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The impacts of spear and other recreational fishers on a small permanent Marine Protected Area and adjacent pulse fished area

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Abstract

I used shoreline creel surveys to quantify fishing activities in and around a small (0.34 km^2) Marine Protected Area (MPA) in Hawaii (Waikiki Marine Life Conservation District). Spear fishing and shoreline pole & line fishing (angling) were the dominant fishing activities at Waikiki. Spear fishing had a greater overall impact on reef fishes than shoreline pole & line fishing, accounting for 70% of the total reef fish harvest at Waikiki, despite accounting for only 25% of fishing activities observed. Fishing activities at Waikiki were unevenly distributed in space and time. The MPA experienced minor illegal fishing and was located between an area of high diurnal spear fishing effort and an area of generally low fishing effort. This pattern of fishing activities allows jacks and goatfishes to evade capture despite nightly excursions from the MPA into fished areas, and may partly explain why these fishes remain more abundant and larger inside the Waikiki MPA than in surrounding fished areas. Quantifying fishing activities at MPA sites can provide valuable insight into how these areas function, and this information can be used to improve MPA design and effectiveness.

Keywords: Marine Protected Area; Fishing impacts; Spear fishing

1. Introduction

There is concern that overfishing has drastically reduced abundance and size of targeted coral reef fishes in the Main Hawaiian Islands, and that this impact is greatest on the most heavily populated island of Oahu (Smith, 1993; Friedlander and Parrish, 1997; Friedlander and DeMartini, 2002; Friedlander et al., 2003). Despite these concerns there have been only two empirical studies quantifying fishing activities *in situ* on Hawaiian inshore reefs, and these were both carried out in coastal bays (Friedlander and Parrish, 1997, Everson unpublished data). Additional empirical studies from the dominant Hawaiian coastal habitat type (fringing reef) are needed to better understand how fishing impacts reef fish populations, and how negative effects can be mitigated.

A related question is how fishing around small Marine Protected Areas (MPAs) impacts the effectiveness of these sites as refuges for mobile, heavily exploited species. A number of small (0.14–1.2 km^2) 'no-fishing' MPAs have been created in the Main Hawaiian Islands over the past 4 decades with the primary goal of providing opportunities for recreational snorkeling and SCUBA diving (Friedlander, 2001, Clark and Gulko unpublished data). When these MPAs were created, few empirical data were available quantifying the movement patterns and habitat requirements of heavily targeted species, and consequently the design (size, habitat content, boundary placement) of these sites was largely *ad hoc*. Several subsequent studies have shown that these small MPAs contain higher standing stocks of reef fishes than surrounding fished areas despite largely *ad hoc* designs (Grigg, 1994; Friedlander, 2001; Meyer, 2003; Williams et al., 2006). However, recent fish tracking studies have also shown that several heavily targeted species have home ranges that are larger than these MPAs, and that individuals of these species are moving back and forth across MPA boundaries on a regular basis (Meyer, 2003; Wetherbee et al., 2004; Meyer and Honebrink, 2005). Empirical data quantifying fishing activities in and around existing small MPAs are needed in order to better understand how these areas function as refuges for mobile, heavily targeted reef fishes, and to optimize the design of future MPAs.

In the present study I quantified the types, distribution and catches of fishing activities on fringing reefs along a 7 km stretch

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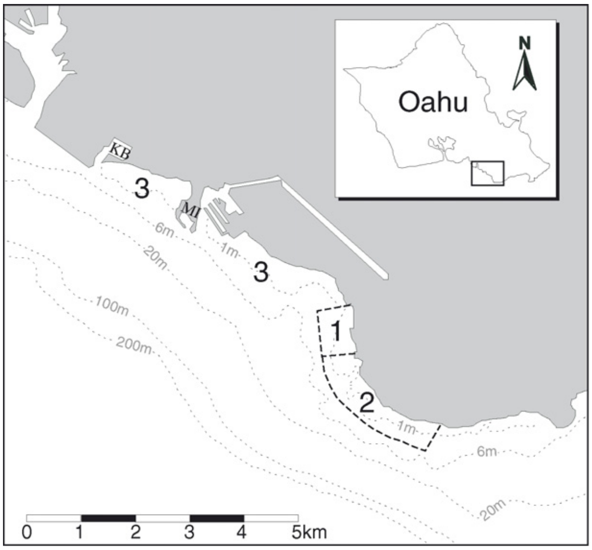

Fig. 1. Location of study sites on the south coast of Oahu. (1) No-take Marine Protected Area (Waikiki Marine Life Conservation District). (2) Pulse-fished area (Waikiki Fisheries Management Area). (3) Areas continually open to fishing. Shaded area = terrestrial habitat, bold dashed line = MPA and pulse-fished area boundaries. MI = Magic Island, KB = Kewalo Basin.

of the most urbanized coastline in Hawaii (Waikiki, Oahu) that is subdivided into three adjacent management areas: (1) a 0.34 km^2 ‘no take’ MPA (Waikiki Marine Life Conservation District), (2) a 0.86 km^2 ‘pulse-fished’ area (Waikiki Fisheries Management Area) and (3) a continually fished area (Fig. 1). Removal of marine life from the MPA has been prohibited since 1988 and the adjacent pulse-fished area undergoes alternate years of closure and fishing (pole & line, daytime spearfishing and thrownetting only). Previous studies have found that heavily targeted jacks and goatfishes are more abundant inside Waikiki MPA than in either of the adjacent fished areas (Meyer, 2003; Williams et al., 2006) despite nightly excursions from the MPA into the adjacent fished areas by several of these species (Meyer, 2003).

I used empirical fishing activity data collected at Waikiki to evaluate three hypotheses explaining these patterns: (H_1) Fishing methods used at Waikiki do not capture jacks or goatfishes and other factors determine fish abundance patterns, (H_2) Overall fishing mortality at Waikiki is low and other factors determine fish abundance patterns, and (H_3) Spatial or temporal gaps in fishing effort allow fish to evade capture during excursions from the MPA.

2. Methods

2.1. Fishing activity patterns

I used a roving creel survey methodology (Malvestuto et al., 1978) to quantify fishing activities at Waikiki. Trained observers patrolled the study site shoreline at 2 h intervals and recorded the number, location and type of fishing activities observed within 455 m (500 yards) of the high water mark. The seaward boundary applied to shoreline surveys was equivalent to the official seaward boundaries of both MPA and pulse-fished areas. Habitat for several hundred meters beyond this seaward boundary was primarily sand and flat reef, and supplementary observations indicated that very few fishing activities occurred in this area. Observers carried out a total of 675 shoreline patrols between June 1998 and August 2001. I stratified sampling effort to obtain data from summer, winter, all days of the week, and all times of day and night (Table 1).

Table 1
Sampling effort matrix illustrating the number of shoreline patrols carried out in each stratum of the survey

Time period (h)	Summer		Winter	
	Weekday	Weekend	Weekday	Weekend
00:00–02:00	3	2	12	6
02:00–04:00	3	2	10	2
04:00–06:00	3	2	4	4
06:00–08:00	4	0	24	7
08:00–10:00	2	1	53	11
10:00–12:00	2	2	64	21
12:00–14:00	7	3	38	29
14:00–16:00	25	4	42	22
16:00–18:00	28	7	43	20
18:00–20:00	9	4	36	10
20:00–22:00	3	4	40	5
22:00–00:00	5	2	38	7
Total	94	33	404	144

2.2. Catch and effort

I used two methods to quantify catch and effort at Waikiki: (1) observers recorded catches observed during shoreline patrols, and (2) observers conducted *in situ* interviews with fishers during shoreline patrols to obtain specific details of catch and fishing effort. Whenever possible, observers inspected catches, identified captured organisms to the lowest possible taxa, and estimated the total lengths (TL) of any fish captured to the nearest 5 cm. Observers asked fishers how long they had been fishing, what they had caught, and the type and amount of fishing gear that they were using. Observers also collected additional catch and effort data on the first day of open season for the pulse-fished area. Opening day attracted up to 269 fishers and provided an opportunity to collect a large amount of catch and effort data. I stationed observers at all major points of entry and exit to pulse-fished area from dawn onward on opening days. Observers intercepted and interviewed all spear fishers as they exited the water, and interviewed pole fishers when they ceased fishing.

2.3. Data analyses

I converted fishing activity counts to densities (number km^{-2}) in order to permit direct comparison between protected and fished areas of different sizes. I then log transformed the resulting densities to meet assumptions required for parametric testing, and analyzed them using a multifactorial general linear model (GLM) (Sokal and Rohlf, 1995). Factors included gear type (pole & line, spear and other gears), area (continually fished, pulse-fished and MPA), time of day (day or night), type of day (weekend or weekday), season (summer or winter) and the status of the pulse-fished area (open or closed). Interactions between area, gear type and the other factors were also included in the model. I evaluated the effects of individual factors on mean densities of fishing activities using Analyses of Variances (ANOVAs) with post hoc Bonferroni pairwise comparison of means. I used χ^2 analyses to evaluate associations between the frequency of gear type use and area, and between the frequency of illegal fishing inside the MPA and the status of the pulse-fished area.

I used χ^2 analyses to examine associations between the frequency of reef fish families in catches and the fishing gear type utilized. I used a Kolmogorov Smirnov two sample test to compare size frequencies of spear and pole & line catches, and an ANOVA with post hoc Bonferroni comparison of means to test the effect of gear type on mean size of fishes captured. In order to calculate catch per unit effort (CPUE) of fishers at Waikiki, I first converted length estimates of fishes from creel censuses to weight using the allometric length-weight conversion: $W = a\mathrm{SL}^b$, where parameters a and b are constants, SL standard length in mm, and W is weight in grams (Polunin and Roberts, 1993; McClanahan and Kaunda-Arara, 1996; Friedlander and Parrish, 1997). I used published and web-based species-specific conversion factors (http://www.fishbase.org/) to convert TL (from the midpoint of each 5 cm size class) to SL, and SL to weight. In the cases where length-weight information did not exist for a given species, the parameters from similar bodied congeners were used (McClanahan and Kaunda-Arara, 1996; Friedlander and Parrish, 1997). I then calculated Catch Per Unit Effort (CPUE) of pole & line and spear fishing by dividing the total catch from each individual fishing 'trip' by the total time spent fishing, to give units of either 'number h^{-1}' or 'kg h^{-1}'. I defined a pole & line fishing trip as the total time elapsed between first deployment and last retrieval of the fishing line, with effort adjusted for the number of lines deployed simultaneously by each fisher. I defined a spear fishing trip as the total time elapsed between entry and exit from the water.

I estimated the annual catch (tonnes) and yield (catch adjusted for area; t km^{-2}) of reef fishes at Waikiki using simple extrapolation of survey catch data. I first calculated the proportion of each year that was sampled during creel surveys. I then multiplied the total catch observed during creel surveys each year by the reciprocal of the proportion of time observed in that year. I applied a correction to catches from the pulse-fished area to account for the pronounced effort (and catch) spike observed on the biennial opening day. I derived this correction factor by averaging the opening day catches across open and closed years, and applying the mean 'January 1' catch to the annual catch derived from shoreline patrol data.

3. Results

3.1. Fishing activity patterns

Spear and pole & line were the dominant gear types used on the fringing reef at Waikiki, collectively accounting for 94–98% of all fishing activities observed in each area (Fig. 2).

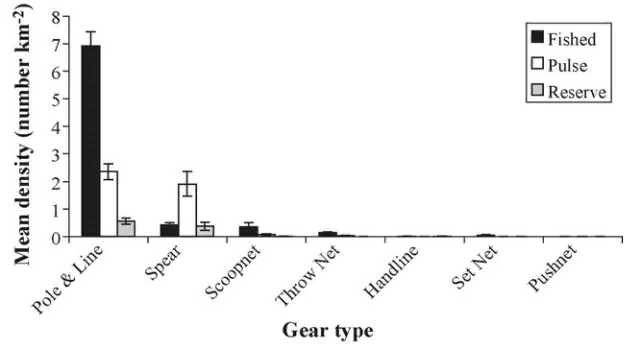

Fig. 2. Mean density of fishers (number km^{-2}) in continually fished (solid bars), pulse-fished (open bars) and no-fishing (shaded bars) areas at Waikiki. Error bars are ± 1S.E.M.

Observers also occasionally recorded several types of net fishing (scoop net, throw net, surround net, gill net) but these were very minor, sporadic components of total fishing activity (Fig. 2). The mean overall density (number km^{-2}) of fishing activities varied significantly ($P < 0.01$) with all factors except season, and the GLM revealed numerous significant interactions, indicating a complex pattern of fishing activities at Waikiki. The mean density (number km^{-2}) of pole & line fishing activities was significantly higher overall than mean density of spear fishing activities ($F = 160.2$, d.f. = 2, 2298, $P < 0.0001$) but the number of fishing activities accounted for by each gear type varied significantly between areas ($\chi^2 = 579.6$, d.f. = 4, $P < 0.001$). Pole & line fishing dominated activities in the continually fished area, whereas activities in the MPA and pulse-fished area were more evenly divided between pole & line and spear fishing (Fig. 2).

Spatial distribution of fishing activities within each area was patchy, with most fishers clustered around public shoreline access points situated close to free parking. Pole & line fishers preferred jetties, seawall railings and sandy beaches where they could set up their poles and cast their lines into natural and manmade channels. Spear fishers entered and exited at points of easy access to the water, and were most frequently sighted in areas of high rugosity reef within a few hundred meters of these access points. A few fishers used surfboards, kayaks and outrigger canoes to gain access to locations away from shoreline access points. The uneven distribution of these 'resources' (free parking, shoreline access, jetties, high rugosity reef) along the Waikiki coastline resulted in different patterns and densities of fishing activities in the areas adjacent to the northern and southern boundaries of the Waikiki MPA. The area immediately adjacent to the southern MPA boundary (Kaimanu Beach Park—pulse-fished area) was the most heavily spear fished location in the entire study site and was also a preferred location for pole & line fishers. The northern MPA boundary had only one location favored by pole & line fishers (a short concrete jetty) and was rarely spear fished. Fishing activities were rare along the 2.5 km stretch of coastline immediately adjacent to this northern boundary even though this area was continually open to fishing. This stretch contained most of the Waikiki hotels, beaches crowded with tourists and lacked free parking. Magic

Island (MI—Fig. 1) and the entrance channel to Kewalo Basin (KB) were the most intensively pole fished areas in the study site, and the reef between these two locations was frequently spearfished.

Pole & line and spear fishing activities at Waikiki had their own characteristic temporal patterns. Thus although both activities were significantly more frequent during daytime than at night (pole & line $F = 10.9$, d.f. = 1, 765, $P < 0.001$; Spear $F = 37.0$, d.f. = 1, 765, $P < 0.001$), spear fishing activity peaked during the morning and was rare at night, whereas pole & line fishing activity peaked during the afternoon and was also relatively common at night (Fig. 3). Spear fishing activity was significantly higher on weekends than weekdays ($F = 6.5$, d.f. = 1, 765, $P < 0.05$), and in winter than in summer ($F = 11.4$, d.f. = 1, 765, $P < 0.001$). There were no significant weekly ($F = 0.4$, d.f. = 1, 765, $P > 0.05$) or seasonal ($F = 0.8$, d.f. = 1, 765, $P > 0.05$) differences in pole & line fishing activities. The biennial opening of the pulse-fished area produced a pronounced, short-lived (1 week) spike in the density of fishing activities in both the pulse-fished area and adjacent MPA. The peak density of fishing activities during the first week of open season was over seven times higher than peak densities at other times. For example, 82 spear fishers were observed in the pulse-fished area at 08:00 on opening day 2000, whereas a maximum of 11 spear fishers were observed simultaneously in this area at other times of year.

Observers documented illegal fishing inside the Waikiki MPA on 9% of the shoreline patrols, recording a total of 54 illegal pole & line fishing events, 35 illegal spearfishing events and 5 illegally captured fishes. The frequency of illegal fishing in the Waikiki MPA was significantly associated with the status of the adjacent pulse-fished area ($\chi^2 = 22.0$, d.f. = 2, $P < 0.001$). Thirty-three (94%) of 35 illegal spear fishing events observed in the MPA occurred when the pulse-fished area was open to fishing, and twenty of these occurred on the first day of open season. Forty-eight (89%) of 54 illegal pole fishing events occurred when the pulse-fished area was open, and 29 of these occurred during the first 2 weeks of open season. Most of these events involved pole & line fishers casting their lines into the MPA from the boundary, or spear fishers venturing just inside the MPA boundary. Observers sighted nine spear fishers fishing in central areas of the MPA. Although observers documented illegal fishing inside the Waikiki MPA, the mean densities of most fishing activities were significantly lower inside the MPA than in the surrounding fished areas (Table 2). The only exception to this general pattern was the lack of significant difference between the relatively low mean densities of spear fishing activities in the MPA and continually fished area (Table 2).

3.2. Catch

Observers recorded a total catch of 657 reef fishes and 110 octopuses during shoreline patrols (167 fish, 31 octopuses) and opening day surveys (490 fish, 79 octopuses). Spear, pole & line and other gear types respectively accounted for 76.9%, 20.5%, and 2.6% of the total catch of reef fishes, and all octopuses were captured by spear. The total (combined) catch included 59 species from 31 reef fish families, of which 55 species were generally retained either for consumption or use as bait. Only toxic or small, unpalatable species (e.g., tetraodontids and synodontids) were routinely released. Catch composition varied between gear types; spear catches included 53 species from 23 reef fish families, and pole & line catches included 32 species from 25 families. Eighteen reef fish families occurred in both spear and pole & line catches, but the frequency with which these families occurred in catches varied significantly between gear types ($\chi^2 = 183.9$, d.f. = 6, $P < 0.0001$) (Fig. 4). For example, surgeonfishes (Acanthuridae) and parrotfishes (Scaridae) collectively accounted for 52% of the total spear catch of reef fishes, but only 2% of pole & line catches. Jacks (Carangidae) were the most abundant reef fish family in pole & line catches but accounted for only 2% of the total spear catch of reef fishes (Fig. 4). Goatfishes (Mullidae) were the 2nd and 3rd most abundant reef fish family in spear and pole & line catches respectively (Fig. 4). The size frequencies of spear and pole & line catches were significantly different (Kolmogorov Smirnov two sample

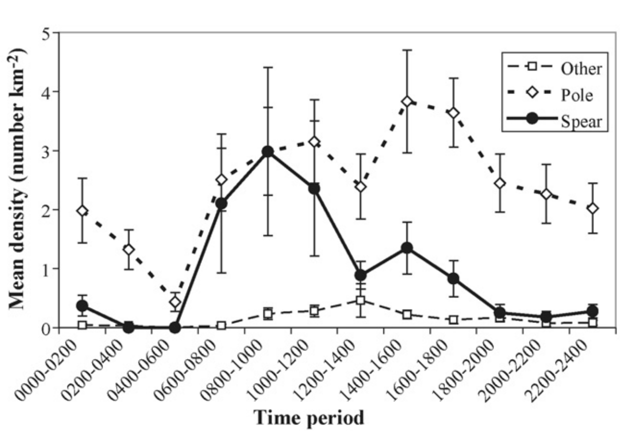

Fig. 3. Diel variation in mean density (number km^{-2}) of pole & line (dotted line), spear (solid line) and other (dashed line) fishers at Waikiki. Error bars are ± 1S.E.M.

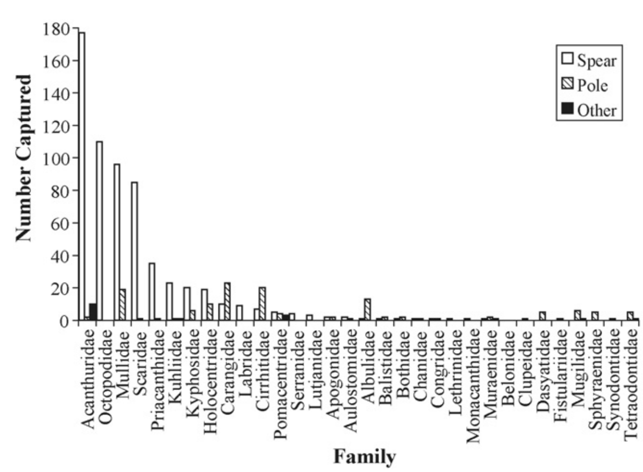

Fig. 4. Frequency of reef fish families (and octopus) in catches taken by spearfishers (open bars), pole & line fishers (shaded bars) and other fishers using other gear types (solid bars) at Waikiki.

Table 2
Results of analysis of variance for densities of fishing activities (number km^{-2}) observed in the continually fished (FA), pulse-fished (PF) and protected (MPA) areas at Waikiki

Gear type	Mean density (S.E.M.)			ANOVA			Bonferroni post hoc test
	Continually fished area (FA)	Pulse-fished Area (PF)	MPA	F	d.f.	P	
Pole & line	6.91 (0.53)	2.37 (0.27)	0.58 (0.12)	209.6	2, 764	0.0001*	FA > PF > MPA
Spear	0.43 (0.08)	1.91 (0.43)	0.38 (0.15)	21.8	2, 764	0.0001*	PF > FA = MPA
Other	0.52 (0.15)	0.13 (0.03)	0.02 (0.01)	33.9	2, 764	0.0001*	FA > PF > MPA

A significant difference (P < 0.05) is indicated with an asterisk (*). Results of post hoc Bonferroni pairwise comparisons of mean densities are indicated as ">" (significantly greater than, P < 0.001) and "=" (no significant difference).

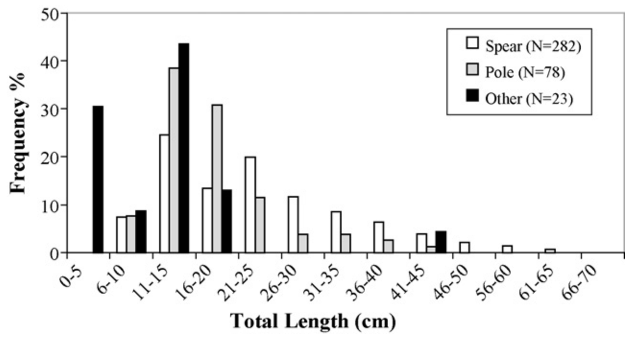

Fig. 5. Size frequency distribution of catches of reef fishes taken by spearfishers (solid bars), pole & line fishers (shaded bars) and fishers using other gear types (open bars) at Waikiki.

test, D = 0.32, P < 0.0001)(Fig. 5), and mean fish size varied significantly between gear types (ANOVA, d.f. = 2, 384, F = 16.9, P < 0.0001). The mean size (cm TL) of fishes captured by spear fishing (33.7 ± 2.7) was significantly larger than the mean size of fishes captured by pole & line fishing (19.2 ± 1.0) (Bonferroni post hoc test, P < 0.001).

Spear fishing CPUE was higher than pole & line CPUE. The mean numerical CPUE (number h^{-1}) was 1.6 times higher for spear fishing (1.53 ± 0.22) than pole & line fishing (0.97 ± 0.36), but the difference was non-significant (t = −0.769, d.f. = 93, P > 0.05). However, the mean biomass CPUE (kg h^{-1}) was 28 times higher for spear fishing (1.13 ± 0.22) than pole & line fishing (0.04 ± 0.02) (t = −2.295, d.f. = 85, P < 0.05). The estimated annual catch (tonnes) of reef fishes varied between gear types and areas at Waikiki (Table 3). Spear fishing produced the largest catch of any gear type in each area, and the largest overall. The estimated annual yield (catch adjusted for area; t km^{-2}) was two to six times lower in the MPA than in the adjacent fished areas. The estimated annual yield from open years in the pulse-fished area was three times higher than in the continually fished area.

Table 3
Estimated annual catch (t) of reef fishes by area and gear type at Waikiki

Gear type	Continually fished area	Pulse-fished area[a]	MPA
Spear	0.228	0.539	0.023
Pole	0.210	0.031	0.005
Other	0.020	0.011	0.000
Total	0.457	0.581	0.028
Total yield (t km^{-2})	0.199	0.581	0.091

Annual yield estimates (t km^{-2}) for each area are given below catch totals.
[a] Catch and yield calculated for open years only.

4. Discussion

Heavily targeted reef fishes are more abundant inside a small (0.34 km^2) Hawaiian MPA (Waikiki MLCD) despite nocturnal excursions by these fishes across MPA boundaries into adjacent fished areas (Meyer, 2003; Williams et al., 2006). My first hypothesis to explain this pattern was that fishing methods used at Waikiki do not capture these species. I rejected this hypothesis because jacks and goatfishes were major components of the shoreline reef fish harvest at Waikiki. In fact catch compositions observed at Waikiki were generally similar to those observed elsewhere in Hawaii and at other locations in the Pacific. For example, jacks and goatfishes are the primary components of pole & line catches in Hanalei Bay and Kaneohe Bay (Hawaii), and goatfishes, parrotfishes and surgeonfishes are primary components of spear fishing catches in many areas of the Pacific (Dalzell, 1996; Friedlander and Parrish, 1997).

My second hypothesis was that overall fishing mortality at Waikiki is low and patterns of fish abundance and size are primarily determined by intrinsic factors. I found that Waikiki pole & line and spear fishing catch rates were generally similar to those observed elsewhere. For example, Friedlander and Parrish (1997) estimated CPUE for shore based line fishing at Hanalei Bay at 0.07 kg line h^{-1}, whereas I calculated Waikiki pole & line fishing CPUE to be 0.04 kg line h^{-1}. Mean spear fishing CPUE estimates from Pacific coral reef fisheries range from 0.4 to 2.4 kg man h^{-1} with a mode around 1.2 kg man h^{-1} (Dalzell, 1996). I found that Waikiki spear fishing CPUE (1.13 kg man h^{-1}) was in the middle of this range and 30% higher than spear catch rates observed in Kaneohe and Hanalei Bay (Friedlander and Parrish, 1997, A. Everson unpublished data). However, I estimated that annual yields for the legally fished areas at Waikiki (0.2–0.58 t km^{-2}) were one to two orders of magnitude below those calculated for fisheries operating in similar sized areas of fringing reef habitat in other locations in the Pacific (4.5–44.0 t km^{-2}; Dalzell, 1996), and below the annual yield estimate of 0.8 t km^{-2} for Hanalei Bay (Friedlander and Parrish, 1997).

By comparing pre MPA closure (1979–1989) estimates of standing stock at Waikiki (1.7–3.6 kg 100 m^{-2}; Brock unpublished data) with annual yield estimates from the present study, I calculated that annual exploitation rate at Waikiki was only 0.6–3.4% (assuming that the pre MPA closure estimates are representative of the standing stock in the fished areas at Waikiki during the present study). These results support the low fishing mortality component of my second hypothesis. I also observed greater abundance and size of non-targeted species (e.g., trigger fishes and Moorish idols) inside Waikiki MPA than in surrounding fished areas (Meyer, 2003), which supports my contention that intrinsic factors are important in determining patterns of abundance at Waikiki. For example, greater habitat complexity inside Waikiki MPA than in surrounding fished areas could explain these fish abundance patterns (Roberts and Ormond, 1987; Grigg, 1994; McClanahan, 1994; Roberts, 1995; Rakitin and Kramer, 1996; Friedlander and Parrish, 1998).

My third hypothesis was that spatial or temporal gaps in fishing effort allow fish to evade capture during their excursions from the Waikiki MPA. I found that fishing activities at Waikiki were unevenly distributed in space and time. The MPA experienced minor illegal fishing but was generally a safe refuge for reef fishes. The area adjacent to the southern MPA boundary (Kaimanu Beach Park) was heavily spear fished during daytime, and also frequently used for shoreline pole & line fishing. The area adjacent to the northern MPA boundary had a single jetty used by pole & line fishers but little other fishing activity along the next 2.5 km of coastline. Fishing activity was near zero for at least several hundred meters beyond the seaward MPA boundary. Thus Waikiki MPA is located between an area of high diurnal fishing effort and an area of generally low fishing effort. Jacks and goatfishes avoid 'high impact' spear fishing by remaining inside the Waikiki MPA during the day (Meyer, 2003), and only risk capture at night if they venture close (i.e., within casting distance) to the pole & line fishing sites at the northern and southern MPA boundaries. These results support my hypothesis that fishing activity patterns allow mobile target species to evade capture despite nocturnal excursions into fished areas, and partly explain why such fishes remain more abundant and larger inside the Waikiki MPA than in surrounding fished areas (Meyer, 2003).

The results of this study have important implications for the design and assessment of MPAs intended as management tools for home-ranging species such as coral reef fishes. For example, MPAs must be large enough and include appropriate habitat to contain the entire daily home ranges of targeted species in order to provide continued effective protection against changing patterns of fishing activities outside their boundaries. The existing Waikiki MPA is too small to protect mobile species such as jacks and goatfishes, and although current fishing activity patterns allow these species to evade capture, a change in fishing activities around the MPA could easily eliminate this effect. For example, nighttime spear fishing or trapping outside the MPA boundaries could intercept fishes exiting the MPA. Greater target species abundance and size inside MPAs does not unequivocally prove that these areas are providing effective protection for these species, despite being the most frequently used metric of MPA effectiveness (e.g., Halpern, 2003). If we rely on this as our primary measure of MPA effectiveness, we risk establishing sub-optimal MPAs that will be vulnerable to changing patterns of exploitation outside their boundaries. Quantifying fishing activities at MPA sites can provide new insight into how these areas function and help us to improve MPA design.

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