Design, development, and implementation of a survey of the fisheries of the Kahekili Herbivore Fisheries Management Area

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Executive Summary

The objectives of this study were to develop a scientifically rigorous and statistically valid survey of the fisheries in and around the Kahekili Herbivore Fisheries Management Area in order to assess the efficacy of the management action and provide the State and the community with the necessary data to facilitate adaptive decision-making.

- Interviews were conducted on 177 days during 2011, and included 265 total survey shifts. Fishing activity was observed during 161 (61%) of these shifts.
- The mean number of fishers per day was 5.4 (± 1.1 SE) with the highest numbers occurring on Tuesdays followed by Sundays.
- Survey results showed that most of the fishing occurred early in the morning (between 6 to 9 am) or early afternoon (between 12 to 3 pm), with less fishing effort later in the day (3 to 6 pm). There were five overnight fishing events observed during the survey period. However, interview with fishers, as well as community members suggest that night time fishing activities occur more frequently than observed in this study.
- The major area used by fishers was to the far south (Zone 1) and far north (Zone 5) of the FMA.
- Total expanded fishing effort for 2011 was 6,896 hours with pole fishing accounting for 57% of the total, followed by spear (41%), and thrownet (2%). Pole fishing showed a strong seasonal variance with the greatest effort occurring during the summer months. Spear fishing showed little variation among seasons.
- The total expanded catch was 1,214 kg with nearly 70% caught using spear, followed by pole (30%), and thrownet (<1%). Catch rates ranged from 0.3 kg (0.7 lb) per hour using spear to 0.03 kg (0.07 lb) per hour for throw net.
- He'e (octopus) had the highest total catch (448 kg), accounting for 37% of the total and was caught exclusively by spear. Weke (*Mulloidichthys flavolineatus/M. vanicolensis*) were the next most abundant taxa by weight, accounting for 17% of the total catch (211 kg). Spear took 68% of the weke while pole fishing providing the remainder of the catch for this species.
- Although KHFMA is a no-take area for herbivorous fishes, kala (*Naso unicornis*) was the third most abundant species caught by weight (106 kg) accounting for 9% of the total catch. While 86% of the kala were caught by spear, 14% was taken by pole fishing, which is somewhat surprising for an herbivore, but is consistent with traditional fishing methods.
- Despite the regulations against the taking of herbivores within the KHFMA, this trophic group accounted for 18% of the total catch by weight during the survey. 15% of the spear fishing events and 7% of the pole events captured herbivores.
- The total nearshore commercial catch for 2011 reported to Hawaii Division of Aquatic Resources for west Maui (Reporting area 301) was 3,287 kg and 2,284 kg excluding akule and opelu. The catch within the much smaller KHFMA was 37% of this total (53% excluding akule and opleu).

I. Introduction

Marine resources were important to the ancient Hawaiians for subsistence, culture, and survival. But in recent times, intensive fishing pressure, particularly in more populated areas, has led to substantial declines in many highly prized and vulnerable species (Friedlander and DeMartini 2002, Williams et al. 2008). Factors contributing to this include a growing human population, destruction of habitat, introduction of new and overly efficient fishing techniques (e.g. inexpensive monofilament gill nets, SCUBA, GPS), land-based pollution, invasive species and loss of traditional conservation practices (Friedlander et al. 2003, Friedlander et al. 2008). These impacts can have negative environmental, economical, and social consequences at the local level.

The Fisheries Local Action Strategy – Hawaii (FLASH) was initiated to address these declines in coral reef fisheries. One of the objectives of the FLASH is: *"To have statistically valid and useful knowledge for management on all catch and effort for Hawaii's coral reef fisheries by 2012."* From a fisheries management standpoint, one of the greatest obstacles to reversing declining resource trends is a better and more accurate understanding of the characteristics and magnitude of current fishing activities. The scope and intensity of recreational and subsistence fishing effort in Hawaii is relatively unknown except for a few focused studies (Everson 1995, Everson and Friedlander 2004, Friedlander and Parrish 1997). The limited work that has been conducted in Hawaii has shown that the recreational and subsistence catch is often equal to or greater than the catch by commercial fishers and these fishers also catch a wider variety of species using a broader range of fishing gear than do their commercial counterparts (Friedlander and Parrish 1997). These activities not only have a significant impact on fish stocks but also on the economy and cultures of coastal communities.

Currently, the Hawaii Marine Recreational Fisheries Survey (HMRFS) is the only mechanism by which to estimate recreational and subsistence fishing effort in the state. Unfortunately, limited resources and the extensive scope of coverage make it difficult to fully characterize and assess subsistence and recreational fishing efforts at the smaller community-level scale. Community-based stewardship is quickly becoming a popular method of co-management of local resource in Hawaii. A number of communities are currently strengthening local influence and accountability for their marine resources through revitalization of local traditions and resource knowledge (Friedlander et al. 2012). As community stewardship develops, it will be important to determine the effectiveness of this approach to resource management. It is also important to provide the State and these communities with the necessary data for adaptive management.

The Kahekili Herbivore Fisheries Management Area (KHFMA), Maui has been established to control the overabundance of marine algae within the area by increasing the local abundance of certain herbivorous fishes and sea urchins by fisheries management methods (HRS §§187A-5, 188-53). Natural controls of marine algae are intended to help the marine ecosystem in the area return to a healthy balance. The KHFMA starts at Hanakaʻoʻo Beach on the southern end and runs to Honokowai Beach Park in the north, a straight linear shoreline distance of 3064 m (Fig. 1). The take of chubs (Kyphosidae), parrotfishes (Scaridae), surgeonfishes (Acanthuridae), and sea urchins is prohibited within this management area. The local community is actively engaged with the state resource management agency and other interested parties in this project.

The objectives of this study were to develop a scientifically rigorous and statistically valid survey of the fisheries in and around the KHFMA in order to assess the efficacy of the management action and provide the State and the community with the necessary data to facilitate adaptive decision-making. The study was designed to supplement HMRFS by providing fisheries information (i.e., catch, effort, species composition, gear type) at a finer spatial and temporal resolution.

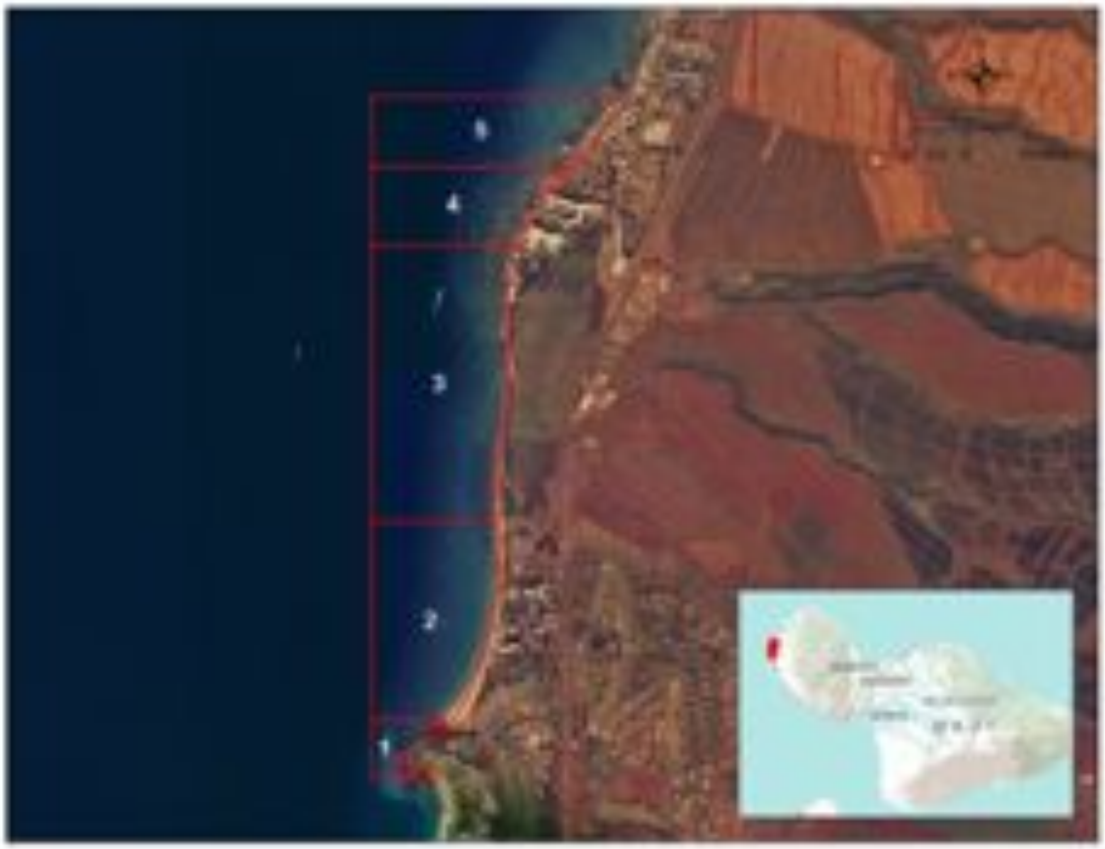

Figure 1. Aerial view of the Kahekili Herbivore Fisheries Management Area (KHFMA), Maui (boundaries and fishing zones delineated with red lines).

II. Method

The term creel survey is applied to sampling surveys that target recreational and subsistence anglers. The name comes from the woven wooden basket, or creel, that freshwater anglers use to hold captured fish while they continue fishing. Traditionally, the survey is conducted on-site at access points along the water and the fisher is asked about the fish species that have been targeted, the numbers of each species caught and released, the time spent fishing, and the gear used. These data are used to estimate the total catch and effort for that fishery in order to manage its harvest (Jones 2006).

Subsistence/recreational fishing (or creel) surveys are one of the few opportunities for scientists and management agency personnel to interact with the fishing community on a personal basis (Malvestuto 1996). Fishing surveys allow for the collection of fisheries data as well as the occasion to gain support and educate the public on management actions. The two basic steps in developing a subsistence/recreational fishery survey are: (1) selecting the statistical survey design that provides the best quantitative estimates of the fishery and (2) finding the most effective method of carrying out this design with the human and financial resources available (Malvestuto 1983, 1996, Guthrie et al. 1996, Pollock et al. 1994).

In order to design a statistically robust creel survey, fishing activities in KHFMA needed to first be identified. We conducted a short-term intense preliminary frame survey from 6 am to 6 pm for 14 days between March and May of 2010 (Table 1). The survey identified major fishing locations, dominant gear types, and the frequency of fishing activities both on a daily and weekly scale. Once the gear types and fishing activities were identified, the following creel survey was designed. Fourteen days of intense frame survey showed pole fishing and spear fishing to be the dominant fishing gear within the area. The mean number of fishers was slightly higher during the weekends compared to weekdays; however the results were not significant (Fig. 2, $p > 0.05$).

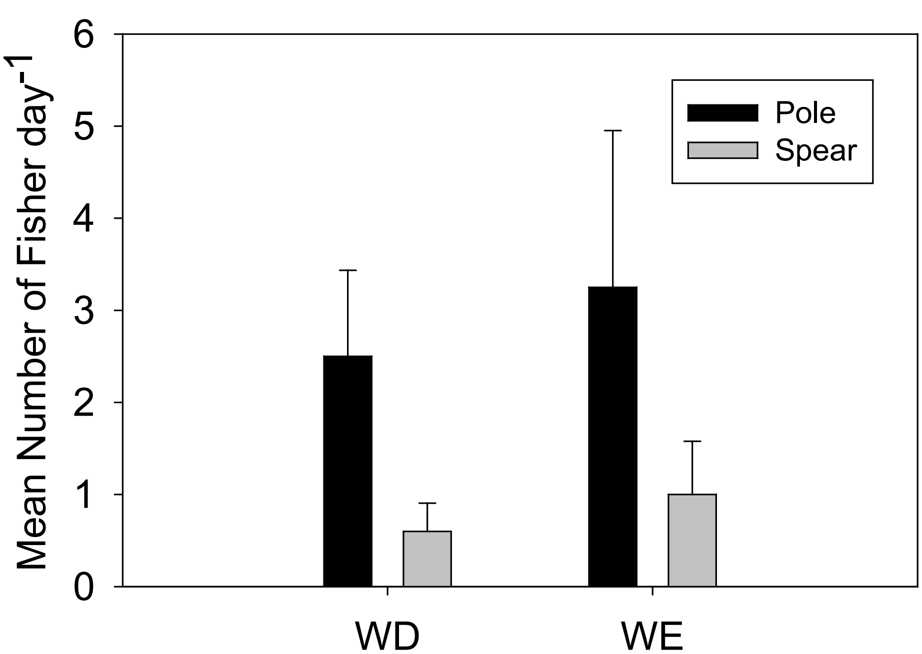

Figure 2. The mean number of fishers grouped by weekdays and weekends. Error bars are one standard error of the mean.

Table 1. Results from the frame survey conducted between 28 March and 20 May 2010. Values are number of fishers per day with the total fishing effort by gear type for that day in parentheses. In certain instances, fishers were recorded without associated effort.

WE_WD	Date	Pole	Spear
WE	28-Mar-10	8 (1.60)	--
WD	29-Mar-10	--	2 (--)
WD	30-Mar-10	--	--
WD	31-Mar-10	1 (--)	--
WD	01-Apr-10	1 (0.93)	--
WD	02-Apr-10	3 (0.47)	--
WE	03-Apr-10	--	2 (1.00)
WD	14-May-10	9 (6.08)	2 (0.03)
WE	15-May-10	2 (1.13)	2 (1.32)
WE	16-May-10	3 (1.17)	--
WD	17-May-10	6 (3.03)	--
WD	18-May-10	--	2 (--)
WD	19-May-10	2 (--)	--
WD	20-May-10	3 (0.42)	--

Two types of creel surveys were conducted to survey the fishing activities within the KHFMA from January 1 to December 30, 2011. One type was an observational survey which does not intervene with the fishers to collect fishing effort information, while the other approach was an interview-based survey which recorded both the fishing effort and catch data provided by the fishers simultaneously (Fig. 3). Both surveys were conducted between the hours of 6 am and 6 pm. The survey was further divided into four shifts; early morning (6 am-9 am); mid-morning (9 am-12 pm); early afternoon (12 pm-3 pm); late afternoon (3 pm-6 pm). These shifts were randomly assigned over the year in order to cover more days without increasing the survey time. The KHFMA was divided into five zones to quantify spatial differences in fishing over the entire FMA (Fig. 1).

Figure 3. Surveyor interviewing a fisherman for their catch and effort in KHFMA near Kahekili Beach Park.

II.A. Survey Schedules

From the preliminary survey, fishing activity was higher on weekend days and holidays compared to weekdays. To account for these fishing effort differences between weekends/holidays and weekdays, the survey efforts were stratified by the aforementioned category (weekdays and weekends/holidays). The ratio of days between the groups for each month was calculated and the survey shifts were allocated to match these ratios (see Table 2). The allocated survey shifts were randomly assigned within the weekday-weekend groups for each month.

Table 2. Numbers of allocated survey shifts for each month.

	No. of weekday	No. of weekend and holiday	No. of shifts allocated / month (for WD)	No. of shifts allocated/month (for WE/Holiday)
Jan	20	11	12	13
Feb	19	9	10	12
Mar	22	9	13	11
Apr	20	10	11	13
May	21	10	13	16
Jun	21	9	11	11
Jul	20	11	12	9
Aug	22	9	11	5
Sept	21	9	10	9
Oct	20	11	12	9
Nov	20	10	11	11
Dec	21	10	10	7
Total	247	118	136	126

II.B. Interview-Based Survey

For the interview-based survey, surveyors walked through each zones during their shift and interviewed as many fishermen as possible to obtain the following data: hours fished (how long the fishermen have been fishing or planning to fish (time start-time end)); type of fishing gear used; number of gears; number of fishermen; catch information (number and species); and fishing area (in zones).

II.C. Observational Survey

The observational survey was carried out from a nearby outcrop (Black Rock) that allowed the observer to see the entire project site. Between the time of 6 am and 6 pm, the observer used a high-powered spotting scope from the outcrop and recorded the following data: start time and end time of each fishing events (if the fishing event spanned longer than the survey time, the start/end time was recorded as the survey start/end time except over-night fishing which was then recorded as the average fishing hour of corresponding gear type); type of fishing gear used; number of gears; the number of fishermen; and fishing area (in zones).

II.D. Expansion of survey data

Values for the major fishery variables; catch, effort, and CPUE, were first estimated individually for each stratum, defined by 1) weekday or weekend/holiday, and 2) the type of gear used. These strata values were used directly to calculate catch or effort across strata (e.g. across weekdays and weekend/holidays, across gears [normally catch only], across seasons [to obtain estimates for a year or for the full period of the study]). The estimate of variance was the sum of the variances of the strata considered. The following section describes estimation of variables for the individual stratum Meyer 1975; Cochran 1977; Malvestuto et al. 1978; Malvestuto 1991; Malvestuto et al. 1991). Mathematical notations for the estimates are as follows:

C = Total catch

$\overline{C}$ = Mean catch per survey shift

C_u = Total catch derived using CPUE

c_{ij} = Catch of fisher j at each survey shift i, where i = 1....d, j = 1....n_i

d = Number of survey shifts fishery was observed

D = Total number of shifts

E = Total effort

$\bar{E}$ = Mean effort per survey shift

E_{ij} = Observed effort of fisher j at each survey shift i, where i = 1....d, j = 1....N_i

f = Finite population correction factor for catch and effort = $1 - \frac{d}{D}$

f_u = Finite population correction factor for CPUE = $1 - \frac{d\sum_{i=1}^{d} n_i}{D\sum_{i=1}^{d} N_i}$

n_i = Number of fishers interviewed during shift i

N_i = Number of fishers observed during shift i

U = Mean CPUE over all fishers

Var( ) = Variance

II.D.1 Effort

An estimate of total effort, E, was obtained by calculating a mean effort per shift by all fishers in the stratum combined (using observed effort on each day and the number of observation days) and expanding by the total number of shifts available for fishing in the stratum, i.e.

$$E = \bar{E} \times D = \frac{\sum_{i=1}^{d}\sum_{j=1}^{N_i} E_{ij}}{d} \times D \quad . \qquad (1)$$

The variance of $\bar{E}$ was estimated as:

$$\mathrm{Var}(\bar{E}) = \frac{\mathrm{Var}(E_{ij})}{d} \times f = \frac{\sum_{i=1}^{d}\left(\sum_{j=1}^{N_i} E_{ij}\right)^2 - d\bar{E}^2}{d(d-1)} \times f \quad , \qquad (2)$$

where $f = 1 - \frac{d}{D}$ is the finite population correction factor, used because $\frac{d}{D}$ was frequently > 0.05. The variance of E was estimated as:

$$\mathrm{Var}(E) = \mathrm{Var}(\bar{E} \times D) = D^2 \times \mathrm{Var}(\bar{E}) \quad .$$

II.D.2 Catch per Unit Effort (CPUE)

The catch was recorded as the number of each species caught. Since size data was not recorded during the survey, biomass was calculated by multiplying the average size/weight reported to Hawaii Division of Aquatic Resources from the Hawaii Marine Recreational Fishing Survey with the numbers caught. A mean CPUE, U, over all fishers in a stratum was estimated by obtaining an individual CPUE for each interview, summing over all interviews, and dividing by the number of interviews, i.e.

Mean CPUE, U, over all fishers in a stratum was estimated by obtaining an individual CPUE for each interview, summing over all interviews, and dividing by the number of interviews, i.e.

$$U = \frac{\sum_{i=1}^{d}\sum_{j=1}^{n_i}\frac{c_{ij}}{E_{ij}}}{\sum_{i=1}^{d} n_i} \quad . \qquad (3)$$

The variance of U was estimated as

$$\mathrm{Var}(U) = \frac{\mathrm{Var}(\frac{c_{ij}}{E_{ij}})}{\sum_{i=1}^{d} n_i} \times f_u = \frac{\sum_{i=1}^{d}\sum_{j=1}^{n_i}\left(\frac{c_{ij}}{E_{ij}}\right)^2 - (\sum_{i=1}^{d} n_i)U^2}{(\sum_{i=1}^{d} n_i)(\sum_{i=1}^{d} n_i - 1)} \times f_u \quad , \qquad (4)$$

where $f_u = 1 - \frac{d\sum_{i=1}^{d} n_i}{D\sum_{i=1}^{d} N_i}$ is the finite population correction factor, similar to the conventional factor, but adjusted to reflect a ratio of fisher-shifts with interviews to total fisher-shifts of the stratum.

II.D.3 Catch

Estimates of total catch were calculated as a product of the mean CPUE, mean shift effort, and total number of shifts in each group.

II.E.3.a Total catch of all taxa

To estimate total catch, we calculated the catch, Cu, as a product of the mean CPUE, mean daily effort, and total number of days in the stratus, i.e.

$$C_u = U \times \bar{E} \times D$$

This calculation made use of the results of Eqn (1) and (3) above. The variance of Cu was estimated as:

$$\mathrm{Var}(C_u) = D^2[\overline{E}^2\mathrm{Var}(U) + U^2\mathrm{Var}(\overline{E}) + \mathrm{Var}(\overline{E})\,\mathrm{Var}(U)].$$

This calculation made use of the results of Eqn (1), (2), (3), and (4) above.

II.D.3.b. Catch of individual taxa

Estimation of catch for each taxon directly from raw sample data was not feasible because of the relatively small sample size of some identified taxa within a stratum. Therefore, estimates for each taxon were derived from the expanded estimates described in Section 2.e.3.a. The raw sample weight of each taxon caught in each stratum was divided by the raw sample weight of the total catch for that stratum to obtain the fractional taxonomic composition. These fractions were then multiplied by the expanded catch for the stratum to obtain an estimated expanded weight of catch for each taxon.

To obtain catch estimates at higher levels of aggregation, appropriate sets of these estimates were added. Because sample sizes were relatively small, summation across different gears with different fishing power was common. Because of small sample sizes, estimates were calculated for these catch estimates.

II.E. Gear and Effort

Fishing effort for all strata was calculated as hours fished multiplied by the number of units of gear used. There were three main gears used in KHFMA. Each gear was analyzed separately since fishing power was not comparable among gears. The gear types observed are described below.

Net: Any fishing effort involving a use of the net (although most of the observed net fishing was throw net). Unit of gear: 1 net

Pole: Broad category including bottom fishing, casting, dunking, and whipping from shore. Unit of gear: 1 pole

Spear Fishing: Spearing while free diving or using SCUBA. The spear can be three prong or spear gun. Unit of gear: 1 spear

Others: Other fishing or harvesting activity along the shore. This included gleaning for limu (seaweed), shell collecting, etc.

II.G. Definition of Fishing Areas

KHFMA was split into five zones to identify general fishing areas and for the ease of surveying (Fig. 4). Zone 4 and 5 had higher coral cover, whereas zone 1 through 3 were mainly uncolonized sand or dominated by macroalgae except a small area near Black Rock in Zone 1. Additionally, there was an old inactive pier in Zone 1, but during the middle of the survey, it was closed by a gate thus reducing the fishing activity in the area. Zone 2 through 4 is also an area where large hotels are established and is heavily used by tourists.

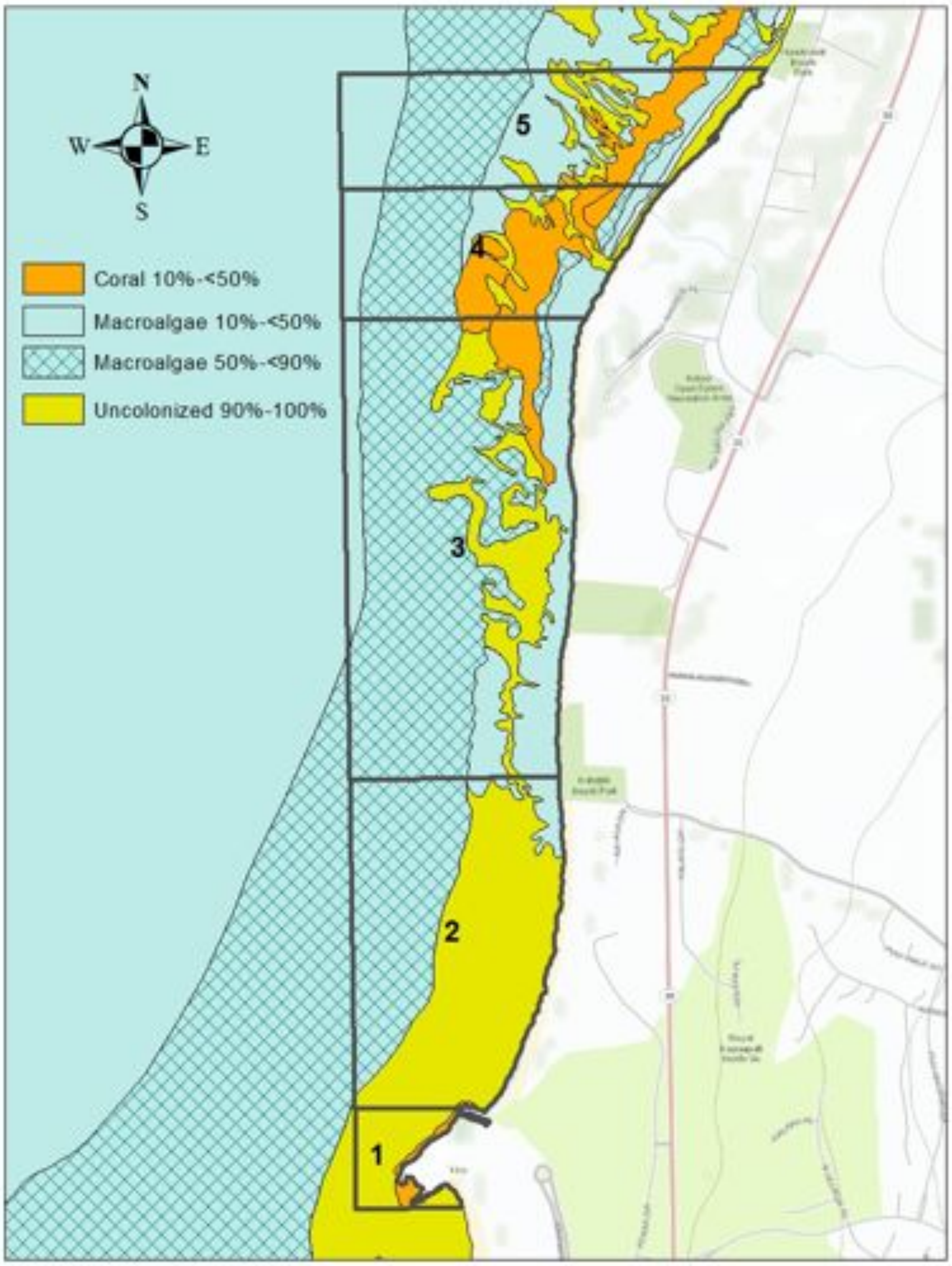

Figure 4. The KHFMA with fishing zones overlaid on NOAA benthic habitat map (Battista et al. 2007).

III. Results and Discussion

The creel survey encompassed 177 days for the year of 2011, and included 265 total survey shifts. Fishing activity was observed during 161 shifts out of these 265 shifts.

III.A General Fishing Activity Patterns

III.A.1 Distribution of Fishing over Days of the Week

The mean number of fishers for each day of the week was examined for the entire study period combined (Fig. 5). Since we were initially interested in the participation of all fishers, all gear types were combined for this analysis. The mean number of fishers per day was 5.4 (± 1.1 SE) with the greatest number of fishers occurring on Tuesdays followed by Sundays. However, none of the days were significantly different from the other days (W = 6.34, p = 0.38).

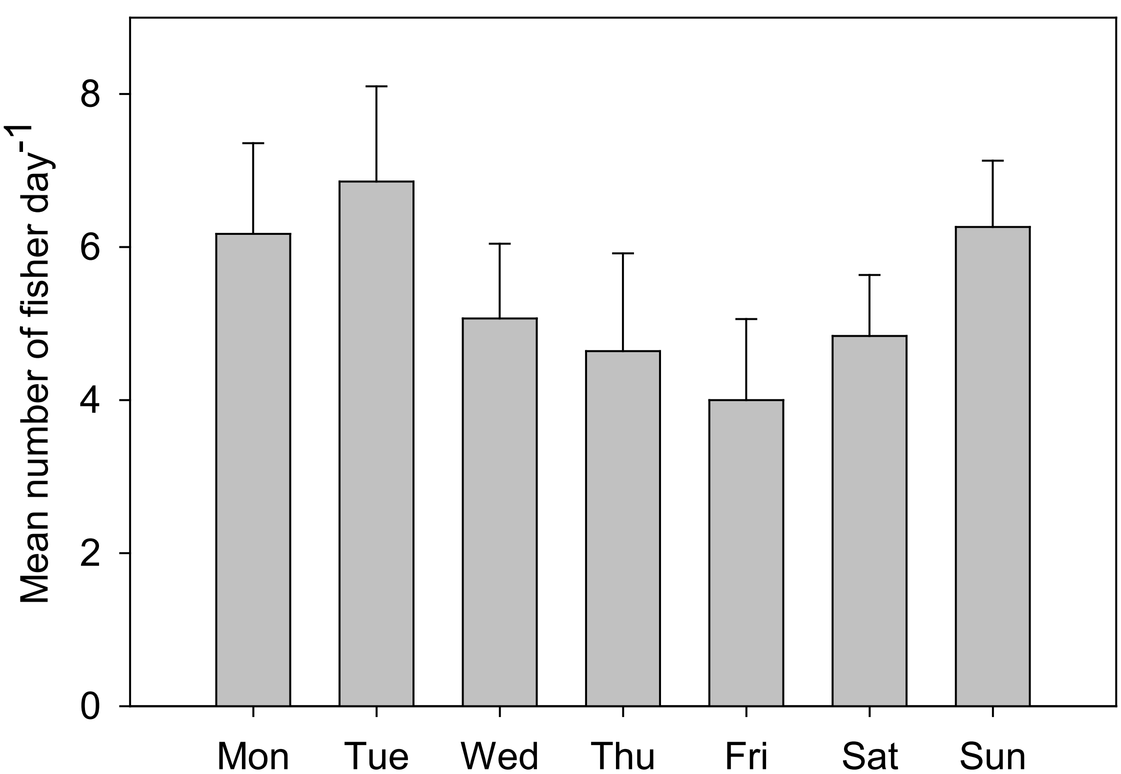

Figure 5. Mean number of fishers (all gear types combined) for each day of the week for the entire survey period (January 1 to December 30, 2011). Error bars are one standard error of the mean.

III.A.2 Diel Distribution of Fishing

Number of fishers across the survey time frame was compared in order to assess the fishing effort over time of the day (Fig. 6). The survey results showed that most of the fishing occurred early in the morning (between 6am to 9am) or early afternoon (between 12pm – 3pm), and numbers dropped later in the day (between 3pm – 6pm). However these differences were not statistically significant ($W = 2.53$, $p = 0.47$).

Additionally, preliminary surveys and communication with the local community indicated overnight fishing occurred within the area. In order to include this in the survey, fishers who were observed before or after the survey start and stop times were recorded as overnight fishing. There were five overnight fishing observed during the survey period. However, interview with the fishers as well as community members suggest that night time fishing activities occur more frequently than observed in this study.

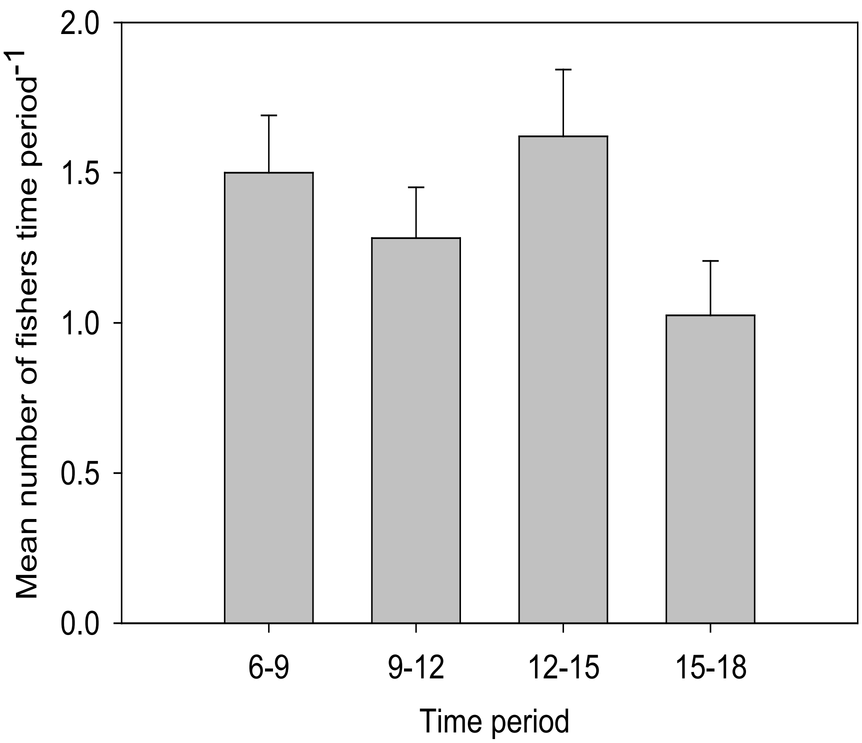

Figure 6. Mean number of fishers per shift (all gear types combined) for each time frame surveyed.

III.A.3 Distribution of Fishing in the KHFMA

Use of fishing areas within the KHFMA in terms of the number of fishers visiting each zone was examined for the entire study period combined. All gear types were combined as above. The major areas used by fishers were Zone 1 and Zone 5. There was a significant difference in mean number of fishers between Zone 1 and 4 only ($H = 18.7$, $p < 0.001$). No other zones were significantly different from one another. Zone 1 was mainly used by pole fishers whereas Zone 5 showed the most diverse gear usage (Fig. 7 & 8). Both zones are also furthest from the hotels, and Zone 1 also has an old pier which is likely a preferred location for pole fishing.

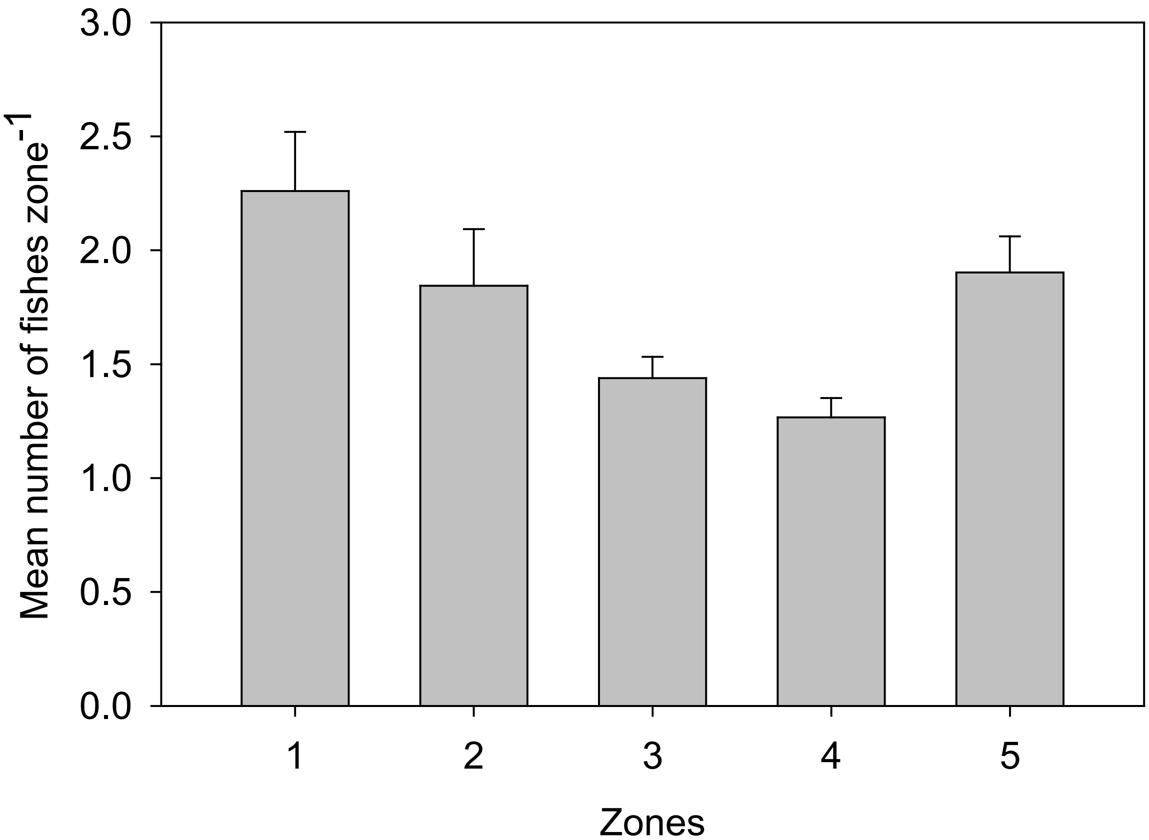

Figure 7. Mean number of fishers per shift (all gear types combined) for each zone.

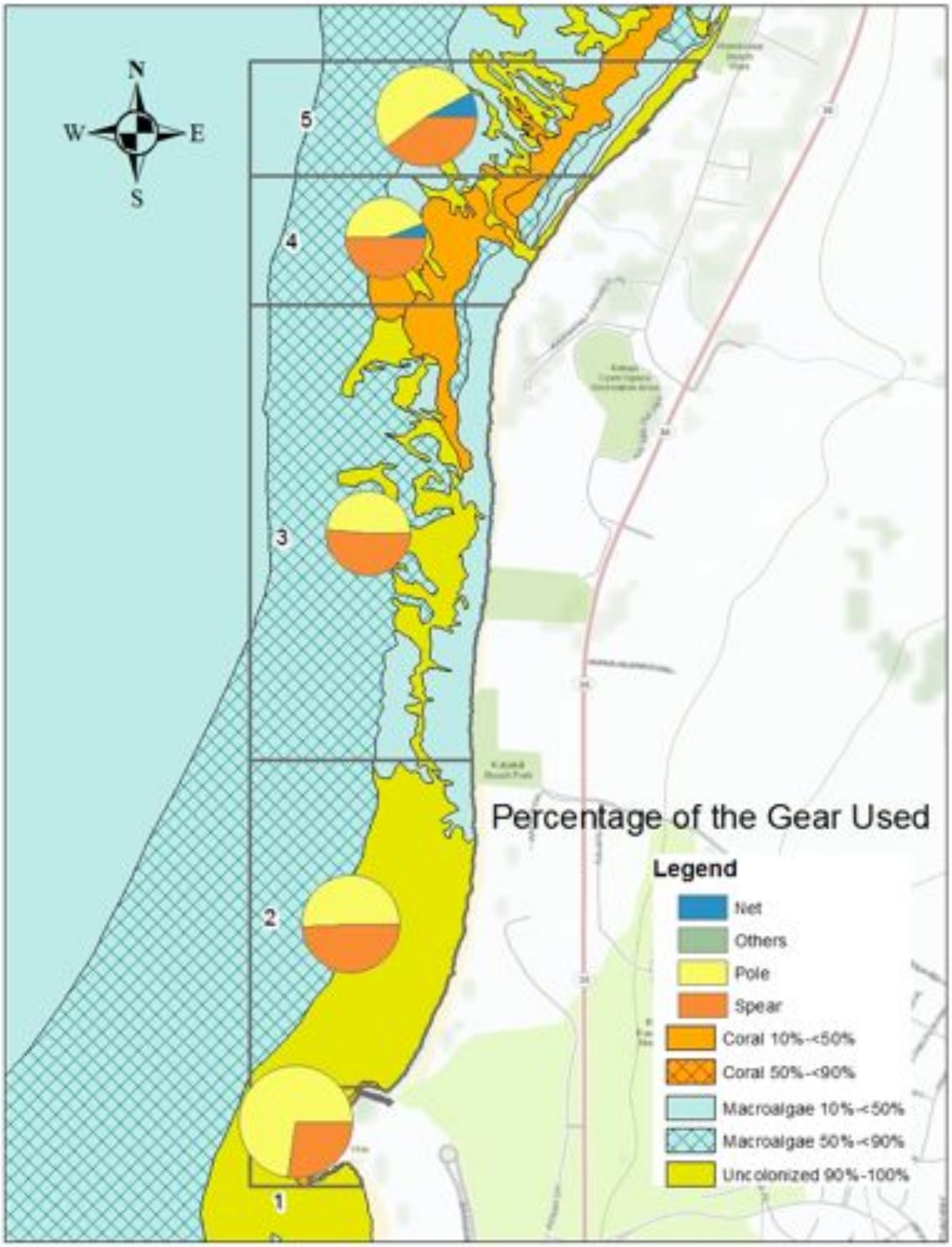

Figure 8. Percentage of gear usage by fishing zone. Size of circles is proportional to mean number of fishers. Base map is NOAA benthic habitat map from Battista et al. 2007.

III.B. Effort

The methods of section II.E.1 were used to estimate total fishing effort for each quarter for each gear type for weekdays and for weekends/holidays. Although weekends did not significantly dominate the fishing effort as thought, it still covered about 1/3 of the total fishing effort for any gears (Table 3, Fig. 9).

Only limited comparisons and no direct, rigorous summation of effort can be made across gear types, because the fishing power and selectivity of each gear is different. CPUE, as used in a following section, largely addresses the issue of fishing power. The present results for effort in the unit used here are of use mainly in connection with estimating CPUE and catch.

In terms of number of fishers, number of units of gear, and total hours fished, pole was the dominant gear type closely followed by spear at KHFMA. The net and other methods of fishing only showed minor use compared to the two dominant gears. Pole fishing showed a strong seasonal variance with the greatest effort occurring during the summer months. Spear fishing showed little difference among seasons (Fig. 10).

Table 3. Expanded quarterly fishing effort (gear-hours) by gear type. Coefficient of variation (COV) for each estimate is in parenthesis. Spring 2011 = Jan – Mar, Summer 2011 = April – June, Fall 2011 = July – Sept, Winter 2011 = Oct – Dec.

	Spring 2011		Summer 2011		Fall 2011		Winter 2011	
Gear	WD	WE/H	WD	WE/H	WD	WE/H	WD	WE/H
Pole	340.55	245.37	1304.95	440.90	369.22	551.42	532.07	140.37
	(7.53)	(17.18)	(28.34)	(25.41)	(13.78)	(44.81)	(7.34)	(10.15)
Spear	166.15	303.16	674.91	138.23	511.00	212.25	603.09	248.59
	(7.41)	(11.57)	(19.24)	(4.80)	(33.26)	(13.48)	(18.64)	(24.89)
Net	49.96	2.69	24.21	26.10	1.91	0.00	0.00	3.33
	(3.42)	(0.96)	(2.42)	(7.05)	(0.40)	NA	NA	(1.29)
Others	0.00	0.00	0.00	5.80	0.00	0.00	0.00	0.00
	NA	NA	NA	(1.97)	NA	NA	NA	NA

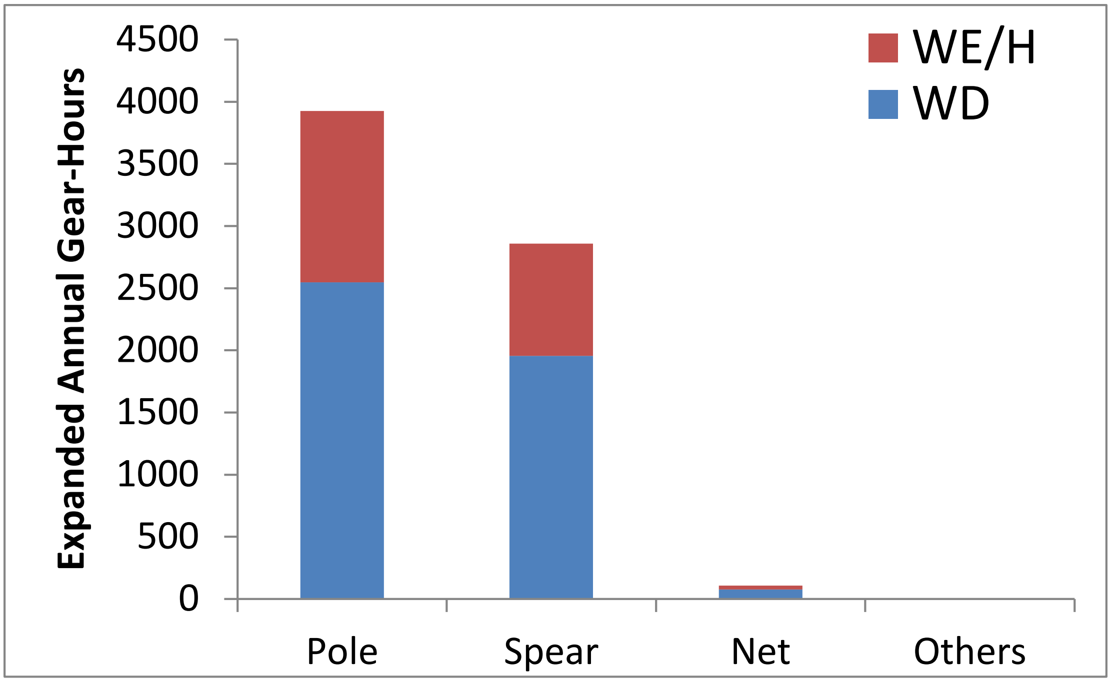

Figure 9. Expanded annual fishing effort (gear-hours) by gear type. WD-weekday stratum, WE/H-weekend and holiday stratum.

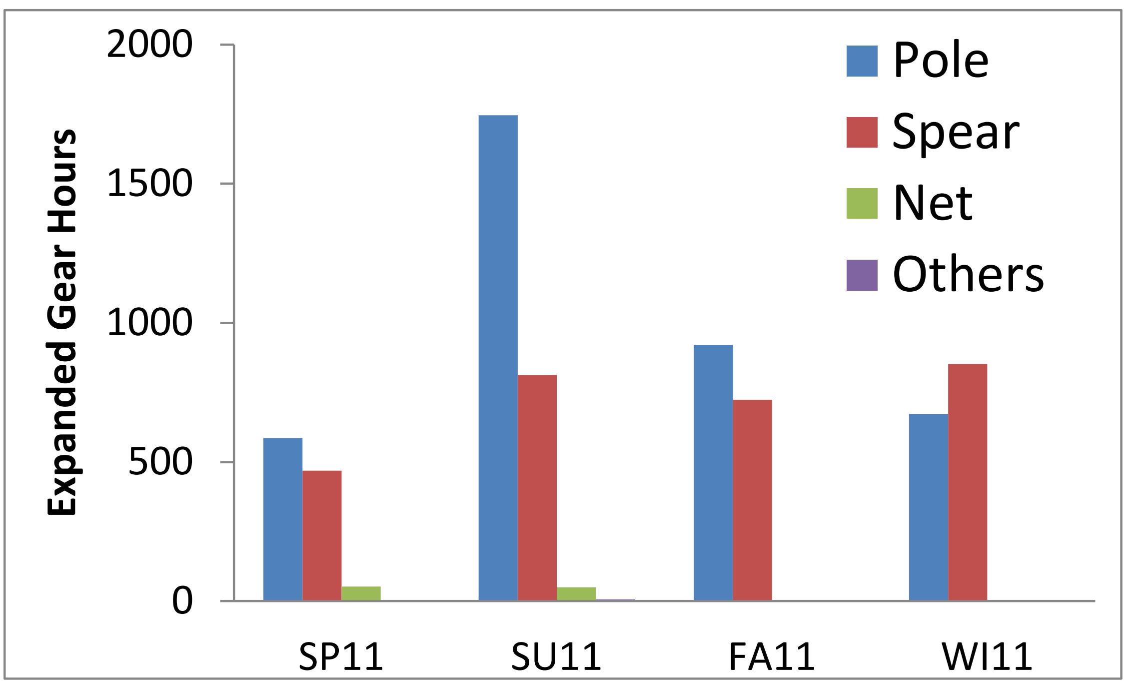

Figure 10. Expanded quarterly fishing effort (gear-hours) for selected gears. Spring = Jan-Mar, Summer = Apr-June, Fall = July-Sept, Winter = Oct-Dec.

III.C. Catch Per Unit Effort (CPUE)

Individual values of CPUE and its coefficient of variation (COV) for each stratum were calculated using the methods of Section II.E.2 (Table 4). Catch rates ranged from 0.3 kg (0.7 lb) per hour to 0.03 kg (0.07 lb) per hour for throw net. Spear fishing showed more than 300% higher CPUE than pole although fishing effort was similar between gear types.

Table 4. Mean catch per unit effort (CPUE) and coefficient of variation (COV) for each major type of gear used in the KHFMA. Other gear type was not included since it only targeted limu.

	Annual CPUE		
Gear	Mean	COV	Units of CPUE
Spear	0.30	0.01	kg/spear-hr
Pole	0.09	0.01	kg/pole-hr
Throw net	0.03	0.02	kg/net-hr

III.D. Overall Catch

There seemed little expectation or evidence that CPUE varied with day of the week, and variability in effort with day of the week is reported above. Therefore, for most purposes reported here, catches are pooled across days of the week as well as time of the days. The total expanded catch was 1,214 kg with nearly 70% caught using spear (Fig. 11).

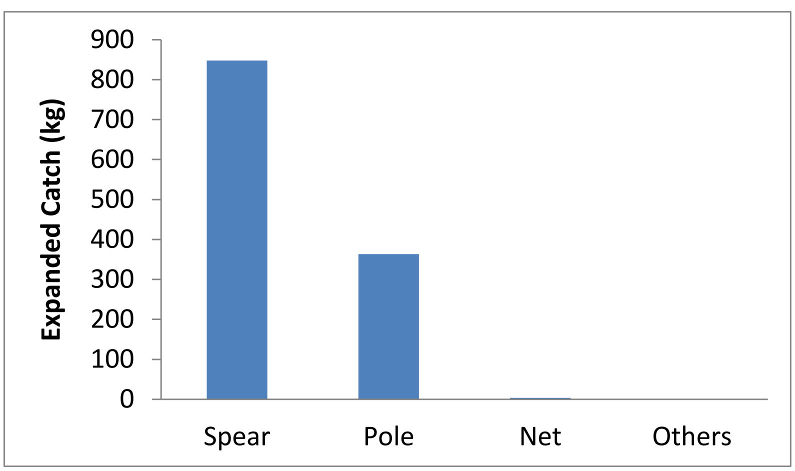

Figure 11. Expanded annual catch (kg) by gear type.

III.E. Catch of Individual Taxa

There were 24 species harvested during the survey period. Among these species, limu, shrimp, and shell were not quantified and therefore not included in the analysis. The remaining catches, broken down by gear type, for the entire year of 2011, is shown in Table 5. Species were all recorded in Hawaiian names, thus some taxon are grouped.

He'e (octopus) had the highest total catch (448 kg), accounting for 37% of the total. He'e were caught exclusively by spear. Weke (*Mulloidichthys flavolineatus/M. vanicolensis*) were the next most abundant taxa by weight, accounting for 17% of the total catch (211 kg). Spear took 68% of the weke with pole fishing providing the remainder. Although KHFMA is a no-take area for herbivorous fishes, kala (*Naso unicornis*) was the third most abundant species caught by weight (106 kg) accounting for 9% of the total catch. While 86% of the kala were caught by spear, 14% was taken by pole fishing, which is somewhat surprising for an herbivore. Awa (*Chanos chanos*) was the next most abundant species in the catch, accounting for 6% of the total, followed by another herbivore, enenue (*Kyphosus* spp.), which accounted for an additional 5% of the catch. Another herbivore, uhu (parrotfish species), ranked 10^{th} in total catch and accounted for an additional 2% of the catch.

Table 5. Species catch in KHFMA by weight (kg) and gear (% in parentheses). **Restricted herbivores shown in bold.**

Hawaiian	Scientific name	Spear	Pole	Throw net	Total
hee	*Octopus* spp.	444.81 (0.37)	-	-	444.81 (0.37)
weke	*Mulloidichthys flavolineatus/M. vanicolensis*	143.64 (0.12)	67.03 (0.06)	-	210.67 (0.18)
kala	***Naso unicornis***	**90.83 (0.07)**	**15.14 (0.02)**	**-**	**105.94 (0.09)**
awa	*Chanos chanos*	-	67.03 (0.06)	-	67.03 (0.06)
enenue	***Kyphosus spp.***	**-**	**57.13 (0.05)**	**-**	**57.13 (0.05)**
roi	*Cephalopholis argus*	53.29 (0.04)	-	-	53.29 (0.04)
papio	*Caranx spp.* (juveniles)	-	41.71 (0.03)	-	41.71 (0.03)
oio	*Albula spp.*	20.38 (0.02)	20.38 (0.02)	-	40.76 (0.04)
kumu	*Parupeneus porphyreus*	32.91 (0.03)	-	-	32.91 (0.03)
uhu	***Scaridae***	**28.73 (0.02)**	**-**	**-**	**28.73 (0.02)**
palani	***Acanthurus dussumieri***	**13.29 (0.01)**	**13.29 (0.01)**	**-**	**26.58 (0.02)**
aholehole	*Kuhlia spp.*	-	12.98 (0.01)	2.16 (<0.01)	15.14 (0.01)
menpachi	*Myripristis spp.*	9.90 (0.01)	4.93 (<0.01)	-	14.83 (0.01)
moano	*Parupeneus multifasciatus*	9.28 (0.01)	3.08 (<0.01)	-	12.36 (0.01)
mamo	*Abudefduf abdominalis*	-	11.89 (0.01)	-	11.89 (0.01)
oama	*M. flavolineatus/M. vanicolensis* (juveniles)	-	11.13 (0.01)	-	11.13 (0.01)
ama'ama	*Mugil cephalus*	-	9.28 (0.01)	-	9.28 (0.01)
eel	*Muraenidae/Congridae*	-	8.97 (0.01)	-	8.97 (0.01)
moi	*Polydactylus sexfilis*	7.71 (0.01)	-	-	7.71 (0.01)
aweoweo	*Priacanthidae*	7.40 (0.01)	-	-	7.40 (0.01)
kupipi	*Abudefduf sordidus*	-	3.39 (<0.01)	-	3.39 (<0.01)
hinalea	*Thalassoma duperrey*	-	2.47 (<0.01)	-	2.47 (<0.01)
Total		862.17 (0.71)	349.83 (0.29)	2.16 (<0.01)	1,214.13

III.F. Spatial distribution of the species caught

The catch composition varied among fishing zones and was largely driven by habitat and type of access (Fig. 12). Zone 5 had the highest catch with 50% of the catch consisting of he’e, followed by weke (16%), kala (13%), and enenue (12%). The second largest total catch was in zone 4 with he’e accounting for 49% of the catch, followed by weke (34%), roi (7%), and papio (5%). Nearly 87% of all he’e were caught in Zone 4 and 5, where most of the hard bottom habitat was found within the FMA. The catch of weke was spread out among all zones with 42% of the catch in Zone 4, followed by Zone 5 (27%), and Zone 3 (18%). The highest catch for kala (86 kg) occurred in Zone 3 (62%) followed by Zone 5 (37%).

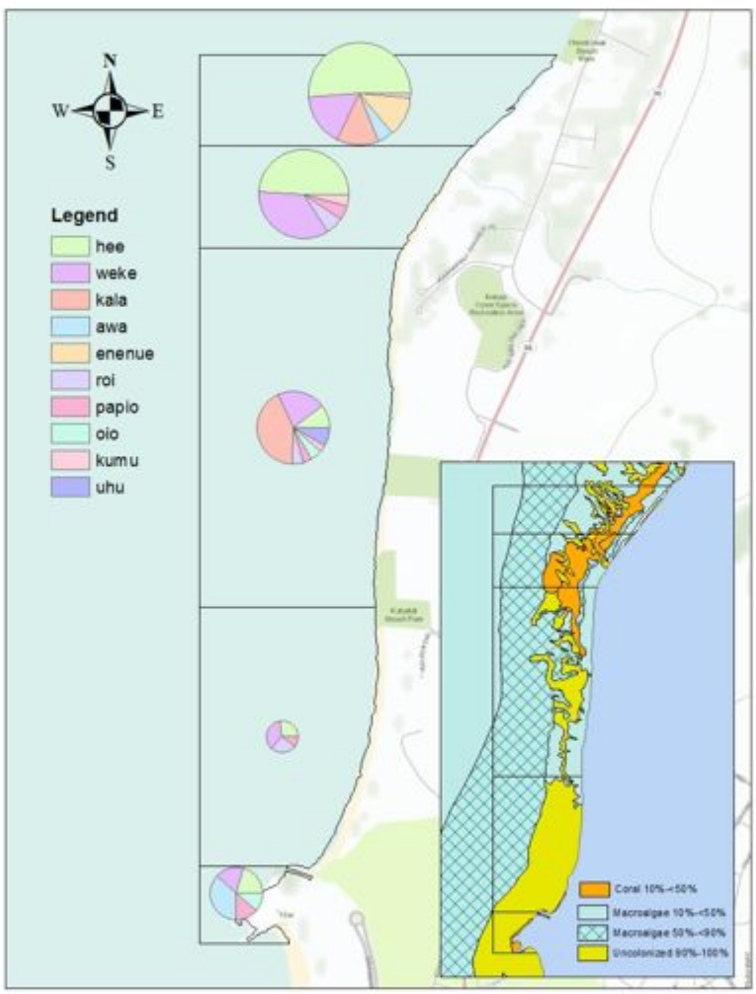

Figure 12. Species composition of the 10 most abundant species overall by zone. Pie size is proportional to the total biomass of fish caught.

III.G. Comparison with the commercial catch data

Catch by species within the FMA was compared to the Hawaii Division of Aquatic Resources (HDAR) commercial catch data for the same time period for reporting block 301. The total nearshore commercial catch for 2011 reported to HDAR was 3,287 kg and 2,284 kg excluding akule and opelu (Table 6). Although the reporting grid is much larger (98%) compared to the KHFMA (Fig. 13), the catch within the FMA was nearly 37% of the entire reporting block (53% excluding akule and opelu). In addition, the HDAR commercial catch data recorded only seven species compared to 22 within the KHFMA. Nearly 48% of the HDAR commercial catch data was recorded as other species, followed by akule (20%), and opelu (11%).

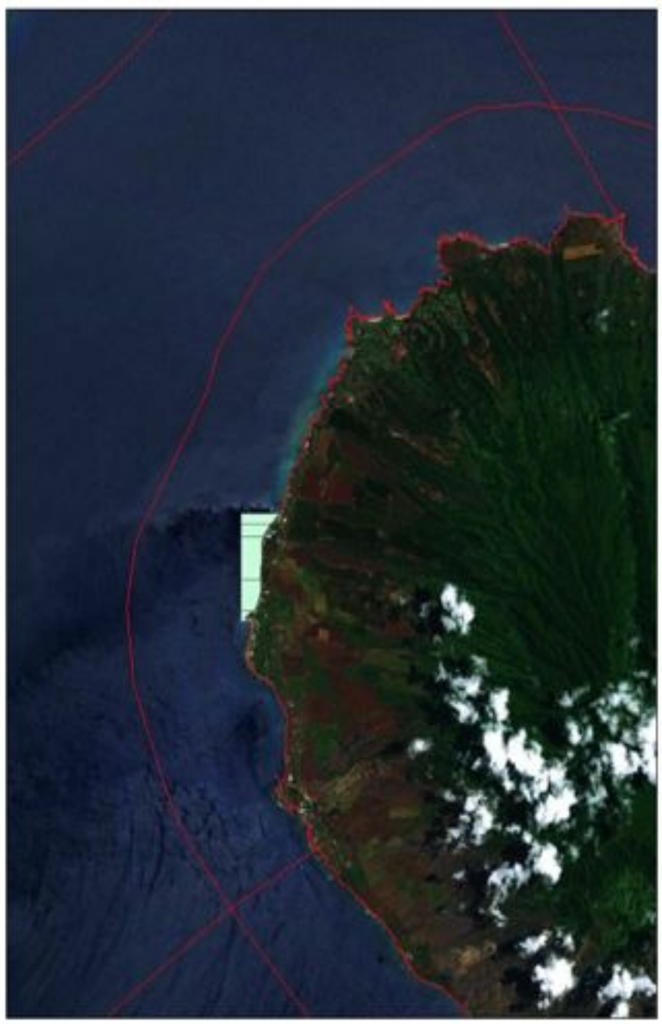

Figure 13. The KHFMA (light blue) within the much larger HDAR Commercial Fishing Reporting Block 301.

Table 6. Catch by species in KHFMA by total weight (kg) compared with the DAR commercial catch report by total weight (kg). Commercial catch in kg obtained from DAR commercial inshore landing record of 2011 (Recording block 301).

Hawaiian	Scientific name	Commercial	KHFMA
Akule	*Selar crumenopthalmus*	650.68	--
Opelu	*Decapterus macarellus*	352.89	--
Papa ulua	*Carangoides orthogrammus*	293.47	--
Palani	*Acanthurus dussumieri*	165.56	26.58
Uku	*Aprion virescens*	139.62	--
Kona crab	*Ranina serrata*	60.78	--
Laenihi	*Xyichthys pavo*	56.02	--
all others		1568.07	--
hee	*Octopus* spp.	--	444.81
weke	*Mulloidichthys flavolineatus/M. vanicolensis*	--	210.67
kala	*Naso unicornis*	--	105.94
awa	*Chanos chanos*	--	67.03
enenue	*Kyphosus spp.*	--	57.13
roi	*Cephalopholis argus*	--	53.29
papio	*Caranx spp. (juveniles)*	--	41.71
oio	*Albula spp.*	--	40.76
kumu	*Parupeneus porphyreus*	--	32.91
uhu	*Scaridae*	--	28.73
aholehole	*Kuhlia* spp.	--	15.14
menpachi	*Myripristis* spp.	--	14.83
moano	*Parupeneus multifasciatus*	--	12.36
mamo	*Abudefduf abdominalis*	--	11.89
oama	*M. flavolineatus/M. vanicolensis* (juveniles)	--	11.13
ama'ama	*Mugil cephalus*	--	9.28
eel	*Muraenidae/Congridae*	--	8.97
moi	*Polydactylus sexfilis*	--	7.71
aweoweo	*Priacanthidae*	--	7.4
kupipi	*Abudefduf sordidus*	--	3.39
hinalea	*Thalassoma duperrey*	--	2.47
Total		3287.09	1214.13

IV. Discussion

The total expanded catch within KHFMA was 1,214 kg with nearly 70% caught using spear, followed by pole (30%), and thrownet (<1%). The dominant species caught by weight was he'e (*Octopus* spp.), accounting for 37% of the total biomass and was caught exclusively by spear. Although KHFMA is a no-take area for herbivorous fishes, this trophic group accounted for 18% (134.67 kg) of the total catch by weight over the survey period.

The average number of fishers observed was highest on Tuesdays followed by Sundays, indicating that some fishers prefer to fish on weekdays when there is less use of the ocean by non-fishers. Overuse by non-fishers may be a particular issue fort the fishing community at the KHFMA since it is bordered by large resorts and is heavily used by visitors. Most of the fishing occurred early in the morning (between 6 am to 9 am) or early afternoon (between 12 pm – 3 pm). The number of pole fishers varied greatly among seasons, whereas the number of spear fishers showed little seasonal variation. The increase in pole fishing during the summer may reflect better weather and more time off from work or school. It was also noted, that during the summer months more tourist fishers were utilizing the area, and they seemed more likely to fish with poles than to utilize more specialized fishing techniques.

The majority of the fishing was pole and spear fishing, with small amounts of throw netting. Catch rates for spear fishing was more than 3 times higher than pole fishing and 10 times higher than throw net. The most common species taken by pole was weke, whereas he'e was the most common species taken by spear. However, spear fishers still caught more weke than pole fishers due to the higher catch rates. He'e had the highest total catch (448 kg), accounting for 37% of the total and was caught exclusively by spear. Weke (*Mulloidichthys flavolineatus/M. vanicolensis*) were the next most abundant taxa by weight, accounting for 17% of the total catch (211 kg). Spear took 68% of the weke while pole fishing providing the remainder of the catch for this species.

The most popular fishing grounds were located in Zones 1 and 5. Zone 1 was heavily used by the pole fishers compared to the rest of the zones, likely due to access to deeper water near Black Rock. Mid-way through the study period, however, an old pier in the area was fenced off preventing access by fishers. This change likely displaced some fishers into Zone 2 and/or towards the rocky shoreline along the southern edge of zone 1. Although fishing effort was highest in both Zone 1 and 5, the catch was much higher in zone 5 where the habitat is dominated by healthy spur and grove coral reefs. In addition shallow nearshore hard bottom habitat in this area appears to support a healthy he'e population. This resulted in the majority of he'e being caught in Zone 4 and 5. This fact seemed to support historical knowledge from fishing families who have traditionally harvested he'e from the Honokowai area. Zone 3 was where all of the uhu and the majority of kala were harvested (both restricted herbivorous species). This area is a good place for spearfishers to enter the ocean and the shallow water reef area is easily fishable for spearfishers of average abilities. Perhaps more importantly, however, the close proximity to parking within Zone 3 may allow illegal fishers direct and easy access to the water from their vehicles. This may facilitate a quick departure when they capture illegal fish.

Although KHFMA is a no-take area for herbivorous fishes, kala (Naso unicornis) was the third most abundant species caught by weight (106 kg) accounting for 9% of the total catch. While 86% of the kala were caught by spear, 14% was taken by pole fishing, which is somewhat surprising for an herbivore, but is consistent with traditional fishing methods whereby the seaweed "limu kala" (*Sargassum* spp.) is used as a bait to catch herbivores such as kala and enenue. Overall, herbivores accounted for 18% of the total catch by weight during the survey within the KHFMA and 25% of the total within Zone 3. More than 15% of individual spear fishing events caught regulated herbivores, accounting for 15.4% of the total spear fishing catch. Although only 7% of the pole fishing events took regulated herbivores, these species accounted for 24.5% of the total pole catch. Much of the pole catch of regulated herbivores by weight consisted of enenue, while much of the spear catch consisted of kala.

The total nearshore commercial catch for 2011 reported to Hawaii Division of Aquatic Resources for west Maui (Reporting area 301) was 3,287 kg (2,284 kg excluding akule and opelu). The catch within the much smaller KHFMA was 37% of this total (53% excluding akule and opleu). The KHFMA is an order of magnitude smaller in size than commercial report area 301, yet the catch within the FMA represents a substantial proportion of the total reported commercial for the much larger area and caught a greater number of species compared to the HDAR commercial catch records.

Differences between the estimates may consist of at least two components: (1) underreporting by commercial fishers on catch reports, and (2) large non-commercial catches contained in the creel survey. Underreporting is a common problem with unmonitored catch reports generally and is widely believed to be substantial in Hawaii. A creel survey of the fisheries within Hanalei Bay, Kauai in 1992 and 1993 reported 46,822 kg of fish while the DAR commercial catch reports for the entire north shore of Kauai for the same time period only recorded 5,490 kg (Friedlander et al. 1995). This eight fold difference in actual vs. reported catch highlights the large unreported and non-commercial catch in this area. Similarly, the average annual catch of he‘e in Kaneohe Bay, Oahu from a creel survey conducted in 1991-92 was 13,618 kg while the average annual statewide reported he‘e landings between 1980-90 were only 5,818 kg (Everson and Friedlander 2004).

There are currently a number of efforts underway within Hawaii to develop more systematic creel survey methodology across a wider range of communities. These surveys will provide a far more accurate picture of extractive uses in these areas than the commercial and HMRFS data currently provide and will serve as a baseline for future planning and management efforts. These data will be invaluable for the future development of effective restoration and management activities statewide. An added benefit is an opportunity to establish connections with community fishers, and to better understand fishers' use of the area, as well as the extent and severity of unsustainable/destructive and illegal fishing practices. Additionally, this process will forge relationships between the involved communities and management agencies, laying the groundwork for subsequent community monitoring efforts such like Makai Watch. Other anticipated benefits from this process are a heightened sense of stewardship among community members, and increased participation by fishers who want to promote the sustainable use of their resources.

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