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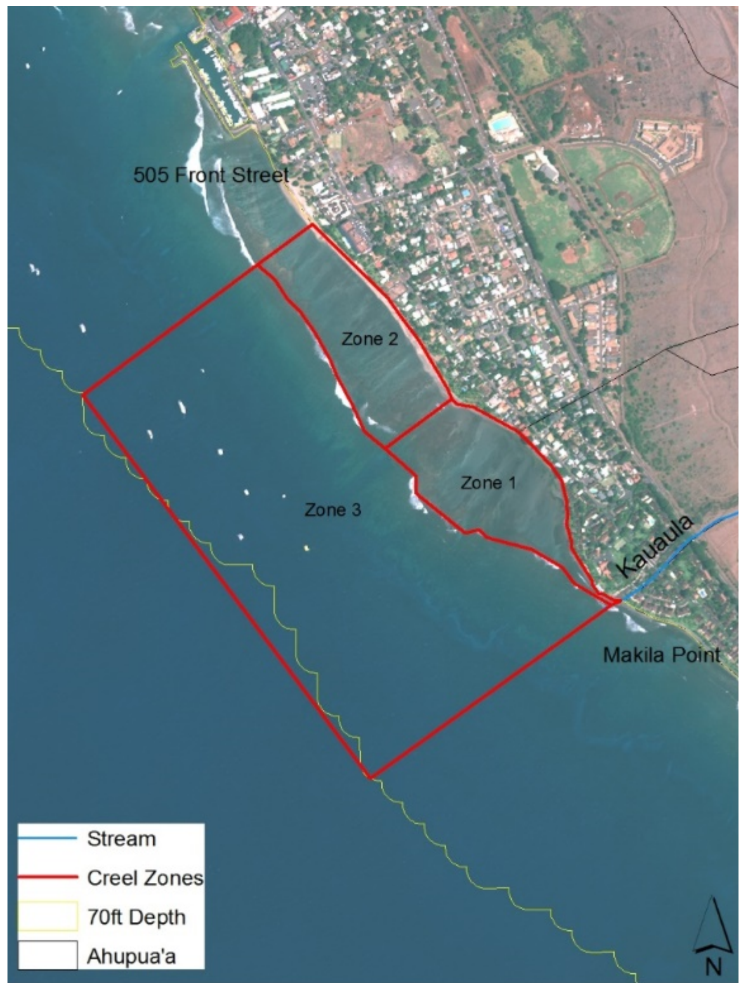

Polanui Hiu
Community Managed Makai Area

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(1) Polanui creel training; (2) Map of creel survey zones © TNC/Roxie Sylva

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NATIONAL FISH AND WILDLIFE FOUNDATION*

NOAA'S CORAL REEF CONSERVATION PROGRAM**

THE JOSEPH AND VERA LONG FOUNDATION

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EXECUTIVE SUMMARY

In the past, the west Maui reef of Nā Papalimu O Piʻilani in the ahupuaʻa of Polanui was thriving. Observing the depletion of fish and limu over time, the community gathered in an effort to return the reef to abundance, and in 2010 formed Polanui Hiu. In 2012, facilitated by The Nature Conservancy the Hiu completed a Community Action Plan to guide their efforts.

One of the first steps was to work with The Nature Conservancy from 2012-2014 to conduct a biological assessment of coral and reef fish that provided a baseline on the status of marine resources. The assessment confirmed the area had some of the lowest fish abundance and coral health compared to dozens of sites surveyed across the state.

With the biological data in hand, Polanui Hiu sought to understand what fishing and human uses were driving coral and reef fish declines to ensure targeted management actions can be taken. Thus, a Human Use and Creel Survey along a half-mile of shoreline in Polanui was planned using an intensive 8-day frame survey in July 2016 to develop a statistically rigorous survey design. A one-year survey was then implemented, with members of the community serving as the principle data collectors. Fishing catch and effort as well as recreational use of the area were recorded on 102 days and 45 nights between November 2016 and October 2017, with special emphasis on quantifying the numbers and sizes of herbivores harvested, since they are important to reef health. Summary findings are as follows:

NON-FISHING ACTIVITY

- Annual non-fishing recreational activities were 32 times greater than fishing effort, at 40,275 activity-hours.
- Swimming, stand-up paddling, kayaking, and surfing were the most common non-fishing activities.
- All common non-fishing activities had contact incidents with reef, totaling 906 reef contacts per year.
- Stand-up-paddling had the highest contact incident rate, followed by kayaking.
- The most used location for non-fishing activities was in close proximity to commercial-recreational operations and to the surf break.
- Most non-fishing activities were conducted in the spring, with the other three seasons having similar levels of non-fishing activity.
- Throughout the year, swimming occurred later in the day whereas other activities occurred earlier.

FISHING EFFORT

- Total annual fishing effort in Polanui was estimated at 1,242 hours in which gear were used (i.e., gear-hours) and 807 visits by individual fishers.
- July and November experienced the highest fishing effort.
- Spear fishing (both 3 prong and spear gun) and rod and reel fishing (dunking and whipping) were the two most common fishing methods.
- Night fishing rarely occurred.

CPUE AND CATCH

- Three-prong spear fishing was the most efficient fishing method at catching marine resources followed by spear gun, hand pole, and whipping.
- A total of 665 fish were estimated to be caught annually at Polanui.
- Dunking, hand pole fishing, and whipping caught primarily ʻoama (*Mulloidichthys* spp.) and papio (*Caranx* spp.).
- Spear fishing caught a greater diversity of organisms which consisted of both fish and invertebrates, including heʻe (*Octopoda* spp.) and slipper lobster (*Scyllarides squamsus*).

Contrary to the community's expectations that the survey would demonstrate high fishing effort, findings from the Polanui Human Use and Creel Surveys showed relatively low incidents of fishing and high incidents of non-fishing recreational use, especially stand-up paddling and kayaking. Polanui experiences less total fishing effort than other areas in Hawaiʻi where creel surveys have been conducted, which may be attributed to a variety of reasons: the Polanui survey area is smaller than most other study sites, fishers may go elsewhere due to the already low levels of fish biomass at Polanui, and the high levels of non-fishing activity that occur near popular tourist areas tend to scare away the fish. A major actionable finding was that these non-fishing uses were directly striking and damaging live coral in the inner reef area, contributing to reef degradation.

Given these findings, Polanui Hiu has since approached the State Division of Boating and Ocean Recreation and is working with neighboring commercial operators and surf schools to spread awareness of frequent reef contact made and encourage the use of the "Pono Pathway" through the sand channels so people are less likely to strike, fall on, and damage the already stressed corals.

While current fishing effort was lower than expected, fish stocks within the area remain severely depleted and the Hiu is taking action with the State Division of Aquatic Resources to design rules and a fisheries management area in the region.

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ACRONYMS AND DEFINITIONS

Apex predators	Species at the top of the food chain
Biomass	Weight of all fish
CMMA	Community Managed Makai Area
CPUE	Catch per unit effort
Gear-hr	Gear-hours, number of hours a (non)fishing gear was used
Gear-min	Gear-minutes, number of minutes a (non)fishing gear was used
Hiu	Call to action, and name of Polanui community group
Kūpuna	Elders
LCT	Large craft transport
Limu	Algae
NFWF	National Fish and Wildlife Foundation
NOAA	National Oceanic and Atmospheric Administration
Non-target fish	Fishes rarely targeted by fishers
Prime spawners	Target fish with the highest reproductive potential
SCT	Small craft transport
SCUBA	Self-contained underwater breathing apparatus
sp.	Singular species
spp.	Multiple species
SUP	Stand-up paddling
Target fish	Fishes highly prized and harvested by fishers
TNC	The Nature Conservancy

SCIENTIFIC (LATIN), ENGLISH, AND HAWAIIAN COMMON SPECIES NAMES

Scientific (Latin) Name	Common English Name in Hawaiʻi	Hawaiian Name
Acanthurus nigrofuscus	Brown surgeon	Māʻiʻiʻi
Acanthurus triostegus	Convict tang	Manini
Bothus sp.	Flounder	Pākiʻi
Caranx spp.	Jacks	Papio
Cephalopholis argus	Peacock grouper	Roi
Ctenochaetus strigosus	Goldring surgeonfish	Kole
Holocentridae spp.	Menpachi/Squirrel fish	ʻAlaʻihi
Lutjanus fulvus	Blacktail snapper	Toʻau
Mulloidichthys spp.	Goatfish < 7 inches	ʻOama
Octopoda spp.	Octopus	Heʻe
Parupeneus multifasciatus	Manybar goatfish	Moano
Priacanthus spp.	Bigeye	ʻĀweoweo
Rhinecanthus spp.	Triggerfish	Humuhumunukunukuāpuaʻa
Scarids	Parrotfish	Uhu
Scomberoides lysan	Leatherback	Lai
Scyllarides squamsus	Slipper lobster	Ula pāpapa
	Variety of algae	Limu

INTRODUCTION

Located 0.5 miles south of Lāhaina Harbor, the community of Polanui, through the grassroots group Polanui Hiu, created a Community Managed Makai Area (CMMA) in 2010 to better manage their coral reef resources. CMMAs are areas where coastal communities are involved in improved management of resources in collaboration with the State. Adjacent to a popular tourist destination, the Polanui CMMA is heavily used by both residents and visitors. The area consists of a mostly sandy and partially boulder beach with a shallow protected lagoon fronted by a fringing reef running roughly parallel to the shore (Fig. 1(A), pg. 4). The reef creates a popular surf break and the inshore lagoon area has calm waters conducive to shore fishing and snorkeling and is frequented by kayaks and stand-up paddleboards rented from nearby commercial ocean operators. The deeper offshore area receives much boat traffic and anchoring due to its proximity to Lāhaina Harbor.

Aerial image of Polanui, the reef Nā Papalimu O Piʻilani, and the survey area.

The reef Nā Papalimu O Piʻilani was once known for its abundance of fish and edible limu (algae). These resources, carefully tended by kūpuna (elders), sustained Lāhaina families for generations. But like other Hawaiian reefs adjacent to high population centers, it now shows signs of significant human impact associated with recreational use, overharvesting, sedimentation, and poor water quality. As resources and habitats disappear, so does the ecological knowledge and management practices used by Native Hawaiians for generations. Polanui Hiu intends to use the information from the Human Use and Creel Survey to help restore the resources and traditions once practiced in this area and spread awareness of detrimental human impacts to the reef.

ABOUT POLANUI HIU

Formed in October 2010, Polanui Hiu is comprised of local community members who are concerned about the decline of the area's marine environment and want to restore and protect important Hawaiian cultural resources through the perpetuation of traditional practices.

Polanui Hiu is building an engaged community of volunteer citizen scientists who help monitor reef fish populations, host educational events, and work to mitigate threats to water quality and the reef. From 2010-2012, facilitated by The Nature Conservancy (TNC), Polanui Hiu developed a Community Action Plan to prioritize marine species for protection, identify threats, and develop strategic actions for improving management. One of the first actions outlined in the Plan was to collect data on the status of the coral and reef fish of Nā Papalimu O Piʻilani to better understand the coral reef ecosystem and inform management decisions.

Polanui Hiu volunteers and The Nature Conservancy team after a monthly meeting and fish survey training.

STATUS OF CORAL REEF AT POLANUI

At Polanui Hiu's request, TNC conducted biological assessments of coral and reef fish in 2012, 2013, and 2014. In these surveys, TNC researchers measured the distribution and abundance of coral and reef fish at depths of 10-50 ft. These surveys concluded that Polanui had the lowest total fish biomass (weight of all fish) of all sites surveyed on the island of Maui and among the lowest of 40+ sites surveyed across the State of Hawaiʻi. While the biomass of non-target fish (fishes rarely targeted by fishers) was comparable to other areas, the biomass of target fish (fishes highly prized and harvested by fishers) and prime spawners (target fish with the highest reproductive potential) were among the lowest surveyed. Apex predators (species at the top of the food chain) were not observed during surveys in 2014 (Minton and Conklin 2016). These findings suggest fishing has had a substantial impact on fish populations at Polanui, where the consistency of these finding over multiple years is indicative of the relatively poor condition of the area's fish resources (Minton and Conklin 2016), and may be a factor in the decline of coral health.

Twelve species of coral were observed at depths of 10-50 ft and average coral cover was about 20%. Turf algae, which can smother or stress reefs, was common on hard bottom in shallow water. Sand and silt covered as much as 80% of the bottom at deeper sites. Several species of coral showed evidence of paling, bleaching, disease (e.g., growth anomalies), and "pink tissue," which is a characteristic response to stress (Minton and Conklin 2016). Compounding this stress, most reefs on Maui experienced severe coral bleaching in 2015, including the Polanui area, which TNC has since monitored for coral bleaching recovery and resilience. Since 2016, the volunteer-powered water quality monitoring partnership, Hui O Ka Wai Ola, has repeatedly measured high sediment levels in the shallow waters of Polanui (Falinski *et al*. 2018), which can be detrimental to coral reef health. Around the same time frame, Polanui Hiu observed an increase in recreational activities, putting additional stress on the reef.

HUMAN USE AND CREEL SURVEY

With evidence of significant fishing pressure compounded by increasing stresses from recreational use, warming ocean temperatures, and degraded water quality, Polanui Hiu needed quantitative information on just how much of what types of activities were impacting the CMMA area so that they could focus their management efforts on the highest priority threats. To obtain this information, TNC and Polanui Hiu enlisted the assistance of Haruko (Hal) Koike PhD. of Science Projects Quality Resources, formerly with the Cooperative Fisheries Unit, University of Hawaiʻi, to design and conduct a one-year Polanui Human Use and Creel Survey. This survey, conducted from November 2016 to October 2017, improves understanding of how recreational activities and fishing pressures impact the area, and its results will help Polanui Hiu develop proposed rules for improved and effective management of their coral reefs and reef fisheries. Polanui Hiu is one of few areas in the state to conduct human use and creel surveys and is so far the only one that captures nighttime activity.

PROCESS AND METHOD

SURVEY DESIGN, PROCESS & DATA COLLECTION

The human use assessments were designed to record data on how many people are utilizing the coastal area in what ways, where those activities occurred, and where and how many activities involved reef damage. The creel assessments recorded data on fishing effort and harvest, including the number of fishers, types of gear, duration of fishing events, and, if possible, the quantity, species, and size of catch. Special emphasis was placed on quantifying the numbers and sizes of herbivores harvested, since they are important to reef health through their ability to control the growth of algae that could otherwise compete with corals for reef habitat.

Five surveyors affiliated with Polanui Hiu were contracted through Pono Pacific Ecosystem Restoration Services and trained by Dr. Koike to assist with data collection and input. TNC staff and Polanui Hiu worked with Dr. Koike to map three survey zones (Fig. 1(B)) and to conduct an intensive 8-day frame survey, which collected human use and fishing data day and night from July 9 to 16, 2016. The frame survey data was used to develop an optimized sampling design for the year-long human use and creel survey.

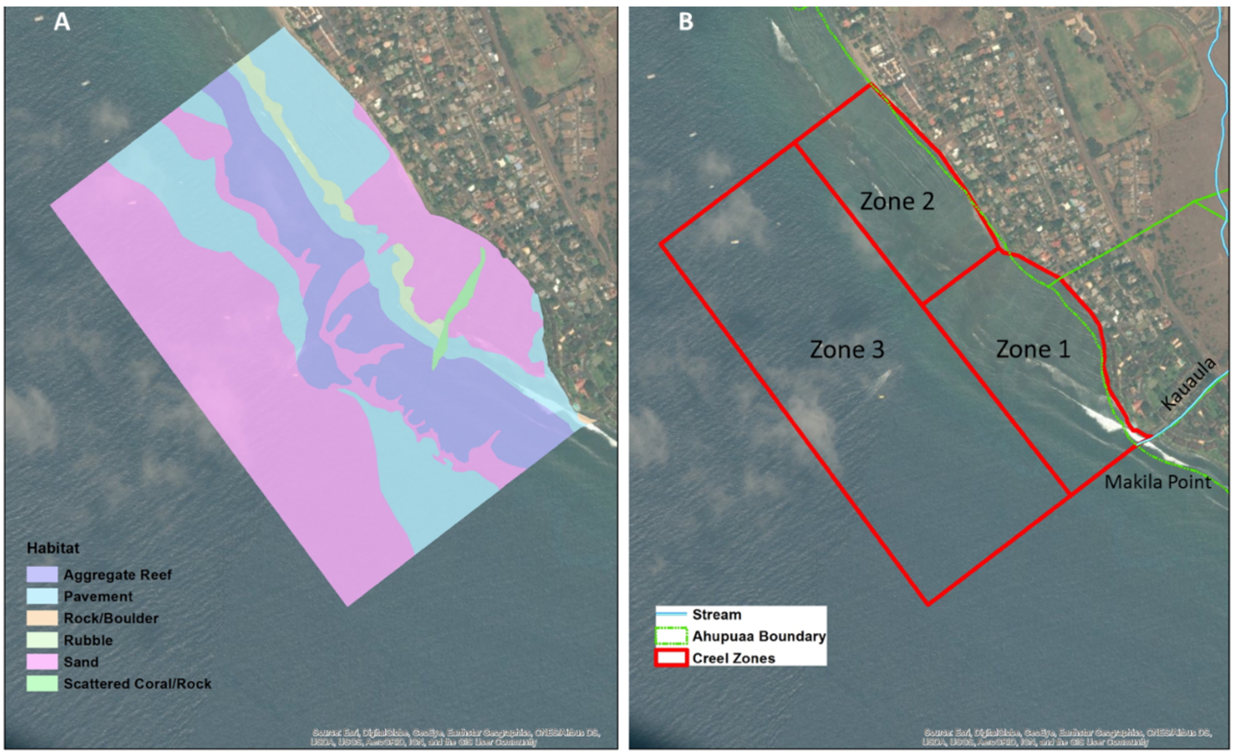

Figure 1. (A) NOAA benthic habitat map of survey area; (B) Polanui survey area with zones.

Results from the frame survey indicated that seven to 11 daytime (6 am to 6 pm), and two to five nighttime (10 pm to 1 am) surveys per month would provide a statistically rigorous characterization of the range of activities within the survey area during the survey period (Fig. 2, pg. 14). A software program was used to randomly select dates for daytime surveys each month. The frame survey also indicated that nighttime fishing was too inconsistent to be effectively surveyed in a randomized fashion, so survey nights were selected with help from Polanui Hiu community members to coincide with periods of the new moon and low tides, the times with greatest nighttime fishing effort. It was thought that most of the catch within the survey area would be occurring at night, when some herbivore species are asleep (Reebs 1992) and thus easier to catch, especially with spears.

Surveys were conducted from a central observation point that allowed surveyors to observe most activities in the three zones. Any areas not visible from the observation point were checked on foot every 20 minutes. During each 20-minute survey period, surveyors used a data sheet to record the start and end time of all activities observed, the zone in which it occurred, number and type of gear used, number of people involved, presence/absence of illegal practices, and whether an activity involved any reef damage. Reef damage occurred when people and/or their gears contacted or struck corals either above or below water. Surveyors also attempted to interview all fishers upon completion of each fishing event. If fishers were receptive, they were interviewed to record their demographic information, their reason for fishing at Polanui, and to record the species, number, size, and weight of their catch. All data collected were entered into a custom designed Microsoft Excel workbook and sent to Dr. Koike, who conducted a Quality Assurance/Quality Control Assessment of the data prior to final analysis.


Photo: Bruce Forrester

Surveyor Ekolu Lindsey recording activities from a central observation point.

DATA ANALYSIS

NON-FISHING ACTIVITY

Non-fishing recreational activity was measured in gear-hours (hr) where the length of the activity in hours was multiplied by the number of gears (kayaks, stand-up paddleboards, etc.). For the calculations, each swimmer was considered to be using one "gear" although this activity does not typically use any equipment. Each non-fishing activity observed during any 20-minute survey block was assumed to last 20 minutes. The activity time in gear-minutes (min) was summed for each day to calculate the daily total gear-min for each activity, month, and zone, and was calculated using the following equation (4):


Photo: Polanui Hiu

Visitors on kayaks and stand-up paddleboards at Polanui's nearshore reef.

$$Daily\ Nonfishing\ Activity\ (gear\_min) = \frac{\sum_{month}\sum_{day} 20\ min * number\ of\ gears}{\#\ of\ survey\ days_{month}} \ldots (4)$$

The estimated average daily gear-min was then divided by 60 minutes to convert into gear-hours and multiplied by corresponding days in the month to estimate monthly effort in gear-hours for each non-fishing activity type. Annual gear-hours for each non-fishing activity in each zone was calculated by summing all the monthly gear-hours. Daily average number of users recorded for each observation time block was examined across seasons. Each season was defined as follows: spring (February, March, April), summer (May, June, July), fall (August, September, October), and winter (November, December, January).

REEF CONTACT INCIDENT RATE

Surveyors noted any time a non-fishing activity came in contact with the reef, referred to as a reef contact incident. The survey assumed all reef contact incidents were observed and calculated the average daily reef contact incident rate for each activity type and zone using the following equation (5):

$$Daily\ Contact\ Incident\ Rate = \frac{\sum_{zone}\sum_{day} number\ of\ incidence}{\#\ of\ survey\ days_{month}} \quad \ldots (5)$$

The estimated daily incident rate was then multiplied by 365 days to estimate the annual reef contact incident rate for each zone.

FISHING EFFORT

The average daily fishing effort was calculated for each gear type per month using the following equation (1):

$$Daily\ Fishing\ Effort\ (gear\_hr) = \frac{\sum_{month}(\#\ of\ gears \times length\ of\ fishing\ (\mathrm{hr}))_{fishing\ event}}{\#\ of\ survey\ days_{month}} \quad \ldots (1)$$

The mean daily fishing effort per month in gear-hours was multiplied by the number of days in the month to estimate monthly fishing effort in gear-hours for each gear type. Each fishing activity observed during any 20-minute survey block was assumed to last 20 minutes. Total fishing effort for the entire year (annual fishing effort) was calculated by summing fishing effort for all the months and gear types. The confidence interval for annual fishing effort was calculated using a Monte Carlo simulation where each month's fishing effort per gear type was simulated and totaled to calculate annual fishing effort 500 times.

The average daily number of fishers was calculated for each gear type per month, and was calculated using the following equation (2):

$$Daily\ Fisher\ Count = \frac{\sum_{month}(fisher\ counts)_{fishing\ event}}{\#\ of\ survey\ days_{month}} \ldots (2)$$

The mean daily fisher count per month was multiplied by the number of days in the month and summed for all months to estimate annual fisher counts for each gear type.

Catch per unit effort (CPUE) was calculated using the number of fish caught and not fish biomass because catch biomass data were too few to reliably estimate the CPUE. CPUE for each gear type was calculated using the following equation (3):

$$CPUE\ (\#/gear\_hr\ ) = \frac{\sum_{event} \frac{\sum_{fishing\ event} \#\ of\ fish\ caught}{fishing\ effort\ (gear\_hr)_{fishing\ event}}}{\#\ of\ Fishing\ Event} \ldots (3)$$

Total annual catch for each gear type was estimated by multiplying the CPUE for each gear type by the corresponding annual fishing effort (in gear-hours). For species catch composition, the number of fish caught was summed by gear type and species.

RESULTS

SURVEY EFFORT

A total of 102 days and 45 nights were surveyed between November 2016 and October 2017. In each month there were seven to 11 daytime and two to five nighttime surveys (Fig. 2, pg. 14).

NON-FISHING ACTIVITY

A total of 40,275 gear-hours of non-fishing recreational activities were estimated for Polanui, which is 32 times greater than the annual fishing effort for the area (Table 5, pg. 15). Swimming, stand-up paddling (SUP), kayaking, and surfing were the most common activities. Zone 2 had the highest non-fishing activity use (Fig. 3, pg. 14), due to its proximity to commercial-recreational operations and access to the surf break; with the most common activity being swimming, followed by SUP. Zone 3 was the second most heavily used area, where most of the surfing occurred due to the presence of the surf break (Fig. 3). SUP and kayaking were less frequent in zone 3 due to deeper and rougher waters, as most users are beginners. Little non-fishing activity occurred in zone 1, the shallow zone farthest from Lāhaina (Fig. 3).

Visitors on stand-up paddleboards in zone 2.

Spring had the highest non-fishing activity use, while the other 3 seasons had similar levels of use (Fig. 4, pg. 16). Throughout the year, swimming occurred later in the day compared to the three other common activities (SUP, kayaking, surfing) (Figs. 4 and 5, pg. 16). SCUBA diving was relatively rare and observed primarily in the spring and winter and towards the end of the day in zone 3 (Fig. 4).

REEF CONTACT INCIDENT RATE

Non-fishing activities had a contact incident rate with the reef of 906 contacts per year. All common non-fishing activities (SUP, kayaking, swimming, surfing) resulted in some level of reef contact. SUP and kayaking had the highest contact incident rate (Fig. 6, pg. 17). Zone 2 had the highest contact incident rate, which was not surprising considering most non-fishing activities occurred in this zone. Reef contact incident rate for SUP and kayaking appeared to be correlated with the peak use time per gear (Figs. 5 and 7, pgs. 16 and 17).

FISHING EFFORT

The total annual fishing effort was 1,242 gear-hours (95% Confidence Interval: 1195-1292), with 807 fisher-visits annually (Table 1). Expanded monthly fishing effort showed that July received nearly 2.5 times more fishing effort (both in gear-hours and number of fishers) than November, the next busiest month (Figs. 8 and 9, pg. 18). July fishing effort was dominated by pole fishing, which comprised 87.6% of the effort. In contrast, 72.9% of the November fishing was spear fishing (Fig. 8). Spear fishing (both 3-prong and spear gun) and pole fishing (dunking and whipping) were the most common fishing methods at Polanui, followed by hand pole and throw-net (Table 1).

Table 1. Annual estimated fishing effort in gear-hours with 95% confidence interval and fisher counts for each fishing method.

Gear Type	*Fishing Method*	*Gear-hours*	*95% CI*	*Fisher Counts*
Spear	3 prong (snorkel)	228.50	220-236	215
Spear	Spear Gun (snorkel)	226.44	202-252	122
Spear	Diving	6.46	6-7	11
Pole	Dunking	353.22	319-386	79
Pole	Whipping	214.12	205-224	218
Pole	Hand Pole	106.87	96-118	36
Pole	Fly Fishing	7.10	6-8	4
Net	Throw Net	74.00	68-80	61
Net	Scoop Net / Dip Net	7.10	6-8	14
Trolling	Trolling	18.43	16-22	47
	TOTAL	**1242.00**	**--**	**807**

Spear fishing was rarely observed using SCUBA, likely due to the shallow water in the nearshore lagoon area and the presence of the shallow reef blocking easy access to deeper water. Night fishing was also rarely observed; only two spear fishing events totaling two gear-hours occurred during the entire duration of the survey (Fig. 8). Night survey dates were selected to maximize the detection of net fishing events, leading to the conclusion that nighttime fishing did not frequently occur at Polanui during the survey period. However, the community observed high levels of nighttime fishing before and after the human use and creel survey was conducted.

Zone 2, the shallow-water zone closest to Lāhaina, had the most fishing effort followed by zone 1, the southeastern shallow zone (Fig. 10, pg. 19). Zone 2 showed similar effort in both pole fishing and spear fishing, whereas zone 1 was mostly pole fishing. Net fishing occurred in both zone 1 and 2 but was not common. Zone 3, in the deeper waters, showed mostly spear fishing with some pole fishing, and to a lesser degree troll fishing, a gear unique to zone 3 (Fig. 10).

CATCH PER UNIT EFFORT (CPUE)

Spear fishing with 3 prong was the most efficient fishing method for catching fish and invertebrates, followed by spear gun, hand pole, and whipping (Table 2). In contrast, fly fishing, scoop/dip netting, and trolling all had zero CPUE (Table 2), but this should be viewed with caution due to the small sample sizes (<18.4 gear-hours and 3 events). Throw netting also had zero CPUE, but the gear had a moderate level of use in the area (74 gear-hours over 17 events).

Table 2. Estimated catch calculated by multiplying CPUE and fishing effort. The table includes average catch per unit effort (CPUE) (#/gear-hours), number of fishing events (n) observed, estimated annual fishing effort (in gear-hours), and estimated annual catch (number of fish) for each gear type.

Gear Type	*Fishing Method*	*CPUE (#/gear-hr)*	*n*	*Fishing Effort (gear-hr)*	*Catch in #*
Spear	3 prong (snorkel)	1	41	228.5	229
Spear	Spear Gun (snorkel)	1	14	226.4	226
Pole	Hand Pole	0.7	8	106.9	75
Pole	Whipping	0.3	51	214.1	64
Pole	Dunking	0.2	19	353.2	71
Pole	Fly Fishing	0	1	7.1	0
Net	Scoop Net / Dip Net	0	3	7.1	0
Net	Throw Net	0	17	74	0
Trolling	Trolling	0	2	18.4	0
	TOTAL	**--**	**156**	**1235.7**	**665**

CATCH

The total number of fish and invertebrates caught in the survey area was estimated to be 665 per year (Table 2, pg. 9). Gear-specific species catch showed dunking, hand pole, and whipping predominately caught ‘oama (*Mulloidichthys* spp.) and papio (*Caranx* spp.) (Fig. 11, pg. 19). Whipping additionally caught flounder (*Bothus* sp.), moano (*Parupeneus multifasciatus*), and to‘au (*Lutjanus fulvus*). The catch obtained through spear fishing with 3 prong was more diverse, consisting of both fish and invertebrates including he‘e (*Octopoda* spp.) and slipper lobster (*Scyllarides squamsus*) (Fig. 11).

Throw net fisher at Polanui.

Most catch came from zone 2, likely due to higher fishing effort there (Fig. 12, pg. 20). In the shallower areas (zone 1 and 2) ‘oama was the predominant catch from July to September (Figs. 12 and 13, pg. 20). In the deeper area (zone 3), catch included roi (*Cephalopholis argus*), ‘āweoweo (*Priacanthus* spp.), to‘au (*Lutjanus fulvus*), and humuhumunukunukuāpua‘a (*Rhinecanthus* spp.), whereas in the shallower areas, fishers caught a more diverse range of species (Fig. 12).

DISCUSSION

Polanui experiences less total fishing effort than other areas in Hawai‘i where human use and creel surveys have been conducted (Table 3 and Delaney *et al*. 2017, pg. 11), which may be attributed to a variety of reasons: the Polanui survey area is smaller than most other study sites where fishing effort data has been collected, fishers may go elsewhere due to the already low levels of fish biomass at Polanui, and the high levels of non-fishing activity that occur near popular tourist areas tend to deter the fish.

Although the total annual fishing effort was small, the survey detected a seasonal pattern in fishing for some species. For example, the survey detected intense summer fishing for ‘oama, with peak pole fishing occurring in July. ‘Oama fishing is a popular summer fishing activity in Hawai‘i (Koike *et al*. 2014), when these juvenile goatfish recruit to the reef in large numbers. ‘Oama prefer shallow sandy bottom habitat (Donovan *et al*. 2016), such as the nearshore areas of zones 1 and 2, making Polanui an ideal habitat and nursery grounds for ‘oama.

Comparison of the CPUE at Polanui with other human use and creel surveys in Hawai‘i is problematic because those studies estimate effort from fish biomass, whereas catch number was used at Polanui because biomass data were too few to reliably estimate the CPUE. However, since most of the fishes caught by pole fishing were ʻoama, a single fish caught by pole likely had a biomass of approximately 0.1 kg. Making this assumption allows us to calculate an estimated CPUE for pole fishing at Polanui of approximately 0.04 kg/gear-hours, a CPUE similar to Waikīkī (Table 4 and Delaney *et al*. 2017). These two sites show similarity in habitat, where the shallow coral reef habitat has been affected by heavy recreational non-fishing activities.

Table 3. Modified table from Delaney *et al*. 2017. Location and estimates of fishing effort for three shore-based gear types (gear-hours). Current study (Polanui, Maui) added.

Location	Pole	Net	Spear
Polanui, Maui	700	81	455
Hanalei, Kauaʻi	15,850	5,370	397
Kahekili, Maui	3,925	108	2,857
Kailua, Oʻahu	3,867	106	2,184
Wailuku, Maui	15,701	2,192	719
Pupukea, Oʻahu	3,685	5	1,511

Table 4. Modified table from Delaney *et al*. 2017. Location and catch per unit effort (CPUE) estimates in kg/hour for three shore-based fishing gear types (pole, net, and spear fishing). Current study (Polanui, Maui) added.

Location	Pole	Net	Spear
Polanui, Maui	0.04	NA	NA
Hanalei, Kauaʻi	0.07	0.96	0.87
Kahekili, Maui	0.09	0.03	0.30
Waikiki, Oʻahu	0.04	NA	1.13
Wailuku, Maui	0.12	0.14	0.22
Kaʻūpulehu, Hawaiʻi	0.23	0.39	0.51

Of the human use and creel surveys conducted in Hawaiʻi, this project was the first to conduct nighttime creel surveys. Nighttime fishing is widely believed to be a source of substantial fish harvest from reefs in Hawaiʻi, since many prized reef fish are sleeping and more easily located and collected at this time. Despite community observations of frequent nighttime spear fishers prior to the survey, this study found that nighttime fishing at Polanui was relatively rare during the survey period. It is possible that the surveyors acted as a deterrence to fishing activity (*pers. comm. with the surveyors*). This is supported by reports from community members who observed nighttime spear fishers soon after the survey ended. It is possible, therefore, that this study underestimates the extent of nighttime fishing activity, as well as annual harvest from the area.

However, even if some forms of fishing effort may have been underestimated here, it is clear that non-fishing activities have become far more common at Polanui, with over an order of magnitude more recreational non-fishing use than fishing use of the area. This intensive use of the relatively small area of the Polanui reef is likely to have a number of impacts on reef condition, with the number of reef contact incidents being raised as an important concern by Polanui Hui.

Although damage caused to the reef by the contact and collisions associated with non-fishing activities observed in this study are estimated to be individually relatively small, the accumulated damage of 900+ incidents per year could have significant negative impacts on coral health. Rodgers and Cox (2003) showed that large numbers of swimmers are capable of causing significant damage on Hawaiian reefs through direct contact (i.e., trampling). Damage at Hanauma Bay, a popular swimming and snorkeling area on the island of Oʻahu, resulted in management changes to reduce degradation at the popular tourist destination.

The consequences of reef damage caused by these types of interactions are also likely to increase over time. With warming oceans causing additional stress to corals, bleaching events already documented to impact the health of corals on the Polanui reef, and research showing that physical damage to corals can catalyze the spread and development of coral diseases (Haapkylä *et al*. 2013), minimizing the stress and human induced damage to corals is ever-more important. Reducing the number of contact incidents would likely improve reef conditions and lower stress on the marine ecosystem at Polanui.

The incident data for this survey shows that collisions happen throughout the day, likely indicating that it is related to tide height. Since most incidents happen in zone 2, where stand-up paddling and kayaking commonly occurs, identifying and avoiding vulnerable areas in this zone could be an effective approach to minimizing damage.

OUTCOMES

This study has helped Polanui Hiu gain a better understanding of human use and how it impacts the coral reef ecosystem of Nā Papalimu O Piʻilani. Spurred by the high level of reef contact incidents measured in this survey, the group has approached the State Division of Boating and Ocean Recreation and is working with neighboring surf schools to address concerns and provide guidance on recreational and coral reef management in the area. To date, Polanui Hiu has provided a “Pono Pathway” map as a navigational aid for surf schools to avoid coral reef areas by routing through sand channels, especially during the morning low tides. In addition to the map, Polanui Hiu is interested in setting up small buoys along the sand channel to provide a visual aid to indicate safe passage areas for recreational groups with or without a guide.

While fishing effort and catch quantified here were lower than expected, fish size and abundance at Polanui remain far below historical levels. To facilitate recovery of these vital fisheries resources and improve reef ecosystem function at Polanui, Polanui Hiu is working with the State Division of Aquatic Resources on designating a fish management or replenishment area along with proposed rules.

CITATIONS

Delaney, D.G., Teneva, L.T., Stamoulis, K.A., Giddens, J.L., Koike, H., Ogawa, T., Friedlander, A.M., and Kittinger, J.N. 2017. Patterns in artisanal coral reef fisheries reveal best practices for monitoring and management. PeerJ PrePrints.

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Reebs, S. 1992. Sleep, inactivity and circadian rhythms in fish. In Rhythms in fishes. pp. 127-135. Springer, Boston, MA.

Rodgers, K. S. and Cox, E. F. 2003. The effects of trampling on Hawaiian corals along a gradient of human use. Biol. Conserv. 112: 383-9.

SUPPLEMENTAL INFORMATION

Figure 2. Number of surveys (daytime and nighttime) conducted for each month.

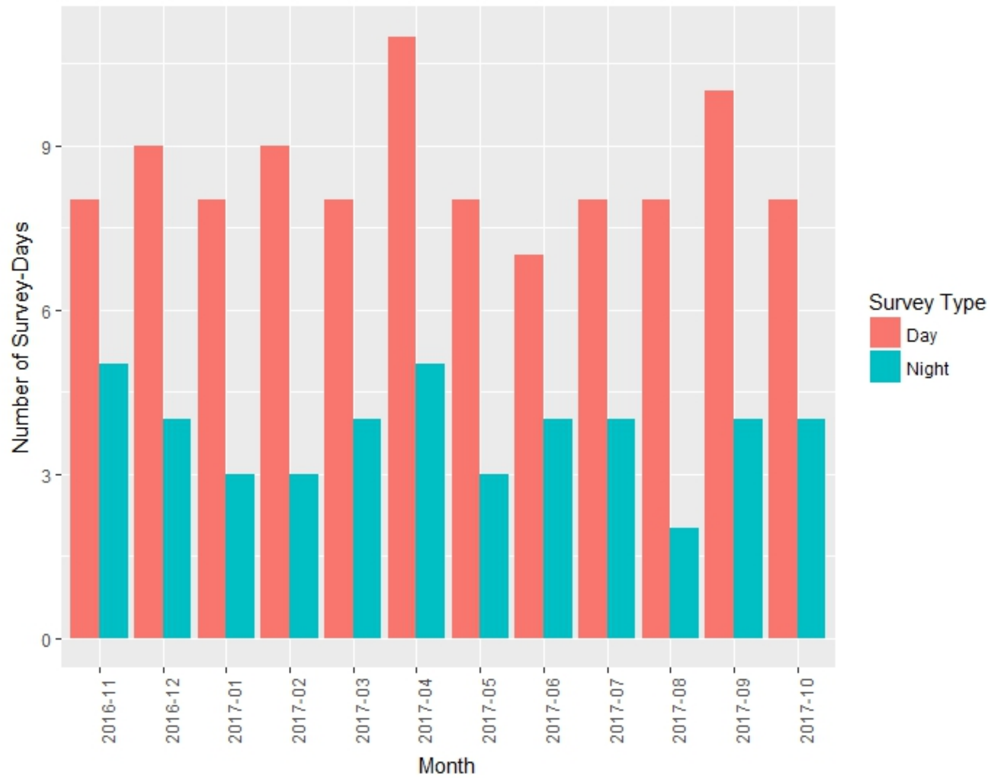

Figure 3. Estimated annual non-fishing activity in gear-hours for each activity and zone.

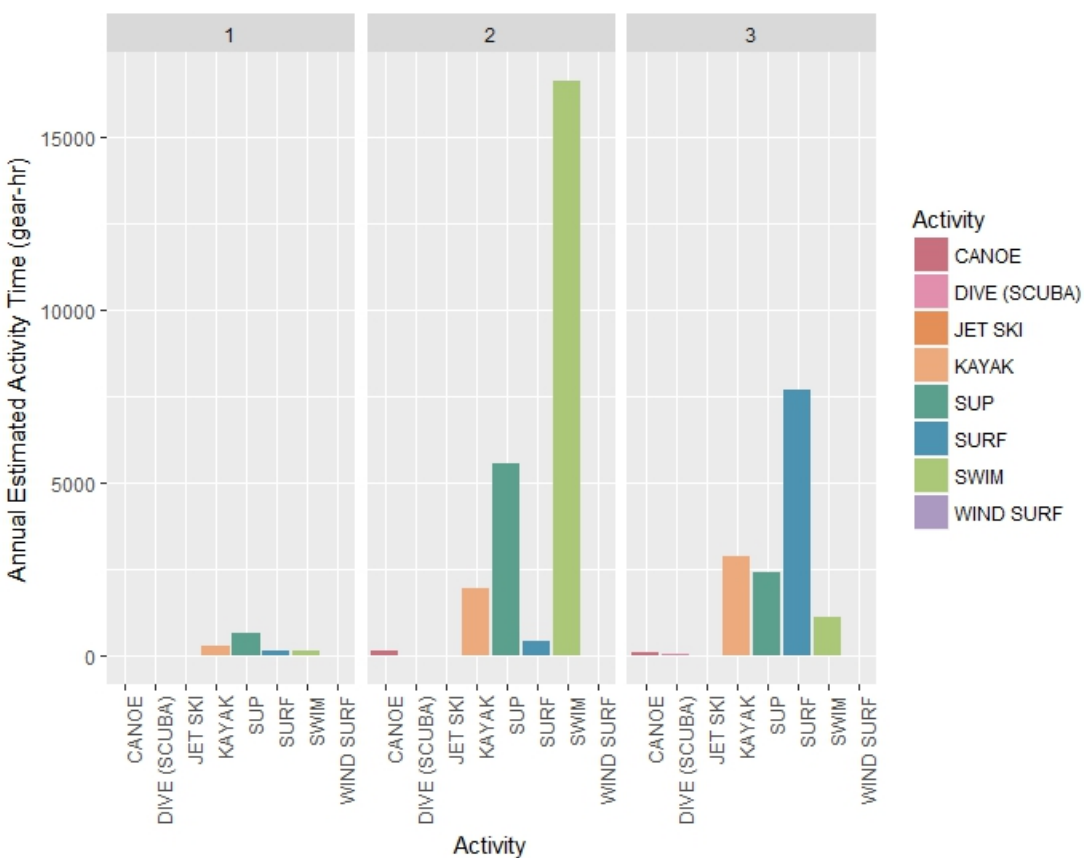

Table 5. Estimated annual non-fishing activity time in gear-hours by activity type for each zone (corresponds to Fig. 5).

Zone	Activity	Annual Activity Time (gear-hours)
1	SUP	666
1	KAYAK	271
1	SWIM	174
1	SURF	142
1	DIVE (SCUBA)	9
1	CANOE	3
1	JET SKI	0
1	WIND SURF	0
2	SWIM	16,599
2	SUP	5,549
2	KAYAK	1,943
2	SURF	446
2	CANOE	148
2	WIND SURF	3
2	JET SKI	0
2	DIVE (SCUBA)	0
3	SURF	7,709
3	KAYAK	2,886
3	SUP	2,420
3	SWIM	1,139
3	CANOE	112
3	DIVE (SCUBA)	51
3	JET SKI	5
3	WIND SURF	>1
	TOTAL	40,275

Figure 4. The daily average number of users engaged in non-fishing activity recorded for each 20-minute observation survey block per season. The height of all activities represents the total average number of users engaged in non-fishing activities. Seasons are defined as follows: spring (February, March, April), summer (May, June, July), fall (August, September, October), winter (November, December, January).

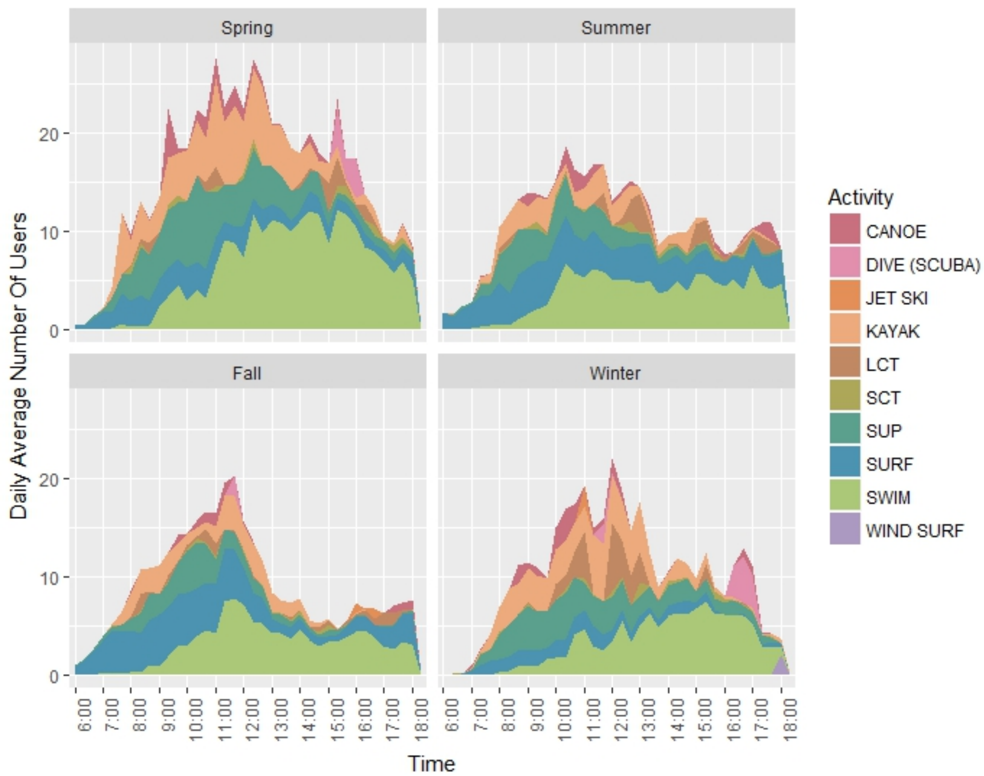

Figure 5. The four most common non-fishing activities recorded for each observation time block throughout the year.

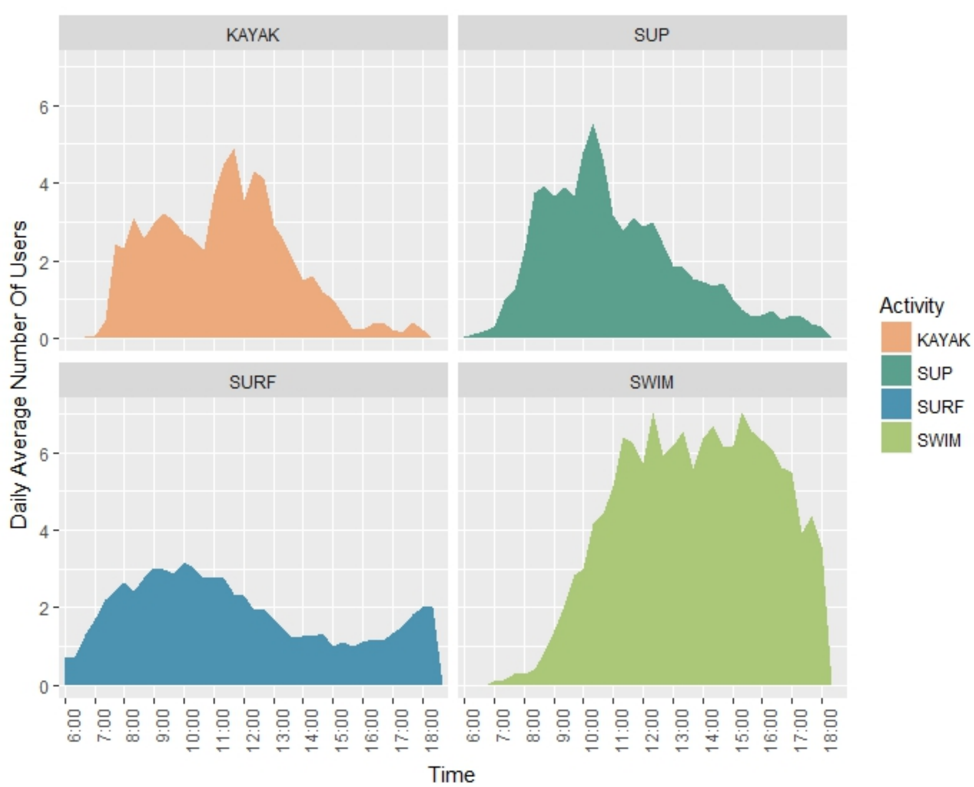

Figure 6. Annual number of reef contact incidents caused by each activity type estimated for each zone.

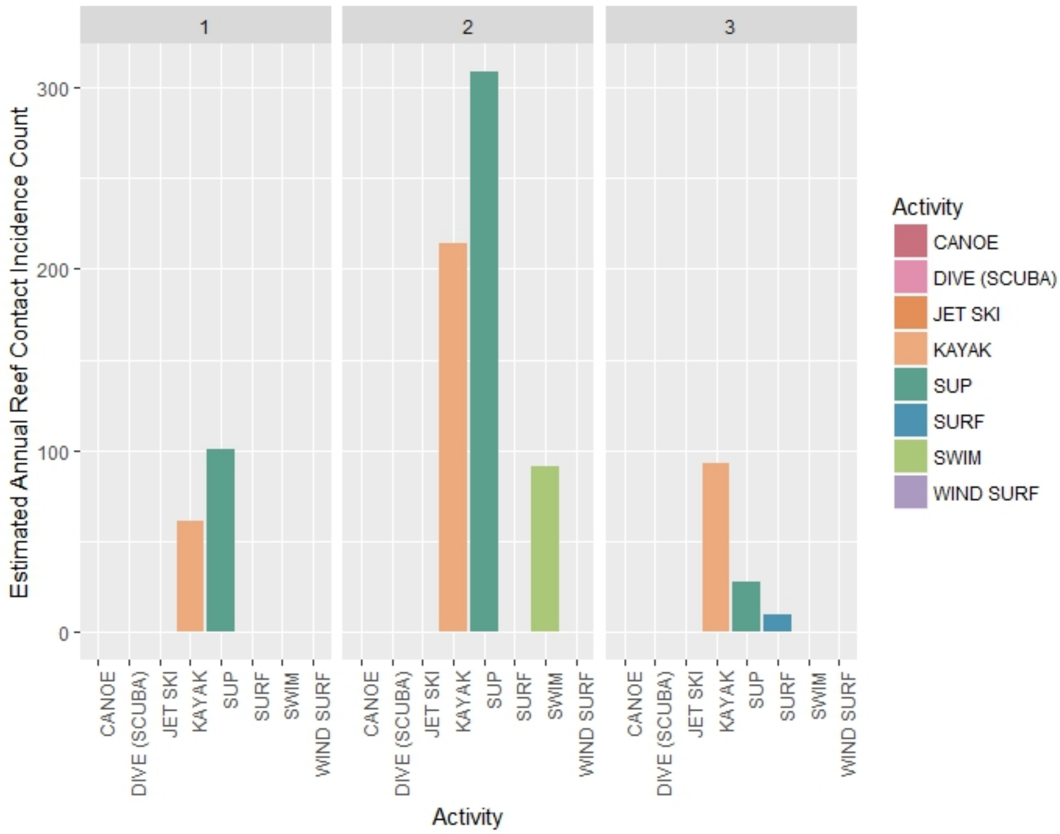

Figure 7. Daily average time and count when reef contact occurs for the four most common non-fishing activities at Polanui.

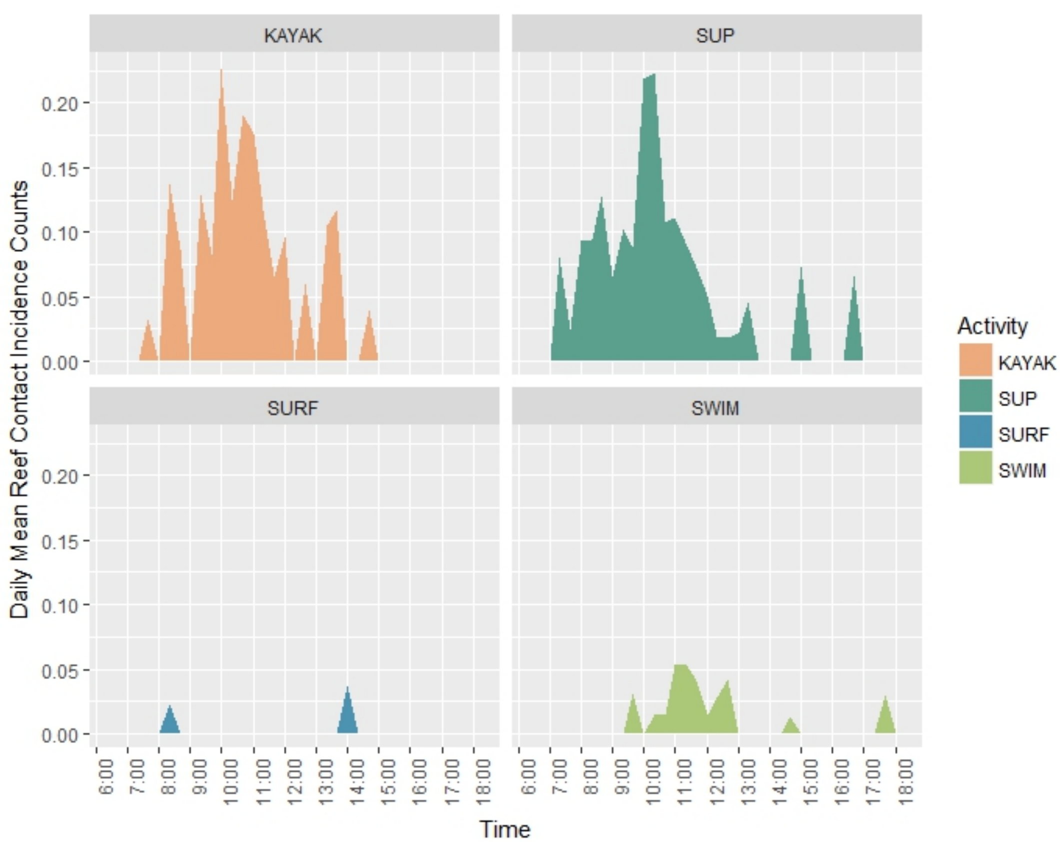

Figure 8. Estimated monthly fishing effort in gear-hours by gear type. Each fishing gear type includes the following fishing methods: Net (surround netting, dip netting, throw netting), Pole (dunking, whipping, hand pole, and fly fishing), Spear (3 prong, spear gun, and diving), and Trolling (trolling from a boat).

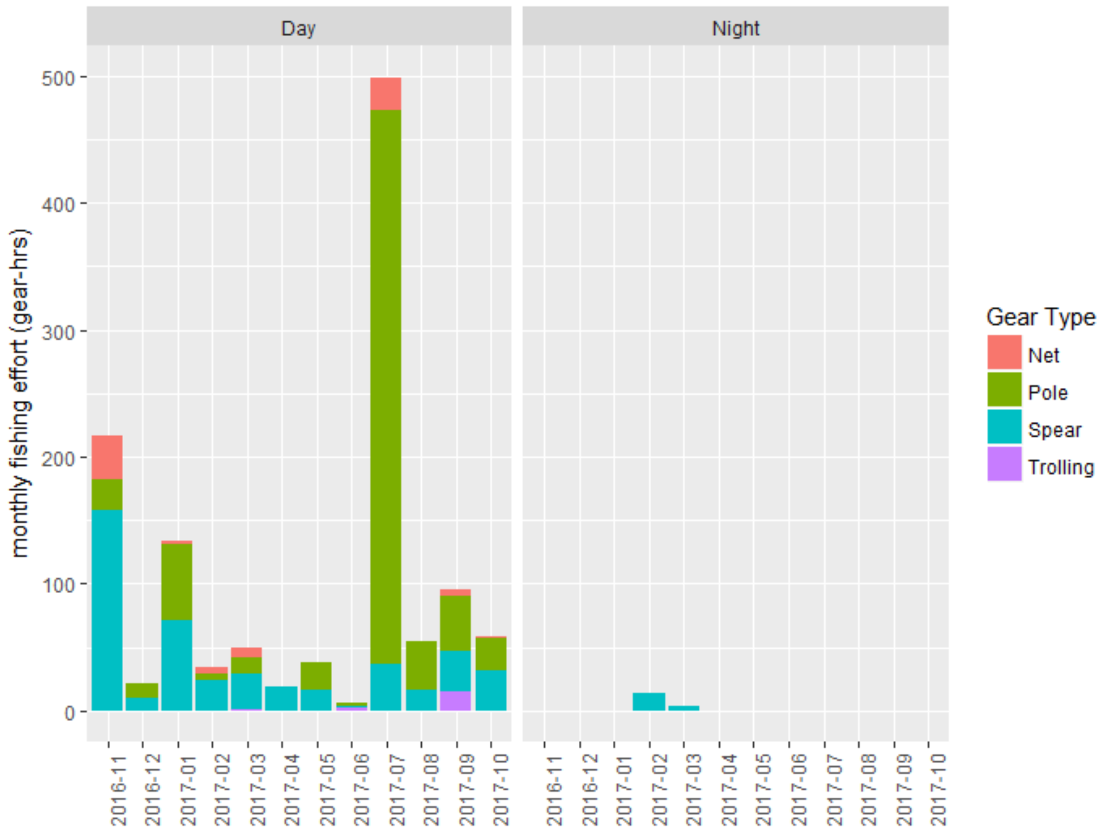

Figure 9. Estimated number of fishers for each month.

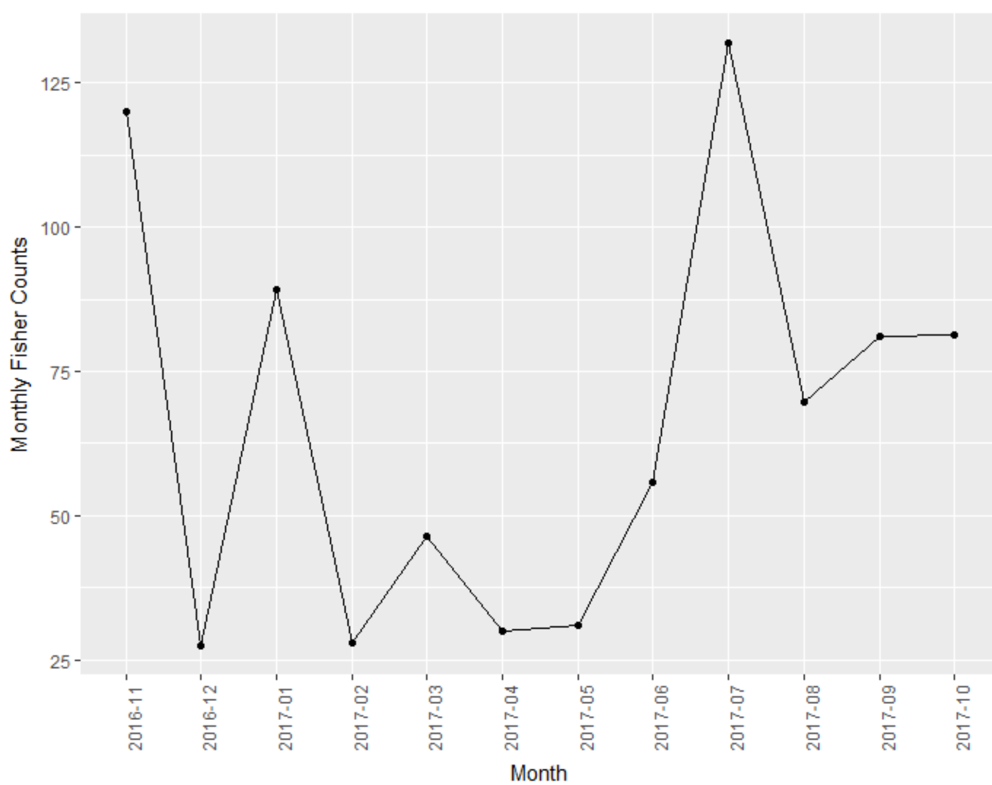

Figure 10. Annual fishing effort (in gear-hours) shown by zone for daytime and nighttime.

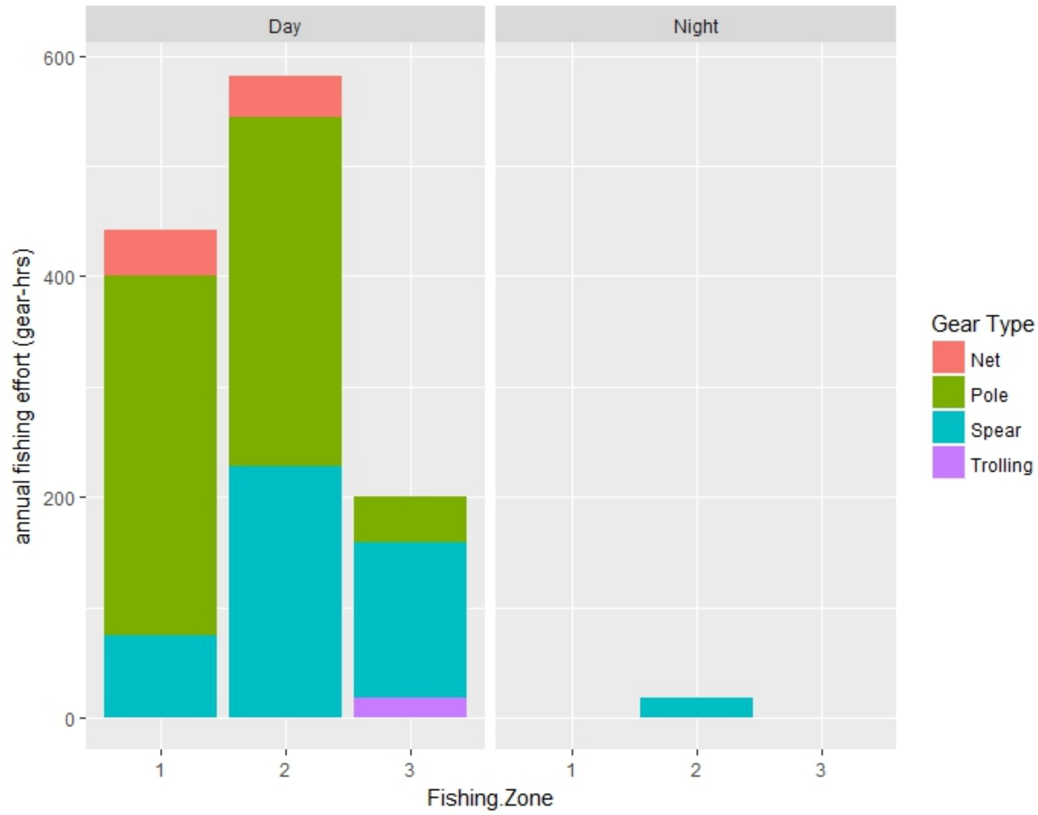

Figure 11. Species catch composition by gear type. Please note that this is the actual observed catch, not the number estimated to be caught over the entire year.

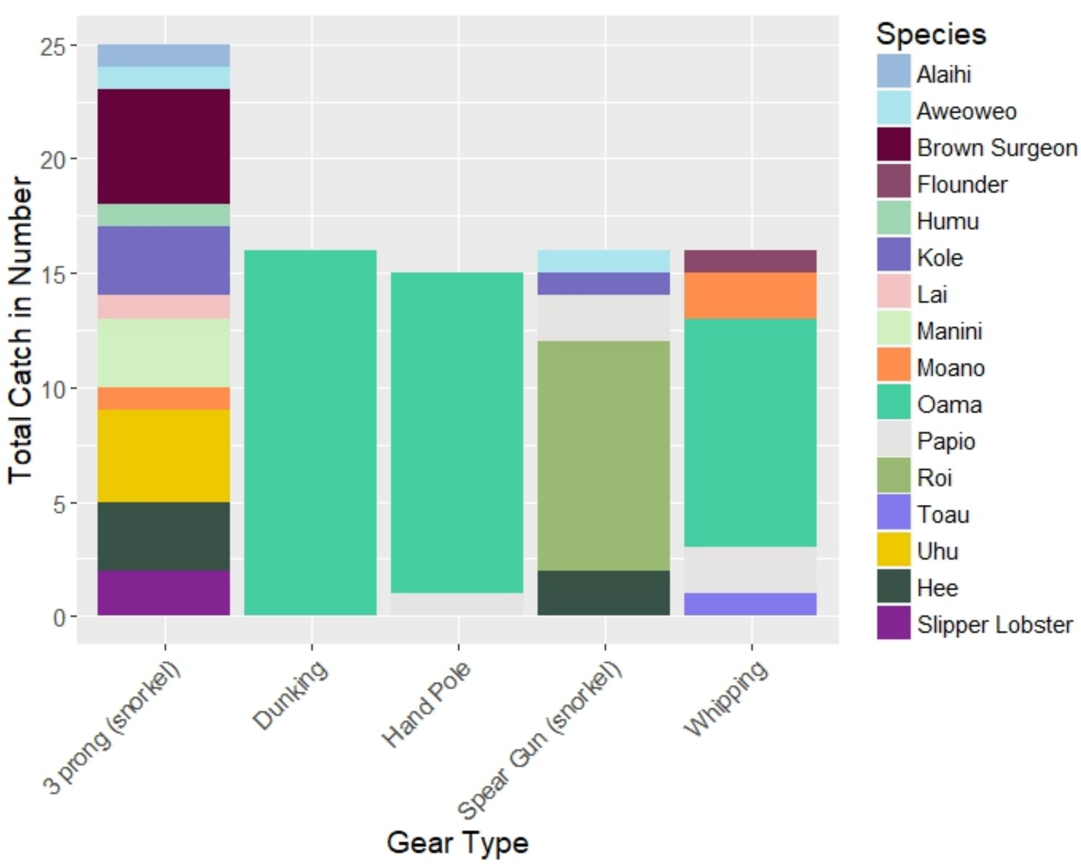

Figure 12. Species catch composition by zone, using actual observed catch, not estimated annualized catch.

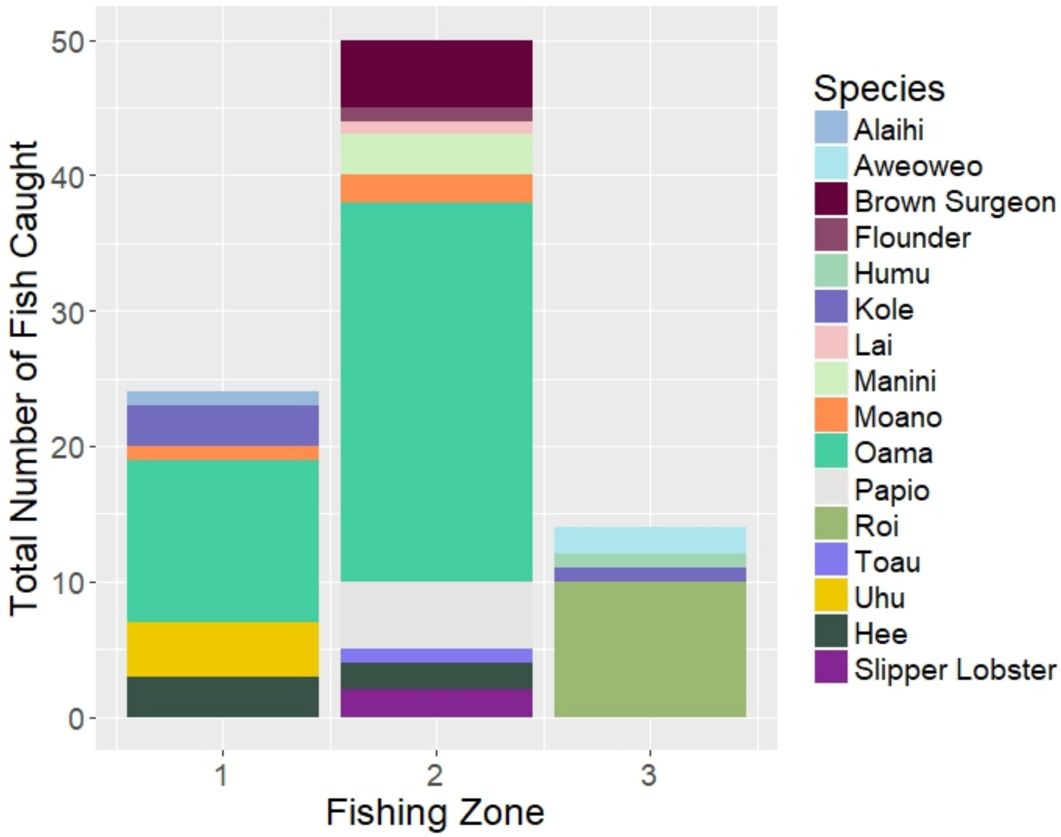

Figure 13. Species catch composition by month, using actual catch observed, not estimated annualize catch.