Findings from acoustic tagging reveal community based MPA in Fiji affords reasonable protection to Lethrinids

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Biological Conservation

Abstract

Are Lethrinids captured at common village fishing areas in Votua Village, Fiji part of the same population as those intended for conservation within the adjacent MPA? To address this question, Lethrinids (27) were caught within and outside the MPA, implanted with acoustic tags, and their movements tracked for up to 5 months. Fishes tagged on the reef flat crossed MPA boundaries moving freely across continuous reef flat habitat, traveling distances up to 700 m. Although the entire home range of Lethrinids does not appear to be incorporated within the present MPA design, the MPA may afford protection since fishing pressure is almost exclusively during the day. Fishes generally left the MPA during the night, and consequently may derive temporal refugia from fishing pressure. Comprehensive diurnal habitat requirements may be better met with minor adjustments in MPA boundaries. Acoustic tagging results are providing crucial recommendations for designing effective MPAs and networks of MPAs in Fiji and the Pacific Islands.

Introduction

Tropical marine ecosystems often exist as spatially heterogeneous seascapes with different habitat types (e.g., coral reef, seagrass, open water, mangrove, sand) connected to one another through various biological, physical and chemical processes. While tides and currents may facilitate the exchange of nutrients, pollutant and pathogens across an area, organisms connect habitat patches through their movements (Sale 2002, Gillanders et al. 2003). For example, many tropical marine species exhibit complex life histories, using resources from spatially and compositionally discrete habitat patches (Parrish 1989, Pittman and McAlpine 2003). Highly mobile species can connect patches through daily foraging movements, including tidal and diel migrations, as well as, broader scale excursions for spawning and seasonal migrations (Zeller 1998, Kramer and Chapman 1999). Furthermore, many reef fish and invertebrate species shift habitats through ontogeny (Dahlgren and Eggleston 2000, Nagelkerken and van der Velde 2002). The ability of an organism to successfully navigate among several (often critical) "ontogenetic stepping stones" or to move successfully to spawning locations will likely be influenced by both the composition and spatial arrangement of the seascape. Seascape characteristics, in turn, can be expected to affect ecological connectivity, with some configurations providing better connectivity for a species (or assemblage) than others (Mumby 2006, Grober-Dunsmore et al. 2007, Pittman et al. 2007b). Ecological connectivity is increasingly recognized as critical to the success of marine protected areas (MPAs) (Meynecke et al. 2008, Mumby 2006, Sale et al. 2005).

Marine protected areas (MPAs) are gaining revived attention particularly throughout Western Pacific Islands region (Govan et al. 2008, Aalbersberg et al. 2005, Sale et al. 2005), as island communities revisit tradition management practices as an effective tool for conserving important reef fish and invertebrate populations (Aalbersberg et al. 2005, Johannes 1981). Community-based management is carried out primarily by the community and the relevant user groups, involving the locally and nationally relevant institutional and private stakeholders. This makes optimum use of social capital such as existing (or assigned) resource rights, local governance, traditional and local information, self-interest and self-enforcement capacity (Govan et al. 2006, Aalbersberg et al. 2005). Noticeable declines in coastal resources have prompted Fijian communities to take far-reaching locally-managed actions to protect their coral reef resources. Supporting these efforts, the Fijian Locally-Managed Marine Areas (FLMMA) Network was formed in 2000 by the University of the South Pacific (USP), government departments, NGOs and stakeholders to engage local communities and coordinate marine resource management efforts (Govan et al. 2008). Presently, over 212 locally managed MPAs have been established within traditional fishing grounds across Fiji. These no-take MPAs, or *tabu* areas, were designed by local communities to address livelihoods, development, inshore fisheries and conservation as a whole (Govan et al. 2008), and consequently have broader objectives than single objective conservation MPAs. In 2006, the Fiji government set a target to include 30% of near shore areas in a network of MPAs. While this enthusiasm has led to the replication of the FLMMA Network beyond expectations, little is known about how these MPAs are working, particularly as a tool for promoting fisheries benefits through spillover.

MPAs can benefit fisheries in two main ways: (i) by providing a reservoir of eggs and larval propagules that passively drift and replenish distant areas, and (ii) through 'spillover' – the active movement of juvenile and adult fishes out from high population refuges within MPAs (Rowley 1994). The spillover value of MPAs can depend upon the density gradient across the MPA boundary, the site fidelity and movement patterns of different species (Corless et al. 1997), and the underlying seascape within which the MPA is located (Grober-Dunsmore et al. 2009). Some seascape features may facilitate movement, while other features potentially inhibit movement (Grober-Dunsmore et al. in press, Chateau and Wantiez 2009). Movement outside MPA boundaries may detract from expected conservation benefits, particularly where MPA boundaries are smaller than the scale of movement of those species targeted for conservation (Chateau and Wantiez 2009, Meyer et al. 2007). Species with individuals that typically move distances greater than the diameter of an MPA will not be fully protected from fishing, hence cannot be expected to substantially increase in population biomass within MPAs (Guenette & Pitcher 1999). Highly sedentary species are unlikely to generate much spillover value because few individuals will move outside the confines of the MPA. Understanding dispersal and movement is arguably one of the most critical factors determining the conservation and fishery enhancement values of MPAs for exploited fishes and invertebrates (Russ et al. 2004, Corless et al. 1997, Chapman &

Kramer 2000, Munro 2000, Ingram & Patterson 2001), yet few studies, particularly on species within the Pacific Islands region, have been conducted.

To address this need, we tagged adult Lethrinids (*Lethrinus harak* and *Lethrinus obsoletus*) with acoustic transmitters inside and outside a community-based MPA in the village of Votua along the Coral Coast of Vitu Levu, Fiji. Our primary goals were to determine: 1) variation in fish movement among individuals and among fishes tagged from disparate habitats, and 2) temporal and spatial variability in diurnal habitat use of fishes inside and outside of an MPA. The following questions were addressed: 1) How well do existing MPA boundaries protect reef fishes?, 2) Are fishes intended for capture at common village fishing areas part of the same population as those intended for conservation within an adjacent MPA?, 3) Are there potential fisheries benefits from the MPA for neighboring local fishing communities?, 4) Does the size & placement of an MPA influence its ability to promote fisheries benefits and conserve reef fishes?

Materials and Methods

Study site

This study was conducted in Votua village in the Korolevu-I-wai district of the Coral Coast, on the main island of Vitu Levu of the Fiji Islands (Figure 1). The Coral Coast consists of fringing reef with a wide reef flat habitat extending approximately 1/2 km from the reef crest offshore. The reef flat habitat contains patch reefs dominated by *Porites sp., Acropora* sp. and *Montipora sp.* interspersed with deeper pools (to 3m). The total area of reef flat is approximately 0.48km ^{2}. The outer edge of the reef crest drops steeply into waters approximately 50-100m in depth. Votua reef is bisected by a deep (30m) channel which cuts in close to shore along a river bed. The inshore area is dominated by soft corals and a small area of seagrass habitat. Votua MPA was established in 2002 and the boundaries were determined using traditional governance boundaries, local knowledge of the habitat types and customary fishing grounds used by neighboring villages. The MPA was located in an area of high coral cover and diversity, upstream of major upland disturbances and has not been moved or opened since it was established 7 years ago.

Study species

Lethrinus obsoletus Forsskal 1775 is found widely distributed in the Indo Pacific, with a maximum length reported to 60 cm (SL), though rarely attains more than 35 cm (Randall 2005). Fishes typically occur singly or in small groups on coral reefs and adjacent habitats by day (Randall 2005). *Lethrinus harak* Forsskal 1775 attains 45 cm length, and is also widely distributed throughout the Indo Pacific region. *L. harak* is generally solitary or in small schools, and occurs mainly in shallow protected habitats, such as seagrass beds, mangrove areas, and sand flats (Randall 2005). Both species are important food fishes in Fiji for subsistence and commercial uses.

Fish tagging

Local villagers assisted with all aspects of fishing, using traditional methods for catching targeted species. Hand-lines were used across the MPA and non-MPA area to catch Lethrinids from inside and outside the MPA. Fishes were captured by village women, place in a bucket with MS-222, and relaxed for surgical implantation. Acoustic Vemco V7 or V8 tags (depending on the size of the fish) were surgically inserted into the gut cavity. Incisions were closed, and fishes were placed in a recovery bucket with fresh water until fishes became active and were revived. Fishes were also externally tagged using colour-coded floy tags, indicating the location where fishes were captured. Release was conducted by hand, and a snorkeler followed the movement of the fish for as long as possible after release. Mortality of acoustically tagged fishes was considered to be minimal, as most fishes were later re-sighted (either visually or by acoustic receivers) during the sampling period.

Twenty-seven fishes were tagged with acoustic transmitters. Thirteen fishes were acoustically tagged outside the MPA; 5 were captured within the back reef habitat within the reef patch contiguous to the MPA (Figure 2). Eight were captured on the western side of the deep channel, in a separate reef patch. This habitat can be characterized as reef channel edge habitat, although the coral species composition and depth was quite similar to the reef flat habitat. However, the channel habitat drops steeply along an edge into a sand channel which stretches 30-40 m in depth. Within the MPA, nine fishes were acoustically tagged inshore within the reef flat habitat and five were captured offshore in the same reef patch on the western middle section of the reef patch.

VR2s were distributed across the reef flat patch and channel habitat in strategic locations with optimal acoustic signaling. Deployment locations were selected based on depth, location, and areas where fishes were likely to transit due to habitat type and surrounding water depth were prioritized. VR2s were also placed strategically along the edge of the reef flat habitat patch to capture movements outside this contiguous reef patch. Throughout the study, the mobile hydrophone was used to search for fishes outside the detection range. However, movement outside the detection range must be assumed. Therefore conclusions from this study are based on positive detections, and not on the absence of detections.

Deployment times for the VR2 recievers varied depending upon the expected battery life of the acoustic transmitters (Figure 3). Stations 1-11 were deployed June 14^{th} and relocated August 1^{st}, after detections from the channel fishes dropped off completely (over period of several weeks). These receivers were then relocated across the reef flat habitat until September 15^{th}, at which time several receivers were redistributed to extend the detection range to areas not originally covered in the sampling design.

Visual census inside and outside MPA

Visual censuses using 20 X 5 m belt transects were haphazardly conducted; 40 located inside and 40 located outside MPA boundaries. Transects were stratified by reef zone to encompass habitats contained across the study area. Data on abundance and average size (fork length) was collected for all Lethrinid species.

Data analysis

Movement data were plotted and analysed within a geographic information system (GIS) to calculate simple metrics for assessing habitat use. Distinct habitat zones were defined using information from visual benthic survey. GPS coordinates for all VR2 locations and MPA boundaries were conducted in the field with a handheld GPS. The total linear amount of reef habitat used was defined as the distance between the most distant receivers visited by each fish.

In addition 103 fishes (Epinephelids, Lethrinids, and Balistids) were externally tagged using color coded tags within the MPA. These fishes were tagged to detect movement of fishes from within the boundaries to areas outside the MPA.

Visual census data were entered into a JMP database for analysis (SAS 2008).

Results

Of 27 fishes tagged acoustically inside and outside Votua MPA, 24 were resighted by Vemco receivers or by mobile hydrophone at some point during study period. Two additional tags may have been dropped or compromised, as detections were limited and consistent in the same position for the duration of the study (Table 1). A total of 253,943 detections of fishes were recorded by the acoustic VR2 receivers over the 5 months of sampling. The average number of detections per fish was 11,041. The most detections for any fish was 81,602. The least detections (disregarding those not detected again) was 4 detections for the sampling period. The recorded number of days a Lethrinid was detected varied widely, ranging from 0 d to 138 days (Table 1).

The site fidelity of tagged Lethrinids varied widely (Table 1). The maximum distance moved by any individual was approximately 700 m. This fish was tagged within the reef flat habitat outside the MPA (Figure 2). The fish travelled inside the boundaries of the MPA to station 10, and outside the MPA boundaries to the acoustic receivers located in the channel (stations 2 and 4). The minimum distance travelled was less than 100 m; one fish was only recorded once by acoustic hydrophone in roughly the same location as the fish was initially tagged. The average distance recorded for the 24 fishes that were detected again by the receivers was 263m. Several fishes remained within the back reef flat MPA habitat consistently; detections occurred at geographically disparate receivers during different times of the day, confirming that these fishes were in fact moving, although movements were limited.

Fishes from disparate habitats moved differently

Fishes from disparate habitats appeared to move differently, with fishes tagged at the deep channel exhibiting strong site fidelity to channel habitat during the day. Eight fishes were tagged on the western edge of the channel habitat; 100% of the detections for these fishes were located within the channel. These fishes then moved predictably away from deep water channel habitat during the night, and generally moved inshore along the channel. Five fishes tagged along the eastern edge of the channel habitat, within the back reef flat, moved unpredictably and widely (Table 1). The range of detected movement was the greatest for these fishes, exhibiting the lowest site fidelity of the three groups of fishes (Table 1). One fish moved across reef flat and channel habitat consistently over the course of several weeks. The other four edge habitat fishes ranged widely inshore and offshore across the reef flat habitat (99% of detections within the outer reef flat habitat). The fourteen fishes tagged within the reef flat habitat inside the MPA were detected only within the reef flat habitat (100 % of detections). Fishes moved widely across the reef flat towards the edge of the reef patch, however detections only ever occurred within the continuous reef patch. Several reef flat fishes moved towards the edges of this habitat, and perhaps outside the detection range.

Movement of fishes inside and outside MPA

MPA fishes

Of the 14 fishes tagged inside the MPA, 7 (50% of the individuals) were recorded outside the MPA during some point in the sampling. Of the 215,839 detections of MPA fishes, <1% occurred outside the MPA boundaries. Of detections outside the boundaries of the MPA, 50% occurred after the sunset, and 25% occurring in early morning (before 7:00 AM) or late afternoon (after 4:00PM). The extent of movement of MPA fishes outside the boundaries of the MPA was limited with movement detected only to the immediate west and east of the MPA

(Figure 4). Four MPA fishes moved outside the MPA to the eastern boundary; this movement occurred almost exclusively during the night at station 9 (Figure 5). This movement was detected on multiple occasions over the course of several weeks. Three fishes were detected outside the MPA to the western boundary; 77% of detections occurred during the day. Although receivers were located strategically to cover as much of the reef flat edge as possible, fishes may have moved over the reef crest or beyond the detection range of receivers; if so movement outside the MPA may have been higher.

Non-MPA fishes

Two fishes tagged outside the MPA (non-MPA fish) were detected within the boundaries of the MPA. Detections within the boundaries of the MPA comprised 7% of the total number of detections for these fishes, and occurred primarily during the day. Movement tracks reveal that fishes moved within the contiguous reef flat patch, inside and outside the MPA during daylight hours.

Visual census of Lethrinids

A total of 51 Lethrinids were counted in 80 visual censuses; 9 were observed outside the MPA and 42 were observed inside the MPA. There was a significant difference in density of Lethrinids inside and outside of the MPA (Kruskal-Wallis $p<0.001$) with greater density of fishes inside the MPA compared to outside (Figure 6). There was no significant difference in size of Lethrinids inside and outside the MPA (Krusal-Wallis $p<0.07$), though the average size of Lethrinids was generally higher inside the MPA (Figure 7).

Floy tagged fishes

One fish (*Epinephelus merra*) tagged inside the MPA was subsequently captured by a fisher outside the MPA. The individual was captured in the contiguous reef flat patch to the west of the MPA boundary several months after being tagged.

Discussion

In addressing the first question of our study, "how well do existing MPA boundaries protect reef fishes?", abundance of fishes targeted by local communities (Lethrinids) is clearly higher within the boundaries of the MPA, with more fish and larger fishes present within this small community-designed MPA. These findings are consistent with other studies that show increased fish abundance, size and biomass inside MPAs (Halpern 2003, Cote 2001) compared to areas outside MPAs, and suggests that small, community-based and designed *tabu* areas can be effective for conserving fish stocks (McClanahan 2006). The ability of a *tabu* area to protect fish stocks likely depends upon the fishing intensity outside the tabu area, as well as the life history strategy of the targeted fishes. In the case of Lethrinids it appears that small tabu areas, when properly enforced, can provide at least some protection to adult populations. The use of small *tabu* areas may under certain conditions bring direct benefits to reef ecosystems and fishing communities by allowing a buildup in fish biomass, as demonstrated in Votua. However, larger, permanently closed areas may be necessary for species that require long periods without disturbance (McClanahan et al. 2006) or large areas within which the fish can safely move and not be regularly caught.

At least a portion of the fish population intended for capture at common village fishing areas appears to be part of the same population as those intended for conservation within the adjacent MPA; though the spatial extent of our sampling design does not allow for this question to be unequivocally addressed. Half of the Lethrinids tagged inside the MPA travelled outside the *tabu* area during the course of the study; however fishes generally left the MPA during the night for short excursions. Excursions outside the boundaries of the MPA were rare, typically brief, occurred during the night, and occurred only within the contiguous reef flat habitat. The nature of these movements may limit their susceptibility to fishing pressure outside the MPA. Since fishing pressure is almost exclusively during the day, Lethrinids may also derive temporal refugia from fishing pressure.

Fishes from disparate habitats appeared to move through the seascape differently, perhaps responding varying predation pressures (Hixon and Jones 2005), access to foraging areas (Dahlgren and Eggleston 2000), or particular seascape features that may inhibit or promote movement. Fishes in the channel habitat moved predictably away from the channel during the night, toward the inshore areas and up into the reef flat habitat and returning to the channel habitat in the early morning. This is in contrast with temporal movement patterns of the reef flat fishes, which remained within the reef flat habitat for most of the day, but moved to edge and channel habitat during the night and early morning. Furthermore, fishes tagged within the channel habitat, do not appear to be part of the same population as those intended for conservation within the adjacent MPA. Movement of Lethrinids from the channel habitat to the MPA was never detected, and fishes exhibited high site fidelity to the channel habitat.

Our findings suggest that the MPA designed by Votua village may offer fisheries benefits to adjacent fishing communities for two of the most targeted reef fish families. Temporal and spatial patterns of movement of Lethrinids within this particular contiguous reef patch may, however, limit fisheries benefits from Votua MPA. While abundance of Lethrinids was considerably higher within the MPA, the density gradient across the MPA of fishes may be insufficient to allow for maximum spillover and timing of movements do not coincide with optimal fishing times. Furthermore, the small size of Votua MPA may be inadequate to protect spawning stocks over long periods of time. Potential fisheries benefits were demonstrated for Epinephelids, when one individual moved outside the MPA and was subsequently captured by fishers inside customary fishing areas. The spatial range of movements for Epinephelids is likely lower than that predicted for Lethrinids; consequently spillover may be expected to be lower in comparison to Lethrinids. Over time the biomass and abundance of fishes inside Votua *tabu* may increase, thereby increasing the density gradient and increasing spillover potential. This response generally requires years of consistent and effective protection of targeted populations (Polunin and Roberts 1993, Attwood and Bennett 1994, Russ and Alcala 1996, Wantiez et al. 1997). With consistent protection, fisheries benefits from Votua MPA will likely continue to accrue to neighboring customary fishing grounds.

Examination of the response of fishes to seascape features in Votua demonstrates that the size and placement of this small, community-designed MPA holds promise for conserving reef fishes and enhancing fisheries benefits. Although the *tabu* area is extremely small, the spatial scale of movements for one of the most heavily targeted species is comparable to the *tabu* area. When normal movements frequently take individuals beyond a protected area boundary and the risk of being caught in that area is high, stock increases within the reserve are unlikely to realize their full potential. Clearly Lethrinids are moving beyond the scale of the *tabu,* however the placement of the *tabu* area within the seascape may be enhancing performance. Most of the contiguous reef flat habitat is contained within the *tabu* boundaries, and movements appear to occur primarily within this reef patch. Movement across edges was limited, and such features may inhibit movement outside the *tabu*. While small or isolated MPAs are more likely to depend upon external sources of larvae, making them vulnerable to recruitment over-fishing in heavily fished areas (DeMartini 1993, Jennings et al. 1996, Roberts 1997, Carr and Raimondi 1998), these findings may help to stimulate a dialogue for networking small community-based MPAs across traditional governance boundaries.

Although Votua MPA affords reasonable protection to Lethrinids within the back reef habitat, understanding how reef fishes respond to the underlying seascape can provide recommendations for enhancing the performance of this and similarly designed MPAs. If the community intends to incorporate much of the diurnal habitat requirements of Lethrinids within the boundaries of the MPA, then minor adjustments to the MPA boundaries could meet this objective. Lethrinids within the MPA appeared to move primarily within the reef flat habitat patch; less than 1% of the detections occurred outside this contiguous habitat patch. Therefore, if the MPA boundaries were extended to incorporate the entire reef flat habitat patch, movement of Lethrinids outside the *tabu* would be even further reduced (Figure 8). Additionally, temporal movement patterns reveal that by limiting fishing to daylight hours adjacent to the MPA, fishing pressure on those Lethrinids whose primary resident habitat is the MPA, could be virtually eliminated. Extending the boundaries of the MPA to include the entire reef flat patch and limiting fishing pressure adjacent to the MPA to daylight hours would enhance protection while stocks continue to rebuild.

While this study provided valuable scientific information that can be integrated into community-based decision making at the village level, a number of tangible benefits were also derived from working directly with the resource users. Critical ecological, socioeconomic and cultural information about the targeted species, fishing practices, and near shore habitats was exchanged between scientists and village members. This exchange was crucial to the success of the scientific study, and served as a forum for discussing the benefits and function of MPAs. Engaging the local community, particularly the women, in the study sampling empowered village members to learn more about their fishery resource to improve management. Additionally, various households within the community derived economic benefits for their participation as research assistants, and local businesses were employed to provide logistical support for the study. Finally, the study gained local attention, demonstrating the successes and challenges of village based resource management within Fiji and to the international community.

This work has important implications for traditional fishery management in Pacific Islands and demonstrates that small community-based and designed MPAs, relying exclusively on local ecological knowledge, can provide conservation and potentially fisheries benefits. While GIS and benthic habitat mapping are undoubtedly useful for MPA design, such tools are generally not available in Pacific Island community settings. By adapting general guidelines from seascape ecology studies to traditional management settings, ecosystem based management approaches can be adapted to a Melanesian context.

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Table 1. Number of individuals tagged, size, mean number of times individual was resighted, max number of times individual was resighted.

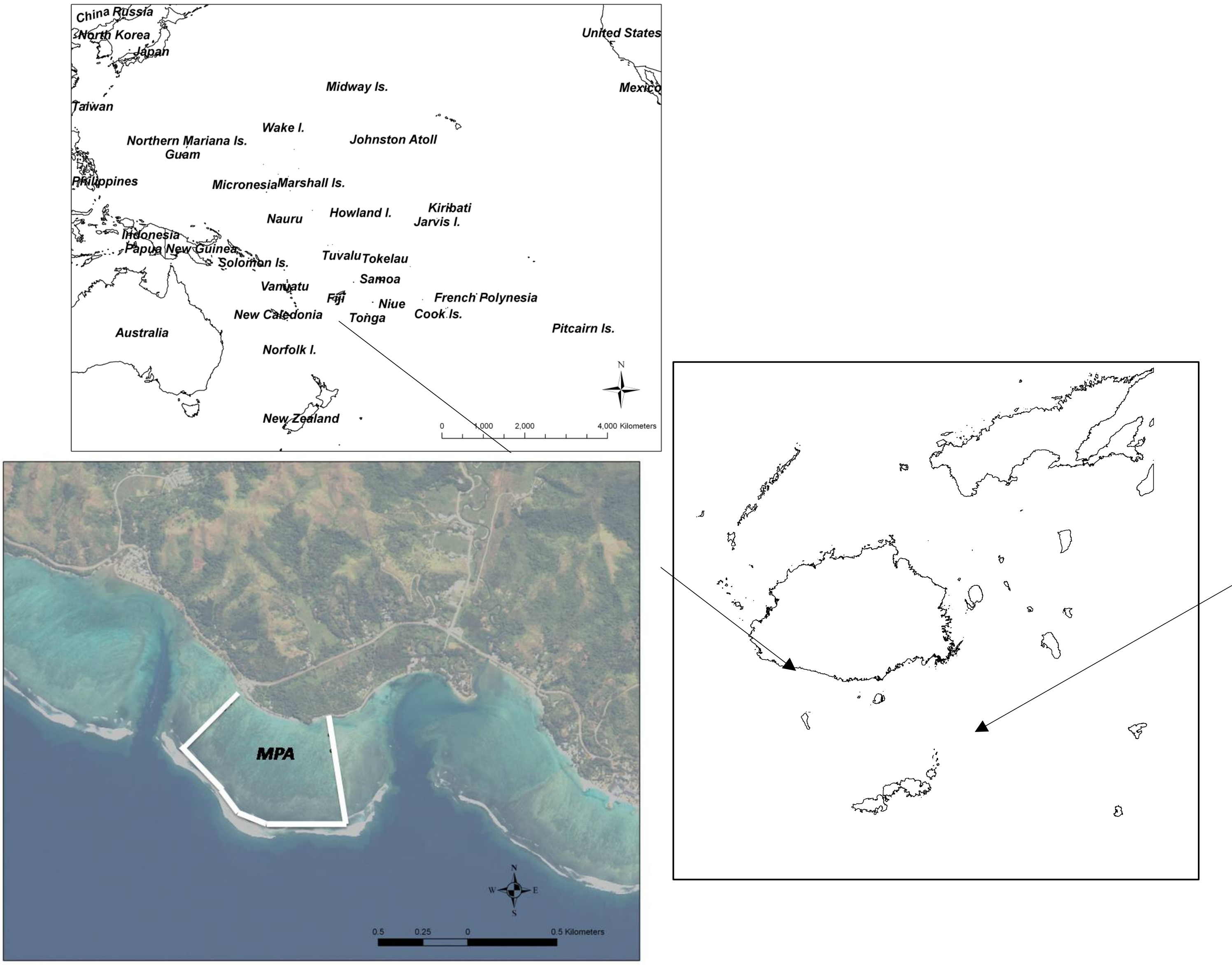
Tagging locations	Fish Species	Tag type	Tag ID	Size (cm)	Recorded days detected	Location of release	Number times resighted	Max number of zones visited	Max distance travelled	Distance (m)
Outside MPA	*Lethrinus obsoletus*	V7	3999	24	27	Channel edge W side	53	channel only	from 2-3	211
Outside MPA	*Lethrinus obsoletus*	V7	4000	24	52	Channel edge W side	7399	channel only	1 to 2 to 3 to 4	231
Outside MPA	*Lethrinus obsoletus*	V7	4001	27	49	Channel edge W side point	3572	channel only	2 to 3 to 4	211
Outside MPA	*Lethrinus obsoletus*	V7	4002	22	44	Channel edge W side	573	channel only	1 to 2 to 4, or 2 3 to 4	231
Outside MPA	*Lethrinus harak*	V7	4003	26	49	Channel edge W side point	3847	channel only	2 3 4	211
Outside MPA	*Lethrinus harak*	V7	4005	19	1	Channel edge E side	Once with V100	Outside MPA pool	unknown	50
Outside MPA	*Lethrinus obsoletus*	V7	4007	23	33	Channel edge W side	1288	channel only	1 to 2 to 3 to 4	231
Outside MPA	*Lethrinus obsoletus*	V7	4009	22	26	Channel edge W side point	2957	channel only	2 to 3 to 4	231
Outside MPA	*Lethrinus obsoletus*	V8	4016	23	85	Channel edge W side	17372	channel only	1 to 2 to 3 to 4	231
Outside MPA	*Lethrinus obsoletus*	V9	4676	21	6	Channel East Edge	61	inshore and outshore back reef MPA	10 and 11	198

Outside MPA	*Lethrinus obsoletus*	V9	4669	20	0	Channel East Edge	0	0	0	
Outside MPA	*Lethrinus obsoletus*	V9	4671	21	23	Channel East Edge	968	channel and back reef inside and outside MPA	2, 4, 5, 6, 10	699
Outside MPA	*Lethrinus obsoletus*	V9	4675	21	3	Channel East Edge	10	outside MPA - big pool and back reef v100	5 and channel edge	228
Inside MPA	*Lethrinus harak*	V9	4670	23	122	Channel East Edge	224	Inside & Outside MPA back reef habitat	5 6 10 12 15 16	475
Inside MPA	*Lethrinus obsoletus*	V9	4667	26	133	Villisites	164	MPA only	7 8 10	215
Inside MPA	*Lethrinus obsoletus*	V9	4668	20	132	Villisites	105	MPA only inshore and offshore	6 7 10 16	240
Inside MPA	*Lethrinus harak*	V9	4673	26	0	Inshore MPA	0	0	0	
Inside MPA	*Lethrinus harak*	V9	4674	25	0	Inshore MPA	0	0	0	
Inside MPA	*Lethrinus obsoletus*	V9	4677	24	10	Villisites	95	Inside & Outside MPA back reef habitat inshore offshore	5 and 10 V100 detections	475
Inside MPA	*Lethrinus obsoletus*	V9	4678	29	127	Villisites	43,476	inside MPA backreef inshore offshore	7 8 10 13 16 18	332
Inside MPA	*Lethrinus harak*	V9	4679	32	138	Inshore MPA	81,602	Inside MPA inshore mostly- offshore periodically	7, 8, 13	110
Inside MPA	*Lethrinus harak*	V9	4680	26	138	Inshore MPA	55,506	Inside and Outside MPA to E channel at	7 8 9 13	390

								night		
Inside MPA	*Lethrinus harak*	V9	4682	32	135	Inshore MPA	12,976	Inside MPA inshore offshore	7 8 10 13	215
Inside MPA	*Lethrinus harak*	V9	4683	31	133	Inshore MPA	1,564	Inside MPA inshore	7 8 possible dropped tag?	100
Inside MPA	*Lethrinus harak*	V9	4684	25	132	Inshore MPA	254,077	Inside MPA inshore, periodic movements outside MPA at night	7 8 9	357
Inside MPA	*Lethrinus harak*	V9	4685	34	134	Inshore MPA	11,995	Inside MPA inshore, periodic movements outside MPA at night	7 8 9 13	414
Inside MPA	*Lethrinus harak*	V9	4686	36	38	Inshore MPA	51	Inside and outside to E of MPA, back reef	8 9	100

Figures

1.Map of Coral Coast along southern coast of Vitu Levu, Fiji, Pacific Islands



2. Location of VR2 receivers inside and outside MPA boundaries.

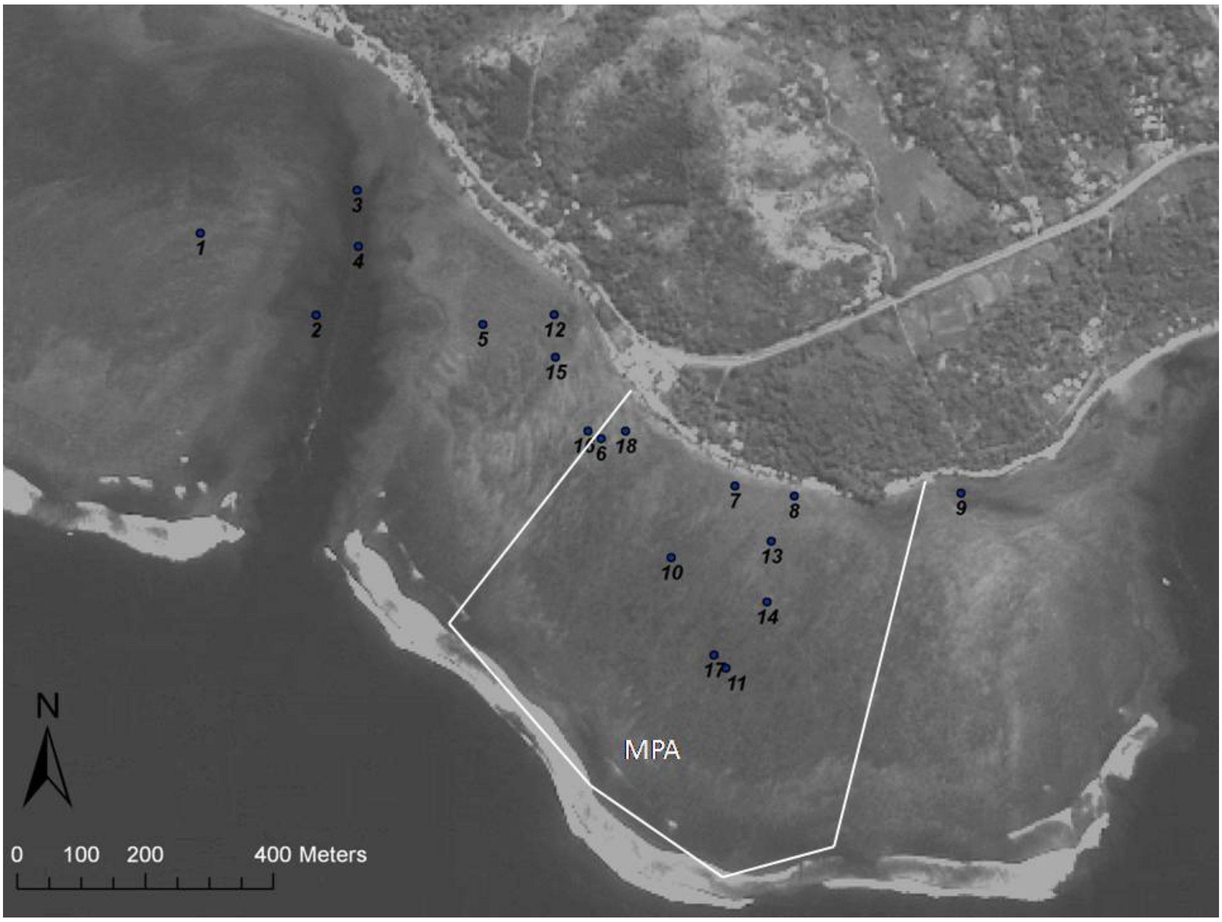


Figure 3. VR2 deployment times for study period June 2007- November 2007

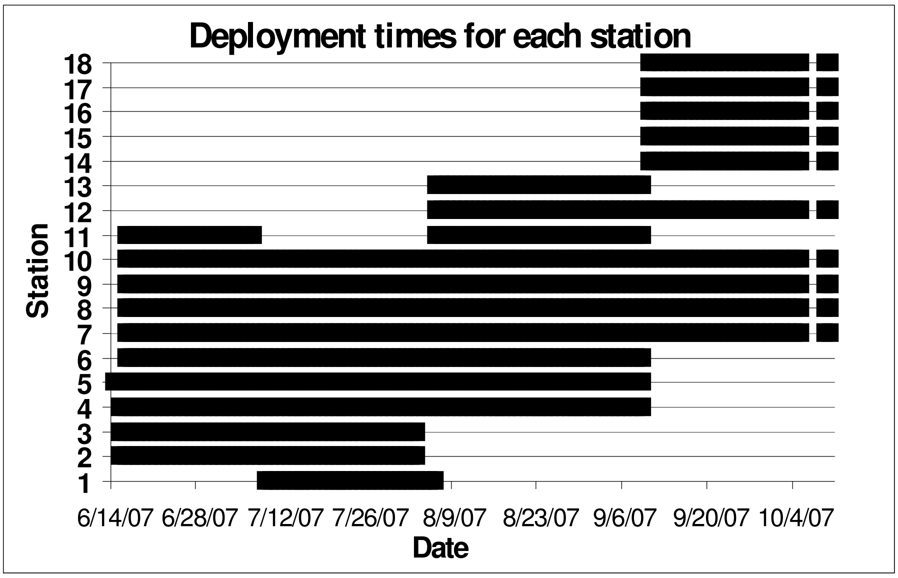


Figure 4. Locations of detections for fishes tagged inside the MPA. Boundaries of MPA indicated in white lines, and receivers with detections are indicated in highlighted blue. Receivers with no detections are indicated in black.

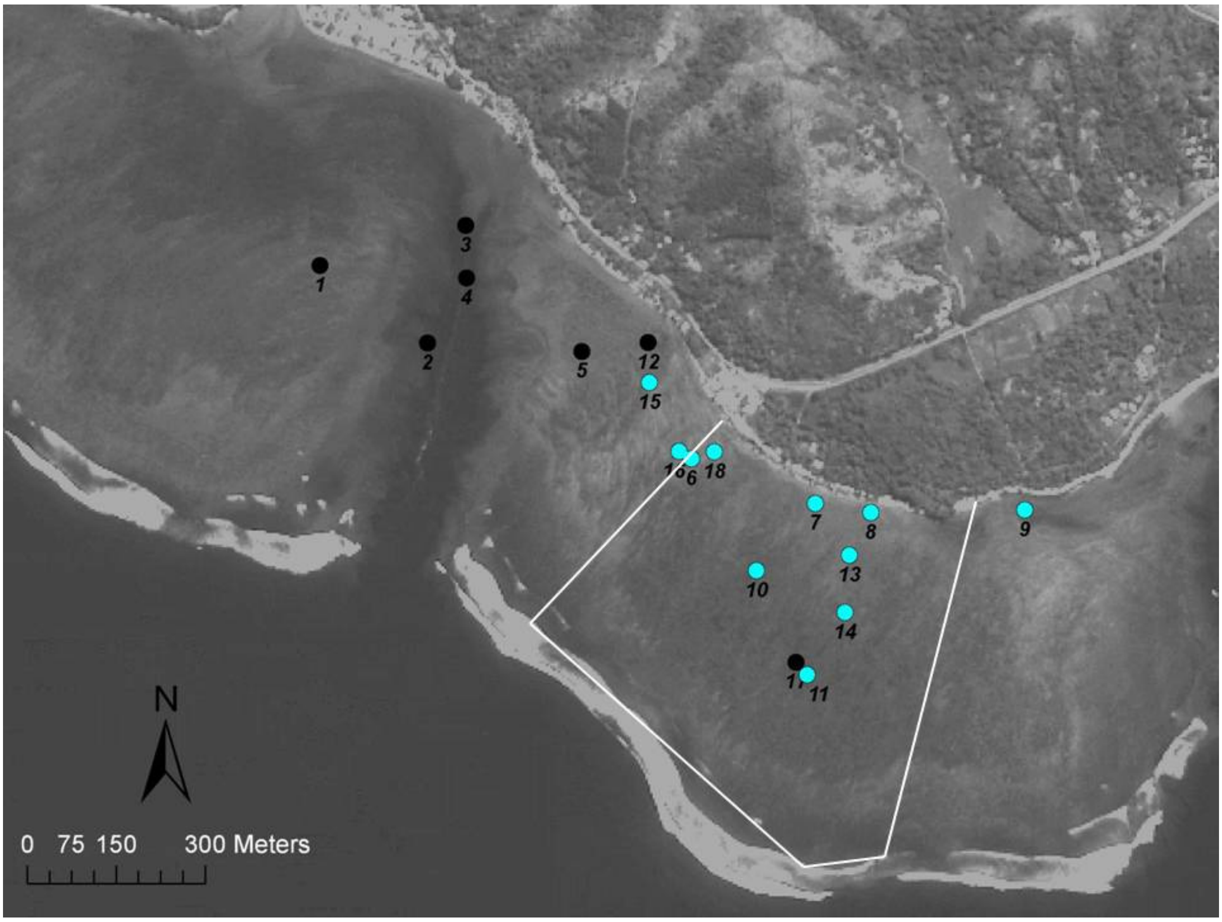


Figure 5. Number and time of day of detections for Receiver Station 9, located outside the MPA to the east.

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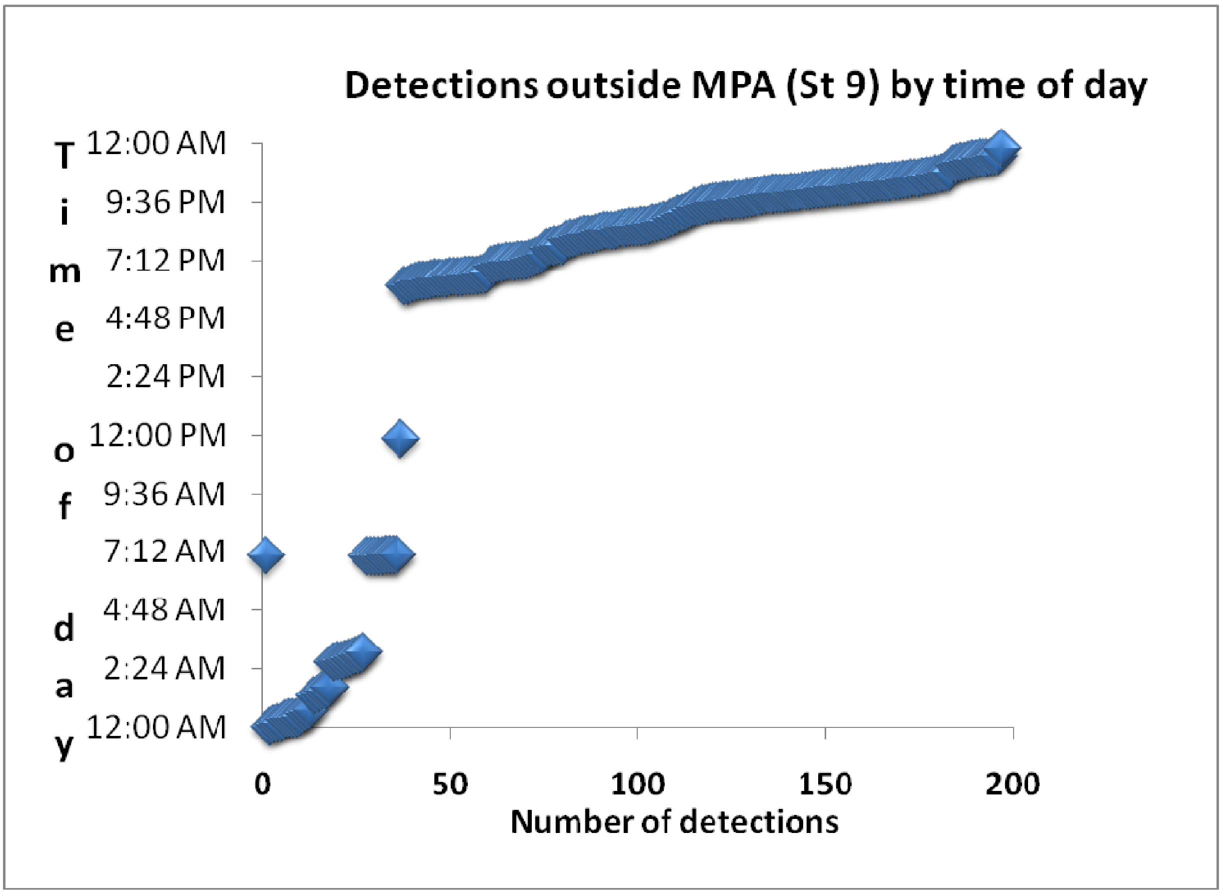

Figure 6. Differences in density of Lethrinids inside and outside MPA boundaries. Bars represent standard error.

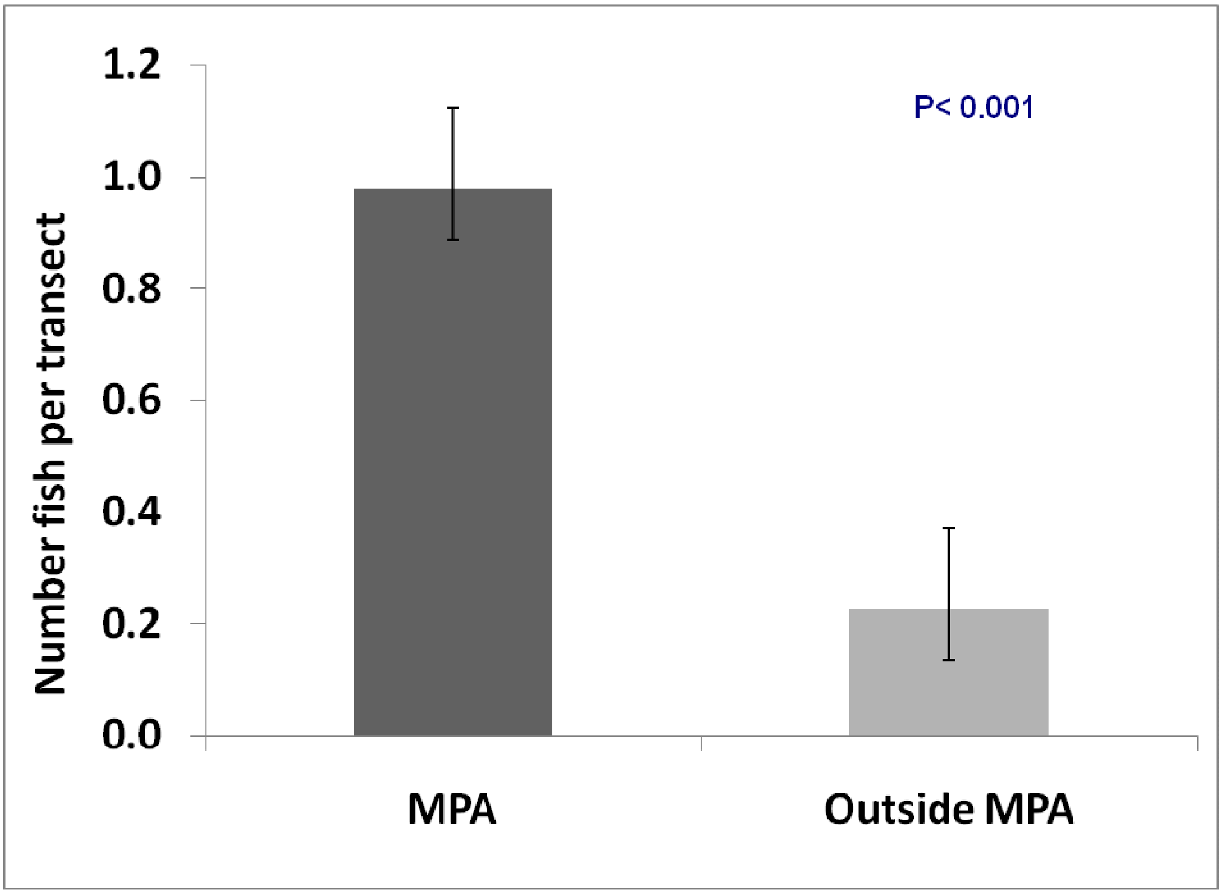

Figure 7. Differences in fork length of Lethrinids inside and outside MPA boundaries. Bars represent standard error.

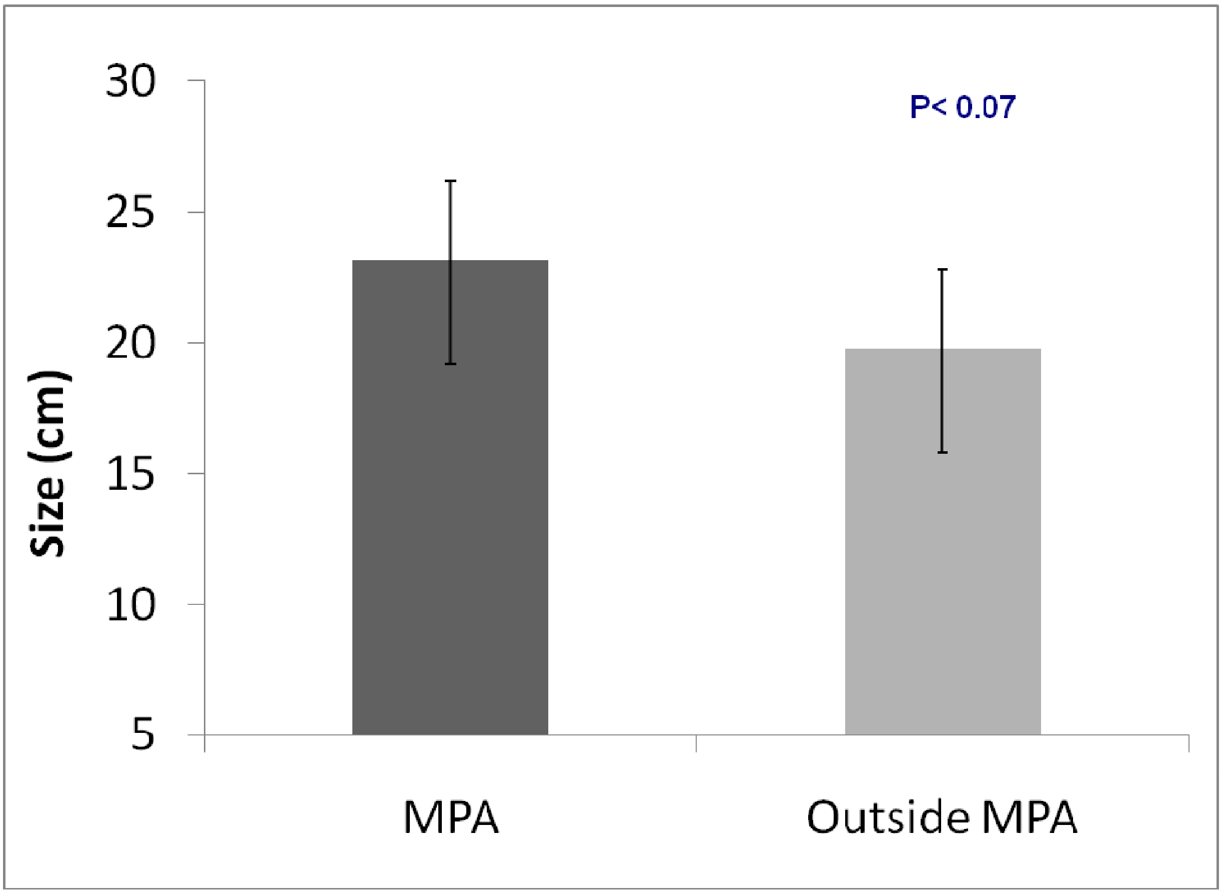

Figure 8. Percentage of time fish remained inside MPA reef flat habitat compared to outside the MPA.