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Movement patterns, home range size and habitat utilization of the bluespine unicornfish, *Naso unicornis* (Acanthuridae) in a Hawaiian marine reserve

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Synopsis

We quantified bluespine unicornfish, *Naso unicornis*, movement patterns, home range size and habitat preferences in a small Hawaiian marine reserve. Bluespine unicornfish were site-attached to home ranges situated within the reserve boundaries and their movements were aligned with topographic features. Two different diel movement patterns ('commuting' and 'foraying') were observed. Commuters made crepuscular migrations of several hundred meters between daytime foraging areas and nighttime refuge holes. Foraying fish did not partake in crepuscular migrations and utilized refuge holes both day and night. Two bluespine unicornfish were also nocturnally active. There was little direct evidence of dispersal from the reserve but differences in bluespine unicornfish abundance and size among reef habitat zones were consistent with ontogenetic habitat shifts. The influence of habitat topography on bluespine unicornfish movements suggests that gross habitat characteristics could be used to predict reef fish movements. This could provide a simple method for setting marine reserve boundaries at sites for which empirical fish movement data are unavailable.

Introduction

Surgeonfishes (Acanthuridae) are a major component of the coral reef fish fauna (Fishelson et al. 1987) and play an important role in structuring coral reef benthic communities by regulating species composition and abundance of algae (Lewis 1986, Hixon & Brostoff 1996, McClanahan 1997). Previous studies of surgeonfish movements found that some surgeonfishes are strongly site-attached (Robertson 1983, Robertson & Gaines 1986, Craig 1996, Bell & Kramer 2000), whereas others wander (Morgan & Kramer 2004a). Some surgeonfishes also make daily crepuscular migrations of up to 1.5 km between separate refuging and foraging areas (Walsh 1984, Mazeroll & Montgomery 1995, 1998) and may migrate up to 1 km to spawning areas (Myrberg et al. 1988, Mazeroll & Montgomery 1995). Previous studies of surgeonfish movements relied on diver observations and hence were primarily restricted to daytime. In this study we use acoustic telemetry (sonic tracking) to continuously follow individual bluespine unicornfish throughout multiple diel cycles, thus obtaining a more comprehensive picture of the scale and pattern of individual movements.

The bluespine unicornfish, *Naso unicornis*, is a large (up to 69 cm total length) surgeonfish that occurs in shallow habitats throughout the Indo-Pacific region where it is extensively targeted by fishers (Randall 1985, Meyer 2003). There are currently no empirical data quantifying bluespine unicornfish movement patterns, home range size and site fidelity. In fact empirical data quantifying movements, home range sizes and site fidelity of coral reef fishes remain scarce despite the growing popularity of ‘no-fishing’ marine reserves as tools for managing exploited coral reef fishes (e.g., Roberts & Polunin 1993, Nowlis & Roberts 1999, Kramer & Chapman 1999, Nowlis 2000). Marine reserve effectiveness depends on resident fish having home ranges that lie within the reserve boundaries and thus remain protected from fishing mortality (e.g. Kramer & Chapman 1999, Nowlis 2000). In the present study we empirically evaluate whether a small (0.34 km^2) Hawaiian marine reserve (Waikiki reserve) provides effective protection for bluespine unicornfish by; (1) Quantifying movement and activity patterns, home range size, habitat use and site fidelity of bluespine unicornfish captured inside the reserve. (2) Comparing bluespine unicornfish abundance and size inside Waikiki reserve with that in adjacent fished areas.

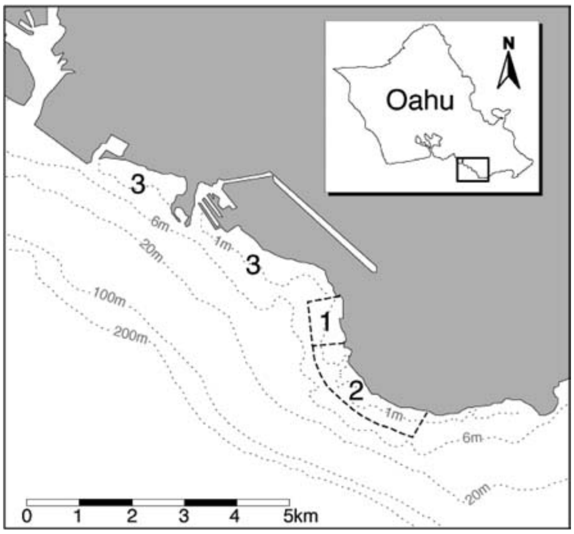

Figure 1. Location of study sites on the south coast of Oahu. 1. No-take marine reserve (Waikiki Marine Life Conservation District). 2. Pulse-fished area (Waikiki Fisheries Management Area). 3. Areas continually open to fishing. Shaded area = terrestrial habitat, bold dashed line = marine reserve and pulse-fished area boundaries.

Methods

Study site

The study site was a 7 km stretch of high-energy fringing reef situated on the south shore of Oahu and divided into three management areas; (1) a ‘no take’ marine reserve (Waikiki Marine Life Conservation District), (2) a ‘pulse-fished’ area (Waikiki Fisheries Management Area) and (3) a continually fished area (Figure 1). Removal of marine life from the reserve 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). Pole & line, daytime spearfishing and thrownetting account for 96% of all fishing activities in the continually fished area (Meyer 2003). The reserve and pulse-fished area have seaward boundaries that run parallel to the shore at a distance of 455 m (500 yards) offshore from the high-water mark. They respectively cover 750 and 1900 m of shoreline and enclose areas of approximately 0.34 and 0.86 km^2. The fringing reef at Waikiki is subdivided into five well-defined habitat zones; 1. a sheltered back reef area consisting of shallow (<1 m) reef interspersed with deeper (2–3 m) sandy areas and backed by sandy beaches, 2. an extensive, shallow (<1 m) reef flat located seaward of the back reef area, 3. a narrow band of high rugosity reef crest forming the seaward margin of the reef flat, 4. a deeper (>4 m) fore reef area of large sand patches and flat, hard reef substrate located seaward of the reserve reef crest, and 5. Spur and groove habitat (>4 m) located seaward of the reef crest in the fished areas.

Acoustic tracking

We used acoustic telemetry (active tracking and remote monitoring) to quantify bluespine unicornfish movement patterns, habitat use and home range sizes. We captured bluespine unicornfish inside Waikiki reserve using surround nets, or by hand from nighttime refuge holes. We anaesthetized each bluespine unicornfish with MS-222 (0.1 g/l) and externally attached an ultrasonic transmitter (V8-2L, 0.8 cm diameter, 3.0 cm long, 21 day nominal battery life, Vemco, Halifax, Nova Scotia) alongside the dorsal fin (Meyer & Holland 2001). We also tagged each bluespine unicornfish with a serially numbered, 8.0 cm plastic dart tag (Hallprint, South Australia) before releasing them at point of capture after resuscitation. We collected no tracking data during the first 5 days after release because initial observations indicated that newly released bluespine unicornfish remained quiescent in refuge holes for up to 72 h.

We actively tracked bluespine unicornfish from a 4 m kayak equipped with a directional hydrophone, acoustic receiver and a handheld Global Positioning System unit (Garmin 12XL) (Meyer & Holland 2001). We recorded fish location at 15-min intervals at which time we maneuvered the kayak to within 5 m of the fish. We periodically corroborated this distance estimate by comparing signal strength with the position of a snorkeler in visual contact with the transmitter-equipped fish. We tracked each transmitter-equipped bluespine unicornfish on two to five occasions over a 2–3 week period. On each of these occasions we followed fish continuously for 12–72 h.

We used the Animal Movement Extension[1] for ArcView® to analyze active tracking data. We first tested the site fidelity of each bluespine unicornfish by comparing observed movements with 1000 random walks incorporating the actual sequence of distances traveled by fish during each 15-min interval[2]. We used minimum convex polygons (MCP) to describe the overall size and shape of the area covered by each bluespine unicornfish (MacDonald et al. 1980, Meyer et al. 2000), and kernel home ranges (KHR) to obtain higher resolution information on habitat and space use (Seaman and Powell 1996).

We used a remote monitoring system to investigate whether bluespine unicornfish activity patterns documented during active tracking were maintained over longer periods (weeks). The system consisted of an omni-directional hydrophone connected via a 100 m cable to an acoustic receiver and computer on shore. We placed the hydrophone in the daytime foraging habitat of a transmitter-equipped bluespine unicornfish and programmed the system to record the times at which the fish visited this area.

Long-term site fidelity and dispersal

Between April 1997 and February 2001, we measured, tagged (externally visible Hallprint dart tags) and released all bluespine unicornfish (N = 141) caught in the Waikiki reserve and adjacent areas. We tagged bluespine unicornfish captured inside the Waikiki reserve (N = 114) and in adjacent areas (N = 27) on the left and right sides of their dorsal fins respectively. Each tag carried a reward notice and a phone number. Tagged fish recaptured by scientific personnel were remeasured and released.

Abundance, distribution and size

We used an underwater visual census (UVC) methodology to quantify bluespine unicornfish abundance, distribution and size at Waikiki. We initially used a 5 × 50 m belt transect methodology (Sale & Douglas 1981) for this purpose, but avoidance behavior resulted in unrepresentatively low counts inside the transect sampling corridor. We therefore used a modified ‘timed swim’ version of the transect method to obtain more representative samples. Each timed swim consisted of a 15-min snorkel through one of the four distinct reef habitat zones (e.g., reef crest) (Polunin & Roberts 1993, Rakitin & Kramer 1996), during which the observer swam slowly in a straight line and recorded the number and size (total length to the nearest 5 cm) of all bluespine unicornfish encountered in that habitat. Observers also recorded the tag placement (left or right side of dorsal fin) of any tagged fishes sighted. The use of a 15-min survey time limit, instead of a narrow (i.e., 5 × 50 m) belt transect, effectively broadened the area surveyed and thus minimized avoidance errors, and helped to integrate small-scale patchiness (Grigg 1994, McClanahan & Kaunda-Arara 1996).

We converted bluespine unicornfish lengths to biomass using species-specific length to weight relationships.[3] We log transformed biomass data

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[1] Hooge, P.N. & B. Eichenlaub. 1997. Animal Movement Extension to Arcview. Ver. 2.0. Alaska Biological Science Center, U.S. Geological Survey, Anchorage, AK, USA. Available from the Internet URL http://www.absc.usgs.gov/glba/gistools/animal_mvmt.htm

[2] Hooge, P.N., W.M. Eichenlaub & E.K. Solomon. 2001. Using GIS to Analyze Animal Movements in the Marine Environment. Alaska Biological Science Center, U.S. Geological Survey, Anchorage, Alaska. 20 pp. Available from the Internet URL http://www.absc.usgs.gov/glba/gistools/anim_mov_useme.pdf

[3] Available online at http://fishbase.org/PopDyn/LWRelationshipList.cfm?ID = 1265 & GenusName = Naso & SpeciesName = unicornis & fc = 412

and analyzed them using a two-way analysis of variance. Factors included management regime ('regime'), habitat type ('habitat'), and the interaction between regime and habitat. Fore reef (reserve) and spur and groove (fished areas) habitats were combined into a single habitat class for analyses. We analyzed bluespine unicornfish size data using a one-way analysis of variance with regime as the independent factor, and used post hoc Bonferroni pairwise comparisons to test the significance of size differences between management regimes.

Results

Movement patterns and habitat use

We tracked five bluespine unicornfish (39.4–54.4 cm TL), each on up to five occasions lasting from 12 to 72 h (a total of 24–118 hours overall per fish), over periods spanning between 9 and 22 days (Table 1). Bluespine unicornfish movements were aligned with topographic features such as the reef crest and back reef channels. Bluespine unicornfish were typically most active during the day and quiescent in refuge holes (narrow reef crevices) at night, but two were also nocturnally active. We observed two broad patterns of behavior ('commuting' and 'foraying'). Commuters (fish #3 & #4) made daily, crepuscular migrations of several hundred meters between nighttime refuge holes and daytime foraging areas, joined conspecific foraging schools on the reef crest during daytime and only used refuge holes at night. Foraying fish (#1 & #5) did not partake in crepuscular migrations, utilized refuge holes during both day and night, and made repeated short (5–15 min), solitary 'forays' into areas of high algal cover situated within 10–40 m of their holes. Subsequent remote monitoring revealed that fish #5 maintained this foraying behavior for 7 weeks (the transmitter lifespan) and was also active at night (Figure 2). Forty-six percent of nighttime forays by fish #5 occurred without moonlight (when the moon was below the horizon). The remaining fish (#2) was quiescent in a refuge hole between dawn and midnight but left this location in the early morning hours, and moved slowly to a location 170 m further west where it spent 2–3 h before returning to its primary refuge hole at dawn. These nocturnal movements occurred without moonlight (on a new moon when the moon did not rise during the night).

Site fidelity and home range size

The movements of four tracked bluespine unicornfish were significantly ($p < 0.001$) more constrained than random movement paths indicating that these fish were site-attached. Their MCP home range sizes ranged from 325 to 7650 m^2 (mean = 3717 m^2) and were smaller in back reef habitat than on the reef crest (Table 1, Figure 3). There was a significant negative correlation between fish size and home range size of the 4

Table 1. Summary of tracking data from five bluespine unicornfish captured and released within the Waikiki reserve.

	Fish Number				
	1	2	3	4	5
Total length (cm)	51.2	44.9	39.4	54.4	47.0
Start date of track	9/06/98	01/07/98	22/02/99	28/02/00	11/08/00
Tracking span (days)	20	22	20	9	13
No. of different tracking occasions	3	3	3	2	5
Total number of tracking hours	79	51	118	24	63
Behavior type	Foray	Commute	Commute	Mixed	Foray
MCP home range size (m^2)	325	6026	7650	57 400*	865
Kernel home range – 50% (m^2)	839	818	824	1181*	845
Kernel home range – 95% (m^2)	1847	2268	5484	6619*	2344
Mean distance traveled (m^{-1} 24 h^{-1})	41	489	464	1653	246
% of total reserve area used	0.1	1.8	2.3	16.9	0.3

* Not significantly site-attached.

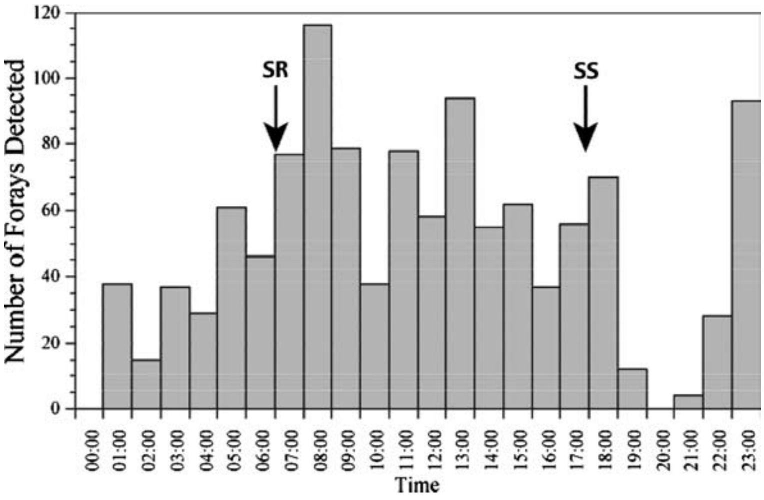

Figure 2. Diel variation in the frequency of forays into foraging habitat by fish #5. Arrows indicate sunrise (SR) and sunset (SS).

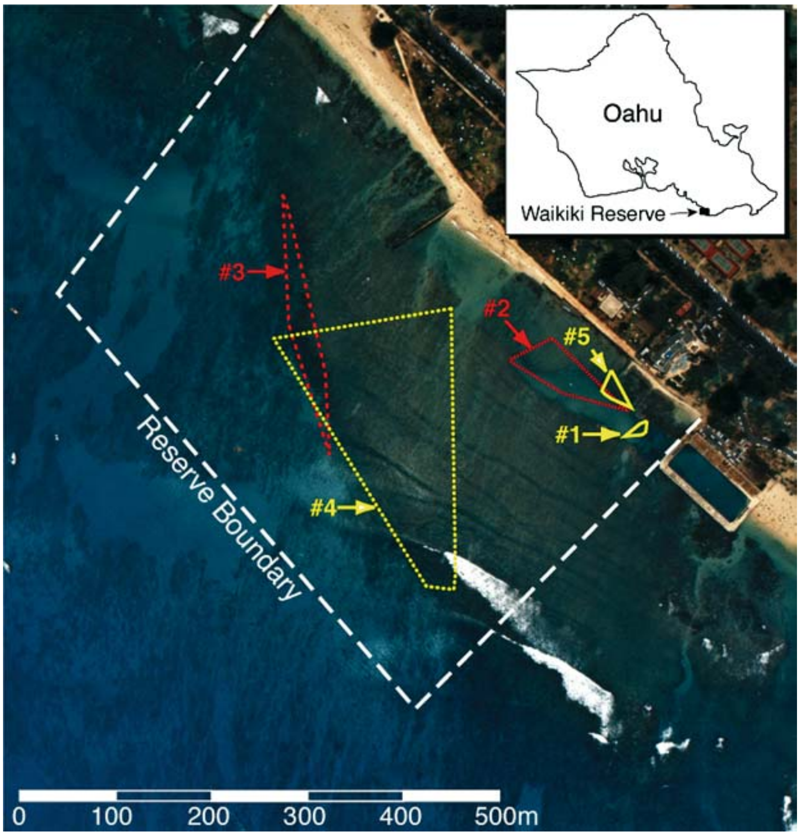

Figure 3. MCP home range size of five bluespine unicornfish tracked in the Waikiki reserve. White dashed line = reserve boundary, red & yellow lines = minimum convex polygons (MCP) denoting home range borders of each fish.

site-attached fish (Pearson correlation, $r = 0.906$, d.f. = 2, $p < 0.05$). Differences in behavior patterns accounted for the differences in MCP home range size. Commuter bluespine unicornfish had larger home ranges and traveled 2–10 times further per 24 h than foraying individuals (Table 1).

Fish #4, which did not show significant site fidelity, used 57 400 m^2 of reef habitat and traveled a minimum of 1653 m during only 24 h of tracking (Figure 3, Table 1). Although MCP home ranges varied in size by an order of magnitude, only a small proportion of each home range was used intensively and core activity spaces (KHR) were similar for all bluespine unicornfish tracked (Table 1).

The movements of all five bluespine unicornfish tracked were contained within Waikiki reserve boundaries (Figure 3). The MCP home ranges of the four site-attached fish each occupied from 0.1 to 2.3% (mean = 1.1%) of the total reserve area, and the movements of bluespine unicornfish #4 occupied an MCP equivalent to 16.9% of the total reserve area (Table 1). Although each bluespine unicornfish home range occupied only a small proportion of the total reserve area, the daily 'commutes' carried out by fish #3 and #4 took them back and forth across 24–52% of the total reserve width.

Long-term dispersal patterns

We tagged and released 114 bluespine unicornfish, ranging in size from 14.6 to 54.4 cm TL (mean = 32.6 cm TL), inside the Waikiki reserve between 1997 and 2001. We recaptured 5 (4.3%) of these tagged fish inside Waikiki reserve (but none outside) after times at liberty ranging from 21 to 83 days (mean 57 days). We also tagged and released 27 bluespine unicornfish, ranging in size from 16.2 to 38.2 cm TL (mean = 24.6 cm TL), in the pulse-fished area (within 100 m of the reserve boundary). We recaptured 2 (7.4%) of these bluespine unicornfish within 50 m of their point of release after 22 and 314 days at liberty respectively. Between 1998 and 2001, we also resighted 33 of our tagged bluespine unicornfish during 513 visual census counts carried out in the reserve (204 counts) and adjacent areas (309 counts). Thirty of these sightings occurred inside the reserve, of which 29 (97%) were of bluespine unicornfish originally tagged and released inside the reserve (i.e., tagged on the left side of the dorsal fin). We sighted one fish tagged in the pulse-fished area inside the reserve boundary. We sighted only three tagged bluespine unicornfish outside the reserve, all such sightings were within 50 m of the reserve boundary and only one of these fish was originally tagged and released inside the reserve.

Abundance, distribution and size

A two-way ANOVA indicated significant management regime ($p < 0.0001$), habitat ($p < 0.0001$) and regime–habitat interaction ($p < 0.0001$) effects on bluespine unicornfish biomass at Waikiki. The significant interaction occurred because the distribution of bluespine unicornfish biomass among habitat zones varied between reserve and fished areas (primarily because spur and groove and fore reef habitats were combined for analyses) (Figure 4). Although we detected a significant interaction, the major effects of regime and habitat on biomass were still clear; bluespine unicornfish biomass was significantly higher overall in the Waikiki reserve ($p < 0.0001$) than in adjacent fished areas, and significantly higher overall in reef crest habitat ($p < 0.0001$), where bluespine unicornfish typically formed large schools, than the other lower rugosity habitats, where bluespine unicornfish were typically solitary, or in small groups (Figure 4). Overall, there were no significant differences in bluespine unicornfish biomass between pulse-fished & continually fished areas ($p > 0.05$).

Bluespine unicornfish sizes in all three areas were similar, although the slight difference observed was statistically significant ($p < 0.0001$). A variable proportion of larger bluespine unicornfish size classes accounted for the differences between management areas. For example, bluespine unicornfish larger than 40 cm TL were rare (<0.2%) in the fished areas but accounted for 4% of bluespine unicornfish observed in the reserve (Figure 5a). There were also some obvious differences in bluespine unicornfish size between habitats. Back reef habitat was dominated by small (<20 cm TL) bluespine unicornfish whereas the majority of bluespine unicornfish in reef crest habitat were larger than 20 cm TL (Figure 5b).

Discussion

Bluespine unicornfish behavior at Waikiki was generally consistent with that of other surgeonfishes. For example, some surgeonfishes are strongly site-attached (Robertson 1983, Robertson

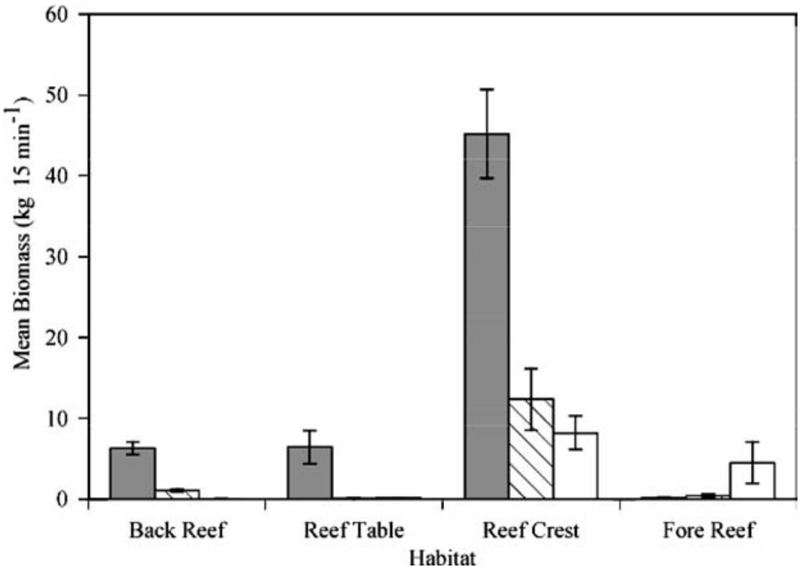

Figure 4. Distribution of bluespine unicornfish biomass (kg^{-1} 15 min^{-1}) among four different habitat types in the reserve (shaded bars), pulse-fished area (hatched bars) and continually fished area (unshaded bars). Error bars ±1 SEM. Fore reef habitat bin also includes spur & groove habitat.

& Gaines 1986, Craig 1996, Bell & Kramer 2000), and several surgeonfishes exhibit different daytime social modes ranging from solitary to schooling (Barlow 1974, Atkins 1981, Wolf 1987, Morgan & Kramer 2004a, b). Other surgeonfishes also make daily crepuscular migrations between separate refuge and foraging areas (Walsh 1984, Mazeroll & Montgomery 1995, 1998). Intraspecific variation in crepuscular behavior (commuting vs. non-commuting) has not been described for surgeonfishes but is known from male striped parrotfish (*Scarus iserti*) that either sleep within their daytime territories or migrate to separate sleeping spots (Dubin & Baker 1982). Variations in crepuscular behavior could be related to predation risks associated with daytime group size. Reduced predation risk associated with daytime schooling could explain why school-forming commuters only returned to their refuge holes at night, whereas solitary foraying bluespine unicornfish remained in close association with refuge holes during both day and night.

This study provides the first description of nocturnal movements in surgeonfishes (previously thought to remain quiescent at night). These nocturnal activities do not appear to be aberrant because they were observed in two of five bluespine unicornfish tracked and occurred repeatedly over a 7-week period in one passively monitored fish. Bluespine unicornfish moved up to 170 m on nights where moonlight was completely absent. The reason for these nocturnal movements is unclear but their discovery emphasizes the utility of acoustic telemetry for revealing previously unknown behaviors.

We recaptured or resighted few of our externally tagged bluespine unicornfish and saw little direct evidence of dispersal from the Waikiki reserve. Our low recapture rates could indicate that bluespine unicornfish frequently shed their tags, perhaps because of physical abrasion associated with their habit of wedging in narrow crevices. Although there was little direct evidence of dispersal from Waikiki reserve, underwater visual census results suggested that bluespine unicornfish undergo ontogenetic habitat shifts from shallow, sheltered areas of the reef to deeper, more exposed habitats. Similar ontogenetic habitat shifts are thought to occur in other surgeonfishes (Harmelin-Vivien 1984, Lawson et al. 1999) and are a possible mechanism of long-term dispersal from marine reserves to fished areas (e.g., Meyer et al. 2000).

Although bluespine unicornfish were significantly larger and more abundant inside the Waikiki reserve than in adjacent fished areas, a

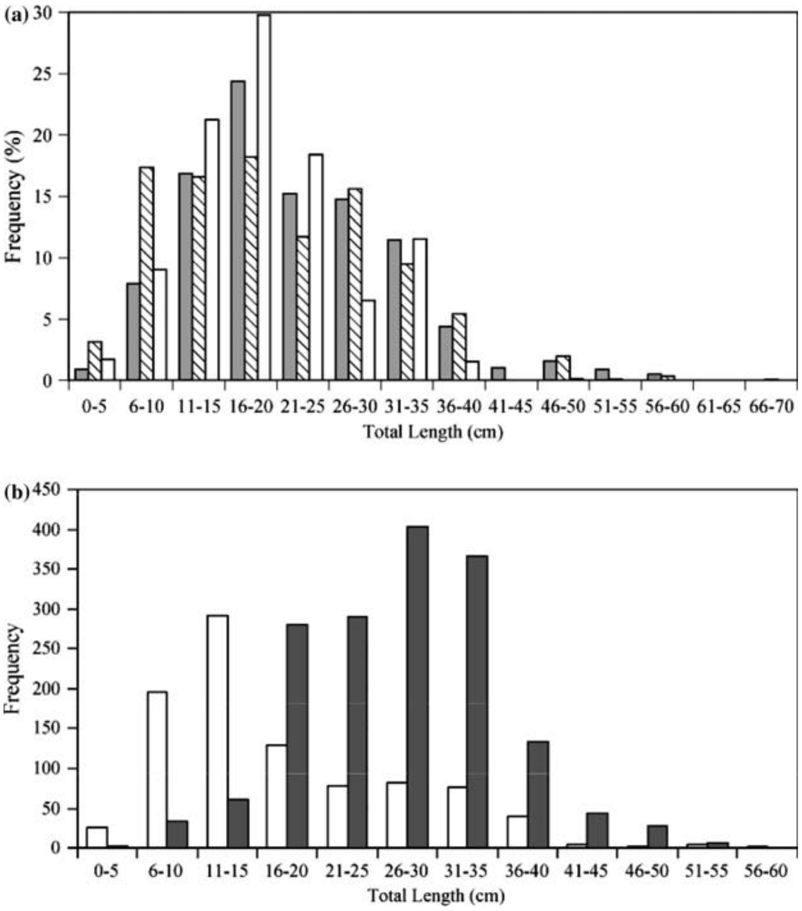

Figure 5. (a) Bluespine unicornfish size frequency in the reserve (shaded bars, N = 8122), pulse-fished area (hatched bars, N = 1730) and continually fished area (unshaded bars, N = 1439). (b) Bluespine unicornfish size frequency in reserve back reef (open bars) and reef crest (shaded bars) habitats.

contemporaneous study revealed similar distributional patterns among non-targeted species such as triggerfishes (Meyer 2003). This suggests that any potential reserve effects were masked by other factors such as differences in habitat quality between Waikiki reserve and adjacent fished areas. Determining the relative contributions of habitat quality and protection from fishing to the observed patterns of bluespine unicornfish abundance and size would require a 'Before After Control Impact' study design. This was not possible in the present study because no comparable visual census data were collected prior to establishment of the Waikiki reserve in 1988 (Meyer 2003).

Bluespine unicornfish daily home ranges typically occupied less than 3% of the total reserve area and no tracked bluespine unicornfish crossed reserve boundaries. However, the daily crepuscular migrations of 'commuter' bluespine unicornfish resulted in narrow, elongated home ranges that spanned 24–52% of the reserve width. This commuting behavior could result in fishes regularly crossing the boundaries of small reserves and should be considered when designing marine reserves. For example, Russ & Alcala (2003) cited increases in *Naso vlamingii* biomass within 250 m of the reserve boundary as evidence of 'spillover' from the Apo Island reserve (Philippines). The limited spatial scale of this spillover was well within the daily range of movements exhibited by commuter bluespine unicornfish at Waikiki. Thus one mechanism of spillover may be the daily movement of fishes back and forth across reserve boundaries. Harvesting these commuters in close proximity to reserve boundaries could decrease spawning biomass within reserve boundaries.

Bluespine unicornfish movements were generally aligned with topographical features of the fringing reef (e.g., the reef crest), suggesting that gross habitat characteristics could potentially be used to predict reef fish movement patterns. This could provide a simple method for placing reserve boundaries at sites for which empirical fish movement data are unavailable. For example, in order to reduce the probability of fish home ranges extending into unprotected areas, reserve boundaries could be placed along natural borders between discrete areas of habitat rather than dividing regions of contiguous habitat (Barrett 1995, Chapman & Kramer 2000).

Acknowledgements

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