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Title: Acoustic monitoring of long-term movement patterns, habitat use and site fidelity of coral reef fishes: Implications for Marine Protected Area design.

P.I.: Carl Meyer, Ph.D., Hawaii Institute of Marine Biology, PO Box 1346, Kaneohe HI 96744, Phone: (808) 236-7477, email: carlm@hawaii.edu

Summary

We need to understand the long-term movement patterns of coral reef fishes in order to design marine protected areas (MPAs) that will provide these animals with effective, long-term protection. We used acoustic telemetry to quantify the movements of parrotfishes, unicornfishes and goatfishes captured inside a Hawaiian MPA (Kealakekua Bay Marine Life Conservation District). We found that parrotfishes and unicornfishes were site-attached to Kealakekua Bay for up to 6 months but that detections of most fishes ceased abruptly within this period, possibly due to emigration. We detected emigration from the MPA by one orangespine unicornfish, which was characterized by increasingly wide-ranging behavior, and eventual departure from the MPA with final detections by a receiver located 2 km N of Kealakekua Bay. Bullethead parrotfishes and sleek uncornfishes that were site-attached to nighttime habitat inside the MPA made daily crepuscular migrations of 500 to 1,800 m between separate day & night habitats. This behavior resulted in bullethead parrotfish home ranges that straddled the NW MPA boundary, with parrotfish ranging up to 1 km outside the MPA boundary by day, and returning to the MPA at night. Natural daily flux of resident fishes back & forth across MPA boundaries may have been misinterpreted as density-dependent 'spillover' in previous mark recapture and visual census studies. Although both parrotfishes and unicornfishes were detected crossing the boundary at the NW end of Kealakekua Bay (which intersected contiguous reef habitat), only 3 sleek unicornfishes (*N. hexacanthus*) were detected crossing the habitat break at the eastern end of Kealakekua Bay, suggesting that this habitat break may function as a barrier to movements of some species. These results indicate that if the management goal is to retain fish inside MPAs, then MPA boundaries should be located at natural habitat breaks rather than intersecting contiguous habitat.

Introduction

There is growing concern that overfishing has drastically reduced populations of valuable coral reef fishes in the Main Hawaiian Islands (Friedlander & Parrish 1997, Friedlander & DeMartini 2002, Friedlander et al. 2003). Marine Protected Areas (MPA's) are widely invoked as a simple management tool that can reverse many of these disturbing trends, yet key anticipated benefits of MPA's remain vaguely defined and unsupported by empirical evidence (Russ 2002). For example, although it is widely assumed that reef fishes are site attached to home ranges contained within MPA boundaries, empirical data quantifying the scale and patterns of movements of most coral reef fishes are scarce (e.g., Roberts & Polunin 1993, Nowlis & Roberts 1999, Kramer & Chapman 1999, Nowlis 2000, Meyer et. al 2000, Meyer & Holland 2005). It is vital that we quantify how far heavily-targeted species range and what habitats they utilize, in order to provide resource managers with information required to design MPA's that will effectively protect resident populations of large, highly-fecund fishes that can in turn supply larvae to replenish fished areas (Bohnsack 1993, DeMartini 1993, Rakitin & Kramer 1996, Nowlis & Roberts 1999, Meyer 2003, Meyer & Holland 2005).

Most existing Hawaiian MPA's are relatively small (<1km^2), anthropocentric in design and the areas surrounding them are often heavily fished (Meyer 2003). The long-term effectiveness of these MPA's depends on resident fishes remaining within MPA boundaries where they can grow and reproduce successfully (Bohnsack 1993, DeMartini 1993, Rakitin & Kramer 1996, Nowlis & Roberts 1999, Meyer 2003, Meyer & Holland 2005). If existing MPA's are too small then resident fishes will frequently roam into fished areas where they may be captured, thereby eroding long-term MPA benefits (DeMartini 1993, Rakitin & Kramer 1996, Nowlis & Roberts 1999, Meyer 2003). Empirical knowledge of the space and habitat requirements of targeted species is therefore a key component of effective MPA design (Dugan & Davis 1993, Bohnsack 1998, Nowlis & Roberts 1999, Meyer 2003, Meyer & Holland 2005).

Short-term active tracking of coral reef fishes at 2 Hawaii MPA sites (Waikiki & Coconut Island Marine Life Conservation Districts) has shown that a variety of targeted coral reef fishes are site-attached to well defined home ranges and have predictable daily movement patterns (Holland et al. 1993, 1996, Meyer et al. 2000, Meyer 2003, Meyer & Holland 2005). These studies suggest that reef fishes are inherently well suited to protection in even relatively small (<1km^2) MPA's (Holland et al. 1993, 1996, Meyer et al. 2000, Meyer 2003, Meyer & Holland 2005). However, active tracking (using a boat to follow a fish equipped with an acoustic transmitter) can only quantify the behavior of a few individual fishes over relatively short periods of time (1 month). Reserves must afford long-term protection to target species in order to maintain resident populations of large, highly fecund individuals (DeMartini 1993, Meyer 2003). It is important to determine whether the behavior observed using short-term active tracking persists over longer time-scales, and is exhibited by multiple individuals. A major concern is that short-term active tracking may underestimate the full extent of fish movements and that this will lead to underestimates of the minimum MPA size required for effective protection of targeted species. For example, although short-term active tracking revealed that omilu (*Caranx melampygus*) utilize 1 km of reef edge on a daily basis (Holland et al.

1996, Meyer 2003), a recent pilot study showed that omilu equipped with long-life acoustic transmitters move back and forth along up to 10 km of coastline over a 9 month period (Meyer & Honebrink 2005). These results suggest that acoustic monitoring can provide valuable empirical data on the long-term space and habitat requirements of heavily-targeted coral reef fishes. This type of information would be of considerable value to resource managers and yet is currently unavailable.

In the present study we used acoustic monitoring to empirically quantify reef fish long-term movements at Kealakekua Bay MPA (Hawaii Island) and address 3 questions relevant to MPA design; (1) Are heavily-targeted reef fishes site-attached to Kealakekua Bay?, (2) Do their daily movements take them back & forth across the MPA boundary? and (3) Does a major habitat break inside Kealakekua Bay (an expansive sandy channel intersecting contiguous reef) function as a natural barrier to reef fish movements?

Methods

Study Site

Kealakekua Bay Marine Life Conservation District is located on the west side of Hawaii Island (Figure 1). The 1.3 km^2 site was designated as an MPA in 1969 and is divided into two management subzones (A & B). Fishing is entirely prohibited in Subzone A, and within Subzone B is restricted to hook-and-line and thrownet, although other methods can be used to target schooling carangids (*Selar crumenophthalmus* & *Decapterus macarellus*) and crustaceans. The bay faces southwest and is bounded by a 200m high cliff intersected at each end by lava flows. Subzone A is fringed by a 20-30m wide shelf consisting of rock and boulders in shallow (<2m) areas, and high coral cover in deeper areas. The edge of the shelf is bounded by a reef wall of high coral cover descending steeply to a sand bottom at 30-40m depth. Reef habitat is contiguous across the northwestern boundary of Subzone A, but a major habitat break exists at the southeastern boundary of Subzone A where the contiguous reef is interrupted by a 500 m wide sandy channel. The coral reef habitat resumes on the south side of the sandy channel in Subzone B (Figure 1).

Deployment of underwater receivers

In December 2005 we deployed 7 underwater receivers at Kealakekua Bay at the sites illustrated in Figure 1. These sites were chosen to provide both a broad coverage of the entire MPA, and to monitor fish movements across MPA boundaries and across habitat breaks within the MPA. We created temporary receiver moorings consisting of sand screws in areas of soft sediment, and chain around inert substrate in hard bottom areas. We anchored the receivers to these moorings and suspended them 1-2 m above the ocean floor. These receivers are identifying and recording the presence of any acoustic transmitters within range (up to 250 m). The transmitter number, time of arrival and departure and the date are recorded and stored until the data are downloaded from the receivers to a computer. The receivers have a battery life of approximately 15 months and are being downloaded at 3 month intervals. The cluster of receivers deployed at Kealakekua Bay are part of 37 receiver array stationed along a 115 km stretch of the west Hawaii coast and capable of detecting longer distance movements by transmitter-equipped fishes.

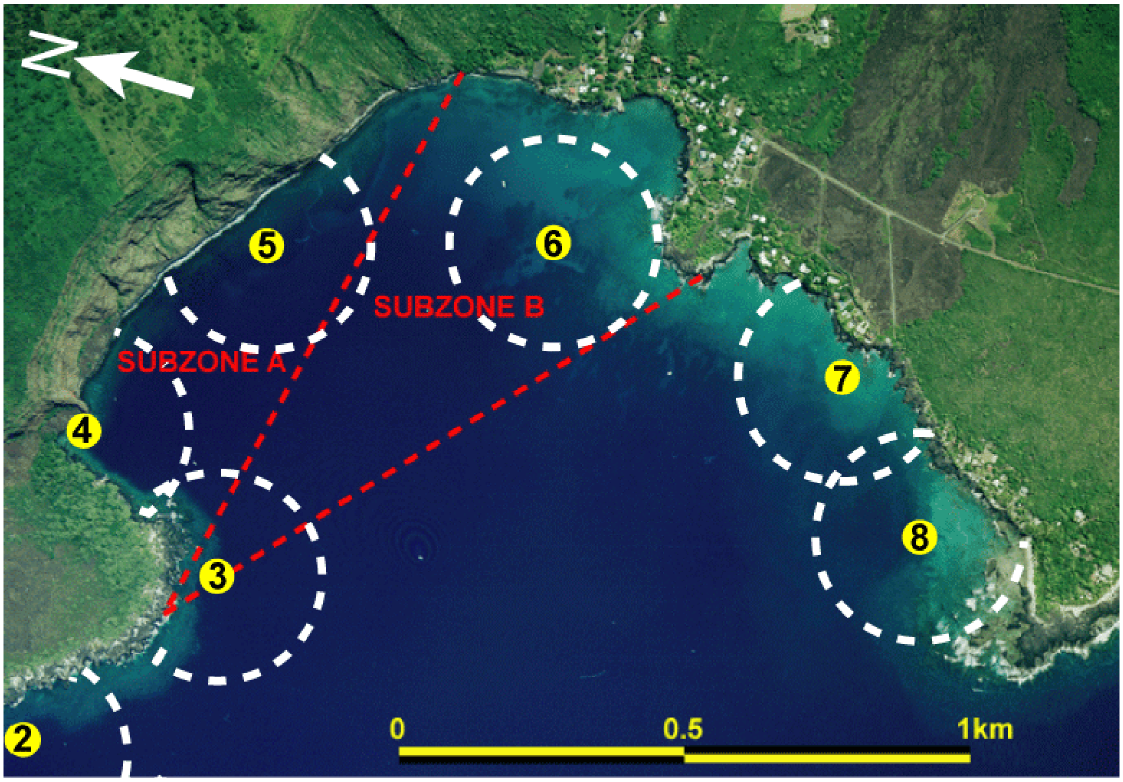

Figure 1. Locations of VR2 underwater receivers (numbered yellow points) deployed at Kealakekua Bay. Dashed circles indicate receiver 250 m detection radii. Red dashed line = MPA boundaries.

Deployment of transmitters.

In December 2005 we captured 30 coral reef fishes by hand-netting at night (Table 1). We recorded the capture location of each fish using a handheld GPS unit (Garmin 12XL). All 30 fishes were captured inside the core 'no-fishing' zone of the MPA, within 5 to 350 m of receiver #4 (Figures 1 & 2). We anaesthetized fishes using a solution of clove oil in seawater and then transferred them to a padded mat for measuring and transmitter implantation. We surgically implanted coded acoustic transmitters (V9-2L, 9 mm diameter, 22 mm long, Vemco, Halifax, Nova Scotia) into body cavities of each fish through a small incision in the abdominal wall. We closed the incisions with interrupted sutures and externally tagged each fish with a serially numbered, 8.0 cm plastic dart identification tag (Hallprint, South Australia). We released fishes close to their capture locations immediately after resuscitation. The entire handling process was typically completed in less than 10 minutes, no mortalities occurred during these procedures and all animals swam away vigorously on release.

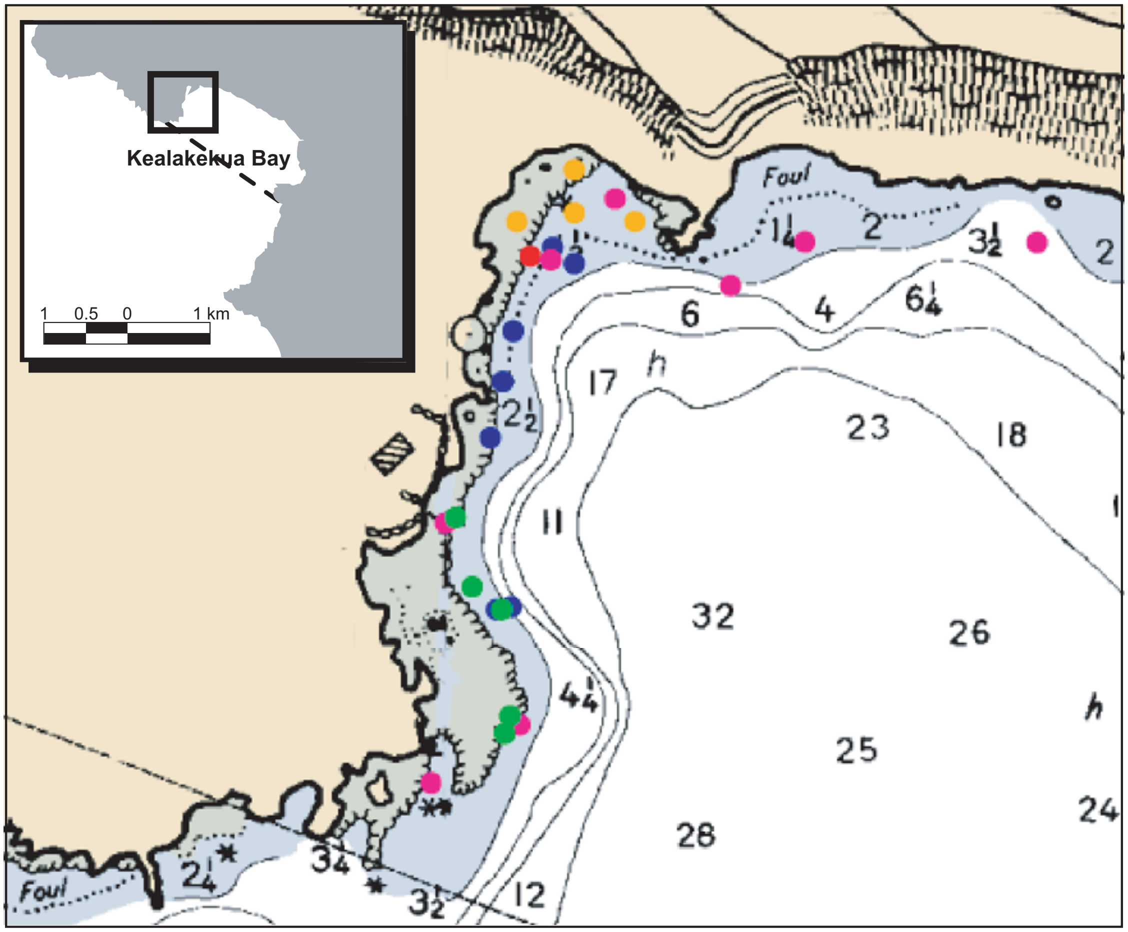

Figure 2. Reef fish capture locations inside Kealakekua Bay (pink points = doublebar goatfishes, green points = sleek unicornfishes, blue points = bullethead parrotfishes, orange points = orangespine unicornfishes, red point = redlip parrotfish).

Table 1. Summary of acoustic monitoring data for 30 transmitter-equipped reef fishes captured at Kealakekua Bay Marine Life Conservation District.

Common Name	Scientific Name	Length (cm)		Sex	Xmitter code	Date Deployed	Overall Detection Period (days)	Total # Days Detected	Total Detections
		Fork	Total						
Bullethead parrotfish	*Chlorurus sordidus*	-	35.8	M	322	12/7/05	1	2	4
Bullethead parrotfish	*Chlorurus sordidus*	-	33.9	M	324	12/8/05	-	-	-
Bullethead parrotfish	*Chlorurus sordidus*	-	33	M	325	12/9/05	-	-	-
Bullethead parrotfish	*Chlorurus sordidus*	-	30.5	F	330	12/7/05	-	-	-
Bullethead parrotfish	*Chlorurus sordidus*	-	30.9	M	331	12/8/05	15	10	17
Bullethead parrotfish	*Chlorurus sordidus*	-	30.1	F	333	12/9/05	84	71	263
Bullethead parrotfish	*Chlorurus sordidus*	-	34	M	336	12/6/05	-	-	-
Bullethead parrotfish	*Chlorurus sordidus*	-	28.4	F	338	12/7/05	0	1	1
Bullethead parrotfish	*Chlorurus sordidus*	-	37.5	F	344	12/6/05	95	96	1024
Bullethead parrotfish	*Chlorurus sordidus*	-	32.4	M	347	12/8/05	182	183	2870
Redlip parrotfish	*Scarus rubroviolaceus*	-	45.3	M	320	12/6/05	191	46	117
Doublebar goatfish	*Parupeneus insularis*	24.6	-	-	323	12/8/05	-	-	-
Doublebar goatfish	*Parupeneus insularis*	24.9	-	-	332	12/8/05	1	2	469
Doublebar goatfish	*Parupeneus insularis*	29.1	-	-	335	12/9/05	88	35	66
Doublebar goatfish	*Parupeneus insularis*	23.7	-	-	337	12/7/05	-	-	-
Doublebar goatfish	*Parupeneus insularis*	32.4	-	-	339	12/8/05	-	-	-
Doublebar goatfish	*Parupeneus insularis*	27.6	-	-	340	12/8/05	-	-	-
Doublebar goatfish	*Parupeneus insularis*	23.3	-	-	342	12/9/05	-	-	-
Doublebar goatfish	*Parupeneus insularis*	27.3	-	-	345	12/7/05	-	-	-
Doublebar goatfish	*Parupeneus insularis*	31.4	-	-	346	12/7/05	56	19	25
Doublebar goatfish	*Parupeneus insularis*	23.8	-	-	348	12/7/05	0	1	1
Orangespine unicornfish	*Naso lituratus*	-	26	-	321	12/6/05	192	191	4274
Orangespine unicornfish	*Naso lituratus*	-	27.6	-	328	12/6/05	111	106	1381
Orangespine unicornfish	*Naso lituratus*	-	27.8	-	329	12/6/05	52	53	869
Orangespine unicornfish	*Naso lituratus*	-	28.3	-	349	12/6/05	69	70	3841
Sleek unicornfish	*Naso hexacanthus*	35	-	-	326	12/9/05	133	134	15280
Sleek unicornfish	*Naso hexacanthus*	39.1	-	-	327	12/9/05	3	4	40
Sleek unicornfish	*Naso hexacanthus*	29.8	-	-	334	12/9/05	162	162	11959
Sleek unicornfish	*Naso hexacanthus*	42	-	-	341	12/9/05	-	-	-
Sleek unicornfish	*Naso hexacanthus*	37.2	-	-	343	12/9/05	3	3	45

Recovery, Downloading & Redeployment of underwater receivers.
In February and June 2006 we recovered, downloaded and redeployed underwater receivers stationed at Kealakekua Bay (Figure 1). Receivers were removed from their moorings and brought aboard a 10 m research vessel, where they were cleaned, downloaded to a laptop computer and reinitialized. We then redeployed the receivers at their original locations. We also retrieved and downloaded the two receivers from the wider array located immediately north and south of the Kealakekua Bay cluster. In June 2006, we conducted extensive manual searches for transmitter-equipped fish in and around Kealakekua Bay using both diver-held and boat-mounted receivers.

Results

Between December 2005 and June 2006, 8 underwater receivers detected 19 (63%) of 30 transmitter-equipped reef fishes over periods spanning from <1 to 192 days (median = 69 days)(Table 1). The total number of days on which each fish was detected ranged from 1 to 191 (median = 46 days)(Table 1). Reef fishes were detected by 4 receivers inside Kealakekua MPA and 4 stationed outside the MPA at distances of up to 2 km beyond the boundary (Figure 3). Each of these receivers detected between 2 and 15 (median = 2.5) reef fishes and the total number of transmitter detections recorded per fish ranged from 1 to 15,280 (median = 263 detections)(Table 1). Eleven reef fishes were only detected inside Kealakekua Bay MPA, whereas 8 fishes were detected both inside the MPA and also up to 2 km outside the MPA boundaries (Figure 3). Individuals of all species except redlip parrotfish (n=1) crossed the NW MPA boundary (which intersects contiguous reef habitat) but only 3 sleek unicornfishes were detected crossing the habitat break within Kealakekua Bay, or the SE MPA boundary (Figure 3).

All transmitter-equipped fishes exhibited distinct diel rhythms in behavior but daily movement patterns varied between species (Figures 4, 5 & 6). For example, bullethead parrotfishes crossed the NW MPA boundary at sunrise and sunset each each day, remaining inside the MPA at night but ranging up to 1 km beyond the MPA boundary during daytime (Figure 3). Conversely, orangespine unicornfishes typically remained inside the MPA within detection range of a single receiver during daytime and probably also remained in this area at night but were not detected because their nocturnal sheltering behavior resulted in signal blocking (Figure 4). Sleek unicornfishes were more variable in their behavior with two individuals showing long-term (up to 6 months) fidelity to day and night habitats, whereas two others were wider-ranging (up to 4.3 km along the coastline) and only detected at Kealakekua Bay for 4 days after tagging (Figure 5).

Detections of most transmitter-equipped fishes ceased before the end of the 6 month monitoring period (Table 1, Figures 4, 5 & 6). In most cases, well-established detection patterns ceased abruptly with no empirical evidence that fish had left the area (i.e., no detections of the fish by receivers further along the coastline). However one orangespine unicornfish (#328, Figure 4) showed clear evidence of a gradual shift in home range over time and increasingly wide-ranging behavior, culminating in emigration from the MPA with final detections by a receiver located 2 km N of Kealakekua Bay. In order to rule out transmitter expulsion as the cause of the cessation of detections, we conducted extensive manual searches for shed transmitters in and around Kealakekua Bay using both diver-held and boat mounted receivers. Only one transmitter was detected in several days of these searches conducted along 7 km of coastline.

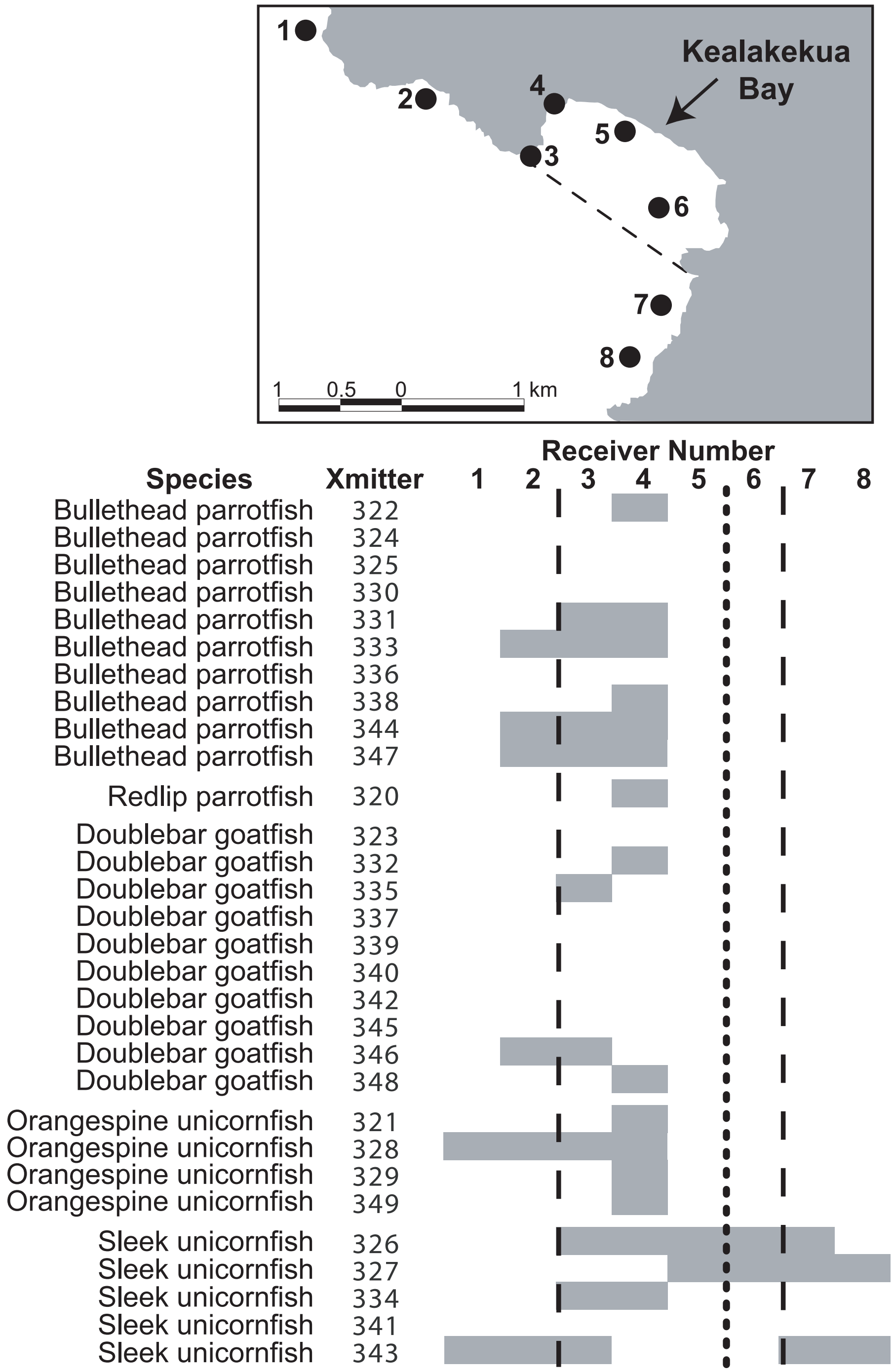

Figure 3. Matrix showing spatial extent of detections (gray shading) of transmitter-equipped reef fishes captured around receiver #4 inside Kealakekua Bay MPA. Receiver numbers in the matrix correspond to locations on the map (top of figure). The MPA outer boundary is indicated by a dashed line in both the matrix & map. Receivers 3, 4, 5 & 6 are located inside the MPA. The dotted line in the matrix indicates the presence of a habitat break (a sandy channel intersecting contiguous reef) between receivers 5 & 6.

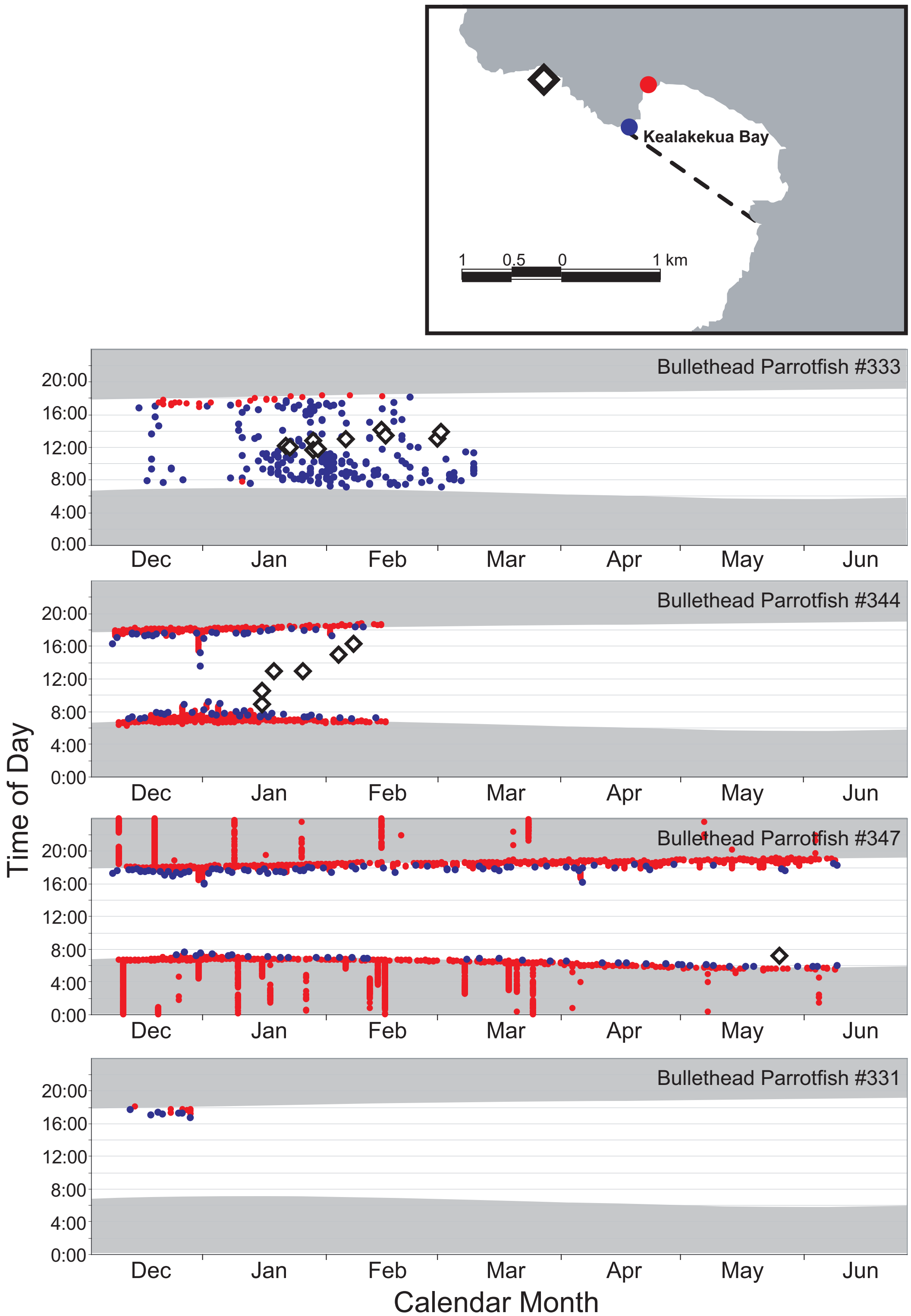

Figure 4. Diel detection patterns of four bullethead parrotfish captured inside Kealakekua Bay MPA in December 2006. Note the horizontal stripes of shading to show nighttime periods on the graphs. Colored symbols on the scatter plots correspond to receiver locations indicated in the map of Kealakekua Bay (top of figure). Dashed line on map = MPA outer boundary.

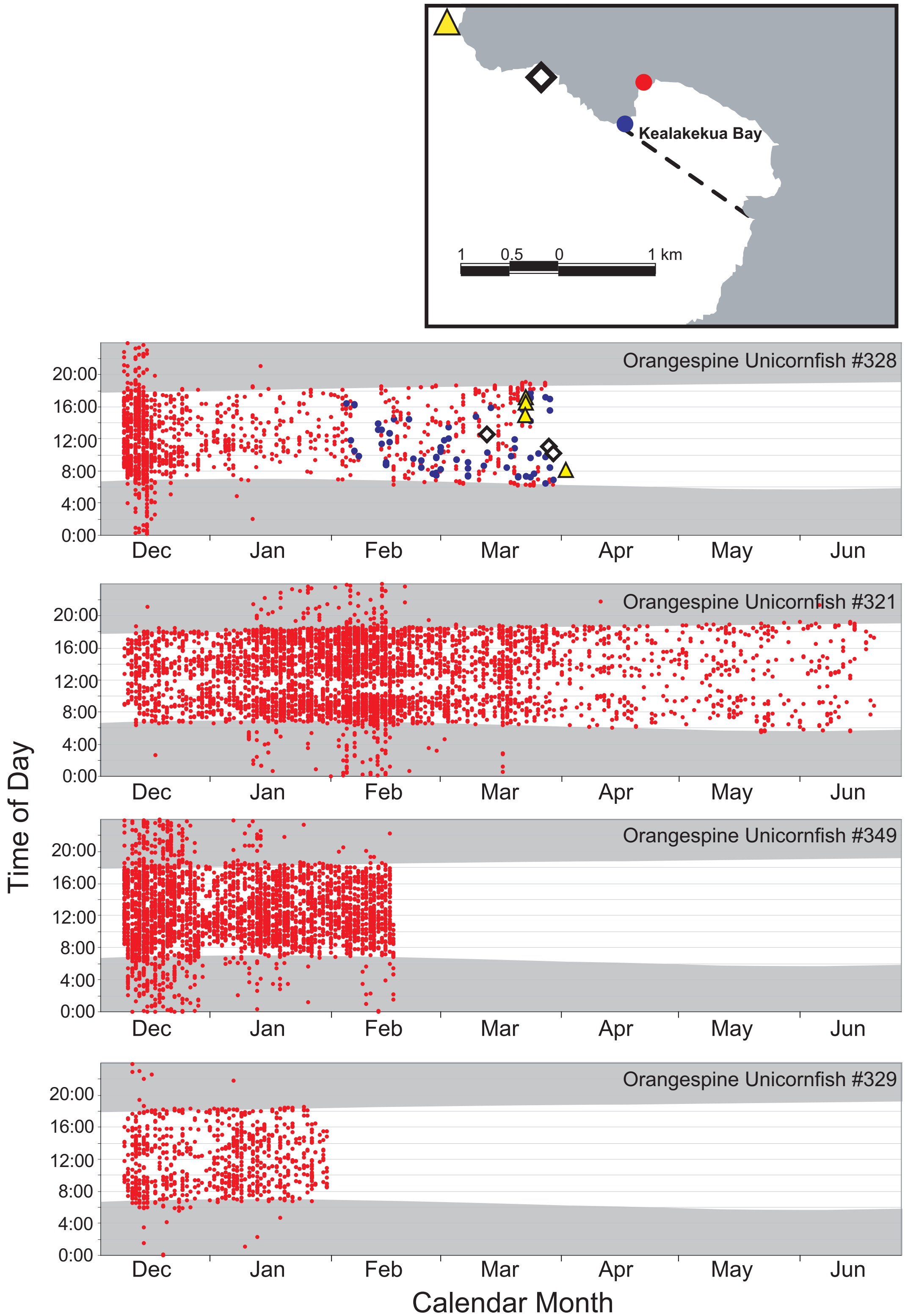

Figure 5. Diel detection patterns of four orangespine unicornfish captured inside Kealakekua Bay MPA in December 2006. Note the horizontal stripes of shading to show nighttime periods on the graphs. Colored symbols on the scatter plots correspond to receiver locations indicated in the map of Kealakekua Bay (top of figure). Dashed line on map = MPA outer boundary.

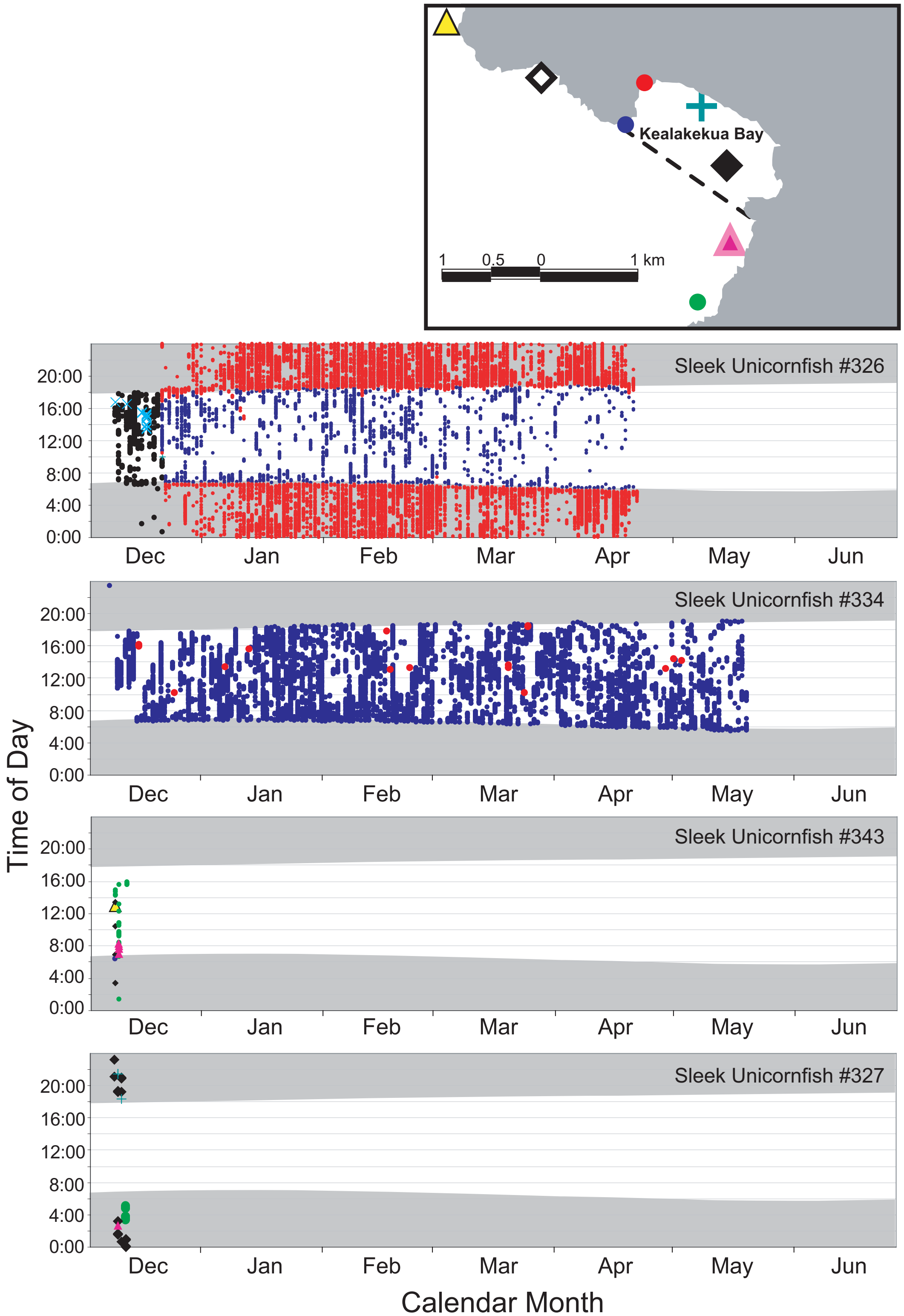

Figure 6. Diel detection patterns of four sleek unicornfish captured inside Kealakekua Bay MPA in December 2006. Note the horizontal stripes of shading to show nighttime periods on the graphs. Colored symbols on the scatter plots correspond to receiver locations indicated in the map of Kealakekua Bay (top of figure). Dashed line on map = MPA outer boundary.

Discussion

We found that parrotfishes (*C. sordidus* & *S. rubroviolaceus*) and unicornfishes (*N. lituratus & N. hexacanthus*) were site-attached to Kealakekua Bay for periods of up to 6 months. However, detections of most transmitter-equipped fishes ceased abruptly within this period. The fate of these fishes is unknown but transmitter expulsion does not appear to be the cause of signal loss because extensive acoustic sweeps of the study area detected only a single transmitter. Transmitter failure could be another explanation for this phenomenon but it would be extremely unusual to experience multiple transmitter failures within a 6 month period. It is also possible that these fishes emigrated from Kealakekua Bay to other areas along the coast. We detected emigration from the MPA by one orangespine unicornfish which began with a gradual shift in home range, followed by increasingly wide-ranging behavior, and eventual departure from the MPA with final detections by a receiver located 2 km N of Kealakekua Bay. We have no direct evidence of emigration for the other reef fishes but this may have occurred along routes that were outside receiver detection range. We plan to continue acoustic monitoring at Kealakekua Bay to determine if any of these fishes return to the site, and to increase our receiver coverage along the MPA boundaries to eliminate gaps in detection range.

Bullethead parrotfishes and sleek uncornfishes that were site-attached to nighttime habitat inside the MPA made daily crepuscular migrations of 500 to 1,800 m between separate day & night habitats. This behavior resulted in bullethead parrotfish home ranges that straddled the NW MPA boundary, with parrotfish ranging up to 1 km outside the MPA boundary by day, and returning to the MPA at night. This is an important finding because natural daily flux of resident fishes back & forth across MPA boundaries may have been misinterpreted as density-dependent 'spillover' by authors using more traditional fieldwork techniques such as standard identification tagging (Kramer & Chapman 1999) and transect-based fish surveys (Russ et al. 2003). However, we did document a long-term home range shift resulting in emigration from the MPA which may be evidence of spillover. Further study is required to resolve whether spillover is occurring from this MPA or whether apparent emigration stems from seasonal movements along the coast.

Although both parrotfishes and unicornfishes were detected crossing the boundary at the NW end of Kealakekua Bay (which intersected contiguous reef habitat), only 3 sleek unicornfishes (*N. hexacanthus*) were detected crossing the habitat break at the eastern end of Kealakekua Bay, suggesting that this habitat break may function as a barrier to movements of some species. These results suggest that if the management goal is to retain fish inside MPAs, then MPA boundaries should be located at natural habitat breaks rather than intersecting contiguous habitat.

References

Bohnsack JA (1993) Marine Reserves: They enhance fisheries, reduce conflicts and protect resources. Oceanus 36:63-71.

Bohnsack JA (1998) Application of marine reserves to reef fisheries management. Aust J Ecol 23:298-304.

DeMartini EE (1993) Modeling the potential of fishery reserves for managing Pacific coral reef fishes. Fish Bull 91:414-427.

Dugan JE, Davis GE (1993) Applications of marine refugia to coastal fisheries management. Can J Fish Aquat Sci 50:2029-2042.

Friedlander AM, Parrish JD (1997) Fisheries harvest and standing stock in a Hawaiian Bay. Fish Res. 32:33-50

Friedlander AM, DeMartini EE (2002) Contrasts in density, size, and biomass of reef fishes between the northwestern and the main Hawaiian islands: the effects of fishing down apex predators. Mar Eco Prog Ser. 230:253-264.

Friedlander AM, Brown EK, Jokiel PL, Smith WR, Rodgers KS (2003) Effects of habitat, wave exposure, and marine protected area status on coral reef fish assemblages in the Hawaiian archipelago. Coral Reefs 22: 291-305.

Holland KN, Peterson JD, Lowe CG, Wetherbee BM (1993) Movements, distribution and growth rates of the white goatfish *Mulloides flavolineatus* in a fisheries conservation zone. Bull Mar Sci 52:982-992.

Holland KN, Lowe CG, Wetherbee BM (1996) Movement and dispersal patterns of blue trevally (*Caranx melampygus*) in a fisheries conservation zone. Fish Res 25:279-292.

Kramer DL, Chapman MR (1999) Implications of fish home range size and relocation for marine reserve function. Environ Biol Fish 55: 65-79.

Meyer CG (2003) An empirical evaluation of the design and function of a small marine reserve (Waikiki Marine Life Conservation District). Doctoral Dissertation. Zoology Dept, University of Hawaii at Manoa. 143 pp.

Meyer CG, Holland KN, Wetherbee BM, Lowe CG (2000) Movement patterns, habitat utilization, home range size and site fidelity of whitesaddle goatfish, *Parupeneus porphyreus*, in a marine reserve. Environ Biol Fish 59: 235-242.

Meyer CG, Holland KN (2005) The role of movement patterns, home range size and site fidelity in greater abundance and size of bluespine unicornfish (*Naso unicornis*; Acanthuridae) in a small marine reserve. Environ Biol Fish 134: 602-606.

Meyer CG, Honebrink R (2005) Retention of surgically implanted transmitters by bluefin trevally (*Caranx melampygus*). Implications for long-term movement studies. Trans Am Fish Soc 134: 602-606.

Nowlis JS (2000) Short- and long-term effects of three fishery-management tools on depleted fisheries. Bull Mar Sci 66: 651-662.

Nowlis JS, Roberts CM (1999) Fisheries benefits and optimal design of marine reserves. Fish Bull 97:604-616.

Rakitin A, Kramer DL (1996) Effect of a marine reserve on the distribution of coral reef fishes in Barbados. Mar Ecol Prog Ser 131:97-113.

Roberts CM, Polunin NVC (1993) Marine reserves: simple solutions to managing complex fisheries? Ambio 22: 363-368.

Russ GR (2002) Yet another review of marine reserves as reef fishery management tools. Chapter 19. Pages 421-433 in PF Sale (ed). Coral Reef Fishes: Dynamics and Diversity in a Complex Ecosystem. Academic Press. London. 500 pp.

Russ GR, Alcala AC, Maypa AP (2003) Spillover from marine reserves: the case of *Naso vlamingii* at Apo Island, the Philippines. Mar Ecol Prog Ser 264: 15-20.