* (11.5%, *C. strigosus*, goldring surgeonfish).

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, Koʻolina, Kahe, and Nanakuli groups (Figure 6). The fish biomass in 2020 (362.0 ± 10.4 g/m^2) was significantly lower than the biomass in 2019 (610.8 ± 37.7 g/m^2) ($p = 0.029$) (Figure 6). However, the number of fish individuals and species diversity along Pipe transect did not change between survey years (2019: 1202 ± 36.7 individual fishes, 53 ± 2.9 fish species; 2020: 986.7 ± 81.0 individual fishes, 50.3 ± 2.1 fish species). Throughout the four 2020 surveys, Pipe transect stayed consistent in biomass, number of fish individuals and number of species present: July: 370.6 g/m^2, 934 individuals, 45 species, September: 379.3 g/m^2, 987 individuals, 52 species, October: 366.3 g/m^2, 1039 individuals, 54 species, and November: 331.9 g/m^2, 1299 individuals, 54 species.

During the July survey, *mamo* (24.5%, *A. vaigiensis*, Indo-Pacific sergeant), *taʻape* (13.8%, *L. kasmira*, bluestripe snapper), *mamo* (12.4%, *A. abdominalis*, sergeant major), and *weke* (11.6%, *M. flavolineatus*, yellowstripe goatfish) were responsible for the majority of the biomass. In September, the biomass was dominated by the invasive *taʻape* (18.4%, *L. kasmira*, bluestripe snapper), *weke* (16.7%, *M. flavolineatus*, yellowstripe goatfish), and *mamo* (10.8%, *A. vaigiensis*, Indo-Pacific sergeant). The October survey found no dominant fish species, with several species contibuting equally to the biomass: *weke* (12.5%, *M. flavolineatus*, yellowstripe goatfish), *hīnālea lauwili* (12.3%, *T. duperrey*, saddlewrasse), *taʻape* (11.6%, *L. kasmira*, bluestripe snapper), *mamo* (11.2%, *A. vaigiensis*, Indo-Pacific sergeant), and *ʻapi* (10.6%, *Acanthurus guttatus*, whitespotted surgeonfish). In November, *taʻape* (29.9%, *L. kasmira*, bluestripe snapper) dominated the biomass, followed by *mamo* (15.1%, *A. vaigiensis*, Indo-Pacific sergeant) and *hīnālea lauwili* (11.4%, *T. duperrey*, saddle wrasse). Combining all four survey timepoints, the most abundant fish species in number and biomass at Pipe transect were *taʻape* (*L. kasmira,* bluestripe snapper, invasive), *hīnālea lauwili* (*T. duperrey*, saddle wrasse),

mā'i'i'i (*A. nigrofuscus*, brown surgeongish), *weke* (*M. flavolineatus*, yellowstripe goatfish) and *weke'ula* (*Mulloidichthys vanicolensis*, yellowfin goatfish) (Figure 11).
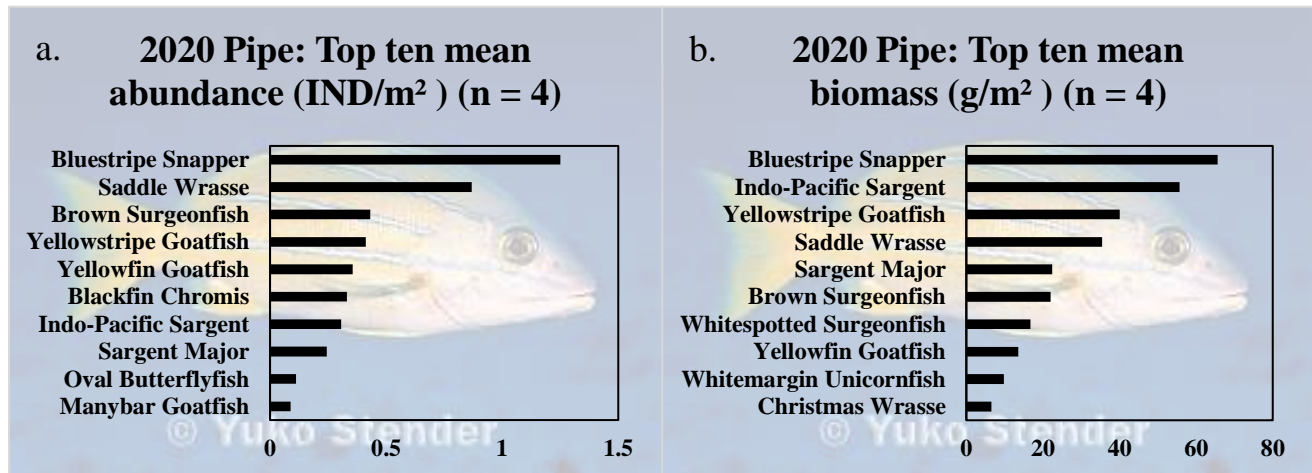

Figure 11. Top ten fish contributing to mean abundance and biomass at Pipe transect grouping in 2020.

SUMMARY

Fish communities remain similar from 2019 to 2020 surveys. The total number of fish species recorded in 2020 surveys (118 species) was similar to that of 2019 (110 species). The dominant species observed in 2019 were identical to those reported in 2020: brown surgeonfish (*mā'i'i'i*, *A. nigrofuscus*) and saddle wrasse (*hīnālea lauwili*, *T. duperrey*). Biomass is contributed mainly by the brown surgeonfish (*māi'i'i*, *A. nigrofuscus*), bluestripe snapper (*ta'ape, L. kasmira,* invasive), orangeband surgeonfish (*na'ena'e, A. olivaceus*), whitebar surgeonfish (*māikoiko, A. leucopareius*), saddle wrasse (*hīnālea lauwili*, *T. duperrey*), goldring surgeonfish (*kole, C. strigosus*), and Indo-Pacific sergeant (*mamo, A. vaigiensis*). Similarly, biomass in 2019 surveys was contributed mainly by the saddle wrasse (*hīnālea lauwili*, *T. duperrey*), brown surgeonfish (*māi'i'i, A. nigrofuscus*), whitebar surgeonfish (*māikoiko, A. leucopareius*), goldring surgeonfish (*kole, C. strigosus*), and yellowstripe goatfish (*weke, M. flavolineatus*). No significant shifts in trophic feeding guilds were observed between 2019 and 2020 surveys, however, herbivorous fishes did increase in biomass from 47% dominance to 60% dominance with no statistical significance. Of the fourteen transects, only the KGS Pipe experienced a significant decline in fish biomass since 2019. Despite the significant decline in fish biomass seen in 2020 surveys, Pipe transect has over three times the fish biomass of the site second highest in fish biomass (Ko' Olina 1). Excluding Pipe, which has the highest fish abundance and biomass, the Ko 'Olina 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. East, Kahe, and Nanakuli naturally have flatter reef that make the environment less favorable to well-developed fish communities. The 2020 surveys found no significant changes in fish communities that can be attributed to the Hawaiian Electric's KGS or CIP facilities.

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