Performance Evaluation of Marine Zoning in the Florida Keys National Marine Sanctuary

Final Report Year 2

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INTRODUCTION

This project uses a multi-tiered approach to evaluate Marine Protected Areas (MPAs) in Florida Keys National Marine Sanctuary (FKNMS). The MPAs in FKNMS were established to protect critical reef habitats from overexploitation, and to insure the sustainability of valuable marine resources. This study aims to address key issues regarding the effectiveness of the Western Sambo Ecological Reserve (WSER) design for protecting essential fish habitat, population structure, species diversity and determine the ecosystem connectivity of exploited predatory reef fishes (snappers and groupers) and of spiny lobsters.

Lobsters were re-surveyed after a decade of protection in 13 MPAs, and movement of sonic-tagged lobsters and finfish in Western Sambo Ecological Reserve (WSER) and across the offshore reserve boundary were tracked for one calendar year (June 2006-August 2007) with quarterly tagging. Additionally, visual surveys of reef fish were completed to compare species diversity, density and size structure within the marine reserve to unprotected areas across the Florida Keys National Marine Sanctuary (FKNMS). The following comprises the final report for all phases of the project for the period October 2006 to September 2007.

We used timed surveys of spiny lobsters inside 13 marine reserve zones and their exploited reference areas (Table 1) in FKNMS during the closed fishing season of 2006 to determine lobster size, sex, and abundance. Sampling was designed to test the hypothesis that no-take zones would sufficiently protect lobsters so that lobsters in these zones would become larger and more abundant than those in unprotected areas. We also surveyed lobsters in 3 of the reserves, WSER, Looe Key SPA (LKS), Eastern Sambo Research Reserve (ESB), and their reference areas in the fishery during the open fishing season in September 2006. In July 2007, we surveyed lobsters in the 3 aforementioned reserves/reference areas using area-based surveys.

From October 2006 through April 2007 we maintained the deployment of 45 sonic receivers in a series of rings around large habitat features such as patch reefs and forereef inside Western Sambo Ecological Reserve (WSER) and a hardbottom offshore bar located south and west of WSER (Figure 2). From June 2007 to August 2007 we re-deployed 33 sonic receivers around and within the forereef of WSER (Figure 3, 4). The rational for this final deployment was to determine habitat usage and movement patterns of spiny lobsters and finfish within the forereef. This deployment was designed to overcome the acoustic difficulties of receiving telemetry from forereef tagged animals

METHODS

Lobster Monitoring - Timed Surveys

Lobsters were surveyed at 13 MPAs and paired reference areas in the fishery during July 2006 (closed fishing season). Ten of the reserves are small SPAs in

FKNMS (Figure 1). These SPAs range in size from 28 to 147 ha (mean size 84 ha). One reserve, LKS, is a small, 115 ha, long-term SPA. Fifty hectares of the forereef at LKS 50 ha forereef has been protected since 1981 as Looe Key National Marine Sanctuary. The protected area was enlarged as LKS in 1997. One reserve, CAR, is a medium-sized reserve. WSER is a large, 3000 ha reserve.

We stratified sampling within Western Sambo Ecological Reserve (WSER) by habitat type because we expected each habitat to shelter a different size range of spiny lobsters (Hunt et al., 1991). Strata included forereef, backreef, offshore patch reef (Figure 5). Three replicate surveys were conducted in each stratum. Surveys were conducted in the dominant habitat within the 12 smaller reserves. We completed three replicate surveys on the forereef at Carysfort/South Carysfort Reef SPA (CAR), and one survey in the remaining 11 reserves. We re-surveyed lobsters in WSER, Eastern Sambo Research Reserve (ESB), Looe Key SPA (LKS), and their paired reference areas in September 2006 (open fishing season) (Table 2).

Divers surveyed spiny lobsters using 60-minute-timed-searches. Two teams of divers (consisting of one searcher and one catcher) searched for lobsters for 30 minutes each. Data from the two teams were pooled and considered as one 60-minute survey. Lobsters observed by the catcher but not by the searcher were neither counted nor captured. Time was kept by the searcher using a stopwatch that was turned off while lobsters were captured.

At the time of capture, each lobster was numbered, and sex and den depth were recorded. All captured lobsters were brought to the boat where size, molt stage, and reproductive status of females (e.g. presence or absence and condition of spermatophores and eggs) were recorded. Lobsters were returned alive to the area of capture. Lobsters that eluded capture were always included in abundance estimates, and, when possible, their sex and estimated-size were recorded.

Lobster Monitoring - Area Surveys

During July 2007, we surveyed lobsters in the 3 Lower Keys reserve/reference pairs using area-based surveys instead of timed surveys. Divers counted and estimated size of all lobsters in 25, 500 m^2 areas on the forereef and backreef of WSER/PEL, and in 10 replicate 500 m^2 areas on the forereef only at ESB/MSB, and LKS/MAR. In July 2004-2006, area-based surveys had been performed in WSER/PEL only.

In conjunction with area based surveys, we also collected approximately 50 lobsters from each survey site. Captured lobsters were brought to the boat where we recorded lobster sex and size, and reproductive condition of females.

Fish Visual Surveys

From May to October 2007, five visual sampling trips per month were conducted

inside WSER, for a total of 30 sampling trips. Visual surveys are used at Florida Fish and Wildlife Research Institute, South Florida Regional Laboratory to collect abundance and length-frequency data on fishes found over fringing reefs, patch reefs, and hard bottom areas in water meeting a minimum criterion of horizontal visibility. Surveys were conducted according to the standard visual sampling protocol used in the Florida Keys. This technique employs the use of two divers using SCUBA gear. During visual survey sampling, fish within a standardized area are enumerated and have a length estimation assigned. Due to the often diminished visibility on inshore patch reefs within WSER, some surveys were conducted in less than 7m of horizontal visibility.

Sonic Tagging - Overview

Receivers were deployed in and nearby Western Sambo Ecological Reserve (WSER) nearly continuously from June 2006 to August 2007, and sonic tagged lobsters and fish were seeded into the area during four separate tagging periods. Prior to deployment, each VR2 sonic receiver was initialized in the laboratory using a computer and special probe and software provided by the manufacturer (VEMCO). A special tag was then placed next to each receiver to insure that it was functioning probably. During quarterly maintenance when receivers were checked and serviced, we downloaded the data from each recovered receiver while in the field using the same equipment and software as in the laboratory. If the receiver required a battery replacement or if the receiver's data buffer was more than 1/3 full, we would re-initialize the receiver. Twice during this project (April 2007 and August 2007) all receivers were recovered and returned to the laboratory. During recovery phases, receivers were returned to the laboratory and cleaned prior to downloading. In the case of the August 2007 recovery, all receivers were placed into a large freshwater tank and "time stamped" with a single transmitter prior to downloading. We "time stamp" receiver during deployments whenever receivers are place such that detection ranges overlap. The time stamp allows us to precisely adjust the time field in the downloaded data as the clocks may vary slightly between receivers. The time adjustment then permits us to accurately know when one given tag transmission is detected by multiple receivers. Having this information gives us a more reliable location estimate of tagged animals under these conditions.

From June 2006 to April 2007, we deployed 45 sonic receivers in a series of rings around large habitat features such as patch reefs (9.2 km^2), the forereef (3.7 km^2) inside Western Sambo Ecological Reserve (WSER) and a hard bottom offshore bar (2.9 km^2) located south and west of WSER (Figure 2). This deployment was designed to investigate broad scale movement patterns within this area. A total of three receivers were lost (all outside just outside the boundaries of WSER), presumably to entanglement with anchor ropes, trap lines, or fishing lines.

In June 2007, we redeployed 33 sonic receivers because of the difficult acoustic properties found within the forereef zone of WSER. Twelve receivers were concentrated along grooves in the forereef near mooring balls 9 and 12 (Figure 3). In addition, three receivers were placed to the south of the grooves in deeper water (7-10

meters) (Figure 3). These receivers were placed to detect lobsters and fishes moving from the grooves for deeper water. Finally, a large ring of receivers encompassed the foreereef and "sentinel" receivers where placed one to two kilometers east and west of the main forereef deployment (Figure 4). We retrieved all 33 receivers on August 24, 2007.

All VR2 sonic receivers were deployed on a concrete pad and pvc pipe mounting that kept the receivers from 1.5 to 2 m off the bottom. All pads were placed over soft bottom and for those receivers placed in "rings", the inter-receiver distance was kept between 400 and 500 m apart.

Sonic Tagging -Lobster Sonic Tagging

The sonic tags used in this study were a VEMCO V16 4K coded pinger tag. Each tag's dimensions were 16 mm diameter and 58 mm long. These tags are among the more powerful tags for their size with a power rating of 158 dB *re* μPa at one meter. They have a four-digit code that is emitted (ping) in a randomized interval between 60 and 183 seconds. The randomization of ping time reduces the probability of signal interference between tags. Tags were activated in the laboratory two days prior to field deployment. The electrical lead ends of wires were trimmed and soldered and then coated with a silicone sealant. The activation of each tag was confirmed by placing the tag next to a VR2 receiver.

To tag lobsters in the field, lobsters were captured by SCUBA divers using tickle sticks and nets. Lobsters to be fitted with a sonic tag were brought to the boat and placed into a large tray partly filled with water. The tray allowed us to dry the top of the lobster carapace with a towel while the lobster could keep its gills wet. Tags were affixed to the carapace using an underwater plumbing repair epoxy. Although the epoxy will adhere on wet surfaces, we found that a damp surface permitted greater adhesion of the epoxy than a fully wet surface. A portion of the clay-like epoxy was molded by hand into a shape similar to the sonic tag. The epoxy was placed along the carapace of the lobster, then the tag was pressed down into the epoxy with the emitter end of the tag resting next to the horns and posterior to the eyes. The epoxy was further molded onto the carapace with special attention given to pressing the epoxy around the spines to insure a secure fit. The lobster was retained in the holding tray for approximately 15 minutes to permit sufficient hardening of the epoxy. Divers then returned each lobster to its den. We record the tagged lobster's sex, carapace length, injuries, and reproductive status for females. The location and depth of the tagging site is also recorded as well as marked by the boat's GPS.

A total of 92 lobsters (including two *Panulirus guttatus*) were fitted with sonic tags during the course of this study. There were three "seedings" of 68 tagged lobsters during the first deployment (June 2006 to April 2007) and one "seeding" of 24 tagged lobsters during the second deployment (June 2007 to August 2007).

Once the data are downloaded, data are combined into a single data set using an application I wrote in Visual Basic for this purpose. Next this file is imported into SPSS in order to remove any duplicate records that can exist if a single receiver is downloaded more than once. Finally, the clean field data are imported into an Access database. This relational database contains other data tables such as the deployment status of each receiver, data regarding the animals we tagged, and data regarding the tagging sites. From the relational database, using Access' structured query language, we can develop datasets that focus on various aspects of the data such as "lobsters seeded in the fall on the offshore bar". Data from the queries are ported primarily to SPSS or Arc View (ESRI) for spatial and temporal analysis. Spatial Analyst and Tracking Analyst (ESRI) and Phil Hooges (1997) animal movement extension.

Sonic Tagging -Fish Sonic Tagging

Fish were tagged and released quarterly: in June 2006, October 2006, January 2007 and June 2007. All fish were captured with hook and line gear (H & L) or fish traps (Z trap) within patch reef and fore reef habitats of WSER and on the offshore bar to the south of WSER. When necessary, excess air in the swim bladder was vented with a 16 gauge hypodermic needle after capture, and fish were immediately placed in a 60 liter tub filled with cooled aerated seawater. Once fish were stable and demonstrated normal behavior and swimming posture, they were considered candidates for surgery. Fish were then placed inverted (ventral side up) in a V-shaped surgical sling. A soft vinyl tube connected to a submersible pump was positioned in the mouth to flush the gills with fresh seawater throughout the procedure. A small (20 - 25 mm) incision was made with a sterilized scalpel posterior to the pelvic girdle and a VEMCO tag was implanted into the peritoneal cavity. The incision was closed with 4 - 5 Ethicon surgical sutures (Ethicon Inc., Somerville, New Jersey) and then fish were positioned dorsal side up in the sling for placement of conventional anchor tag into the dorsal musculature between the dorsal fin spines. Following the completion of surgery, length (total and fork) were recorded and fish were placed in a seawater recovery tank for observation. Once recovered (3-15 minutes), fish were handed to a diver in the water and the diver swam the fish down toward the bottom for release. Each fish was observed on the bottom for a few minutes, or until the fish swam out of visual range.

Movements of individual groupers and snappers were tracked using 45 sonic receivers (VEMCO VR2; VEMCO Ltd., Nova Scotia, Canada) deployed in the WSER and along unprotected benthic habitat (offshore bar) to the south of the reserve boundary. The VEMCO VR2s functioned as passive listening stations and recorded the unique code, date and time of acoustically tagged fish that passed within the receiver's range. VEMCO sonic tags (V9-2L, V13-1H, V16-3H, V16-4 H) each had a unique numerical digit code and transmitted at 69 kHz. Pinger signal minimum and maximum off times ranged from 5 - 30 seconds to 40 - 120 seconds delay. This configuration allowed the tags to transmit information to the receivers for a period of approximately 90 - 120 days and minimized the possibility of tag signal collisions. Each sonically-

tagged fish also received an external dart tag displaying the Fish and Wildlife Research Institute (FWRI) phone number.

RESULTS and DISCUSSION

Lobster Monitoring

We counted a total of 2,423 spiny lobsters using timed surveys --1, 692 during the full census (46 hrs of search time) during the closed fishing season (July 2006), and 731 in the abbreviated census (22 hrs of search time) during the open fishing season (September 2006).

Over the course of the 10-year study, we counted a total of 10,609 spiny lobsters (3,691 sub-legals, 6,355 legals, and 563 unknown size) at our sites in 362 surveys during the closed fishing season. Lobsters ranged in size from 20 mm carapace length (CL) to 148 mm CL. The size of the largest lobster encountered increased from 110 mm CL in 1997 to 148 mm CL in 2006. The 148 mm CL lobster was found in the fishery at Middle Sambo (MSB) between the reserves at Western Sambo (WSER) and Eastern Sambo (ESB). Overall, legal-sized lobsters were significantly larger in reserves than in the fishery reference areas (Kruskal-Wallis: $p < 0.00005$). Legal lobsters in reserves were largest on average in WSER, and smallest in the SPAs (Figure 6).

Lobster Size - Timed Surveys

There was no difference in size of legal-sized lobsters in reserves and references in 1997 (SPAs - ANOVA: $F = 1.62$, $df = 1$, $p = 0.2$; Carysfort -ANOVA: $F = 2.63$, $df = 1$, $p = 0.1$; WSER - ANOVA: $F = 0.05$, $df = 1$, $p = 0.8$) except in small LKS where lobsters were larger than in reference (ANOVA: $F = 4.7$, $df = 1$, $p < 0.05$)(Figure 7). There has been no increase in size of legal-sized lobsters following protection in the 10 small SPAs, the small long-term SPA, or the medium-sized SPA (Figure 7 a-c). However, after one year of protection, legal-sized lobsters were significantly larger in the large reserve than in the fishery and have lobster size has remained significantly larger throughout the decade (Figure 7d).

Lobster Size - Size-Frequency Collections

We collected approximately 50 lobsters from the forereef of 3 Lower Keys site pairs during July 2007. Additionally, approximately 50 lobsters were collected from the backreef in WSER and PEL. A total of 444 lobsters were collected, 307 legal-sized lobsters, and 137 sublegals. Mean size of legal-sized lobsters is shown in Figure 8. Lobsters in WSER were larger on average than in all other locations. However, the largest lobster captured was a 146 mm CL male lobster found in Middle Sambo.

Lobster Abundance - Timed Surveys

Legal-sized lobsters are significantly more abundant in small SPAs than in fishery (Figure 9a). In the small long-term SPA, there was no difference in abundance of legal-sized lobsters between reserve and reference (Figure 9b). Legal-sized lobsters are significantly less abundant in the medium-sized reserve than in fishery (Figure 9c). In the large reserve, however, legal-sized lobsters significantly more abundant in the reserve than in the fishery, but there is no effect of year (Figure 9d). There are significantly more legal-sized lobsters on forereef and backreef than on patch reefs within WSER.

Area-Based Surveys

We completed 140 area-based surveys in July 2007. Twenty-five surveys were done in the forereef and backreef of WSER and PLS. Ten belt-transects were completed in the forereef of ESB and LKS and their references. Legal-sized lobsters were more abundant in than in other SPAs/References (Figure 10).

Sonic Tagging

Overview

All together, the number of transmissions received by the sonic receivers exceed 1.1 million hits over the course of this study. A total of three receivers were lost, all outside WSER in the southeast corner of the study area. Receivers were presumably lost due to fishing activities. All receivers re-deployed during the summer of 2007 were recovered.

Lobster Sonic Tagging

A total of 90 *P. argus* and 2 *P. guttatus* were tagged in four seedings between June 2006 and June 2007 (Table 3). During the first three seedings, lobsters were tagged in Hawk Channel and the forereef of WSER, plus the offshore bar located just south of WSER. The final seeding (June 2007) focused on the forereef where the difficulties of obtaining acoustic signals from this complex topography required a concentration of receivers. Although in total, we tagged approximately half males and females, male lobsters for unknown reasons were difficult to find during October-November 2006.

In all, more than 580 thousand tag transmissions were recorded by the sonic receivers over the course of the study. Every lobster with the exception of one of the *Panulirus guttatus* was detected at least once by a receiver. Useful tracking information was obtained from more than 95% of the lobsters released during this study. Although there is no way to clearly distill these animal movement data results into a few tables, I have attempted to summarize some of the broader aspects of movements for the June

2006 - April 2007 deployment (Table 4) and June 2007 - August 2007 deployment (Table 4) and I will use these tables to organize some detailed results and discussion.

First seeding - June 2006- 30 lobsters tagged (29 *P. argus* and 1 *P. guttatus*).

Principal movement patterns:
(1) Hawk Channel females that were reproductively active exhibited a strong migration pattern characterized by a nighttime rush through the forereef and into deeper water probably beyond the southern boundary of WSER. The travel would generally take two nights. Typically, these females remain approximately 4-5 days then return to Hawk Channel (Figure 11 - representative chart).
(2) Hawk Channel males predominately remain in Hawk Channel. Some make broad lateral movements of perhaps greater than 1-2 kilometers, but they do not venture to the forereef or offshore bar.
(3) Forereef movement patterns were not clear due to the rugose nature of the forereef and it's effect on the sonic transmissions. Nevertheless, all twelve lobsters were detected by backreef or offshore bar receivers at least once. These movements are not reflected in Table 4. We now know after the special forereef deployment in the summer of 2007 that these 2006 detections were part of daily movement patterns where both male and female lobsters may travel after nightfall from the forereef to the backreef to feed. Detections by receivers to the south of the forereef represent either spawning movements by females or movements between the offshore bar and forereef by males or females.
(4) Offshore bar females that were reproductively active remained on the offshore bar to spawn. By the end of the spawning season, half of the females moved toward Hawk Channel, two into WSER and one outside WSER. In one case, we were able to track a female moving from the offshore bar to the north half of WSER (Figure 12).

Second seeding - October - November 2006 - 20 lobsters tagged (all *P. argus*)

Principal movement patterns:
(1) None of the female lobsters tagged were reproductively active and none of these lobsters made movements towards deep water as in the summer.
(2) Only one lobster made a major change in position. This was a small 66 mm CL female lobster tagged in Hawk Channel. From October 12th to November 30th, she trekked from central Hawk Channel to the outside (southern portion) of the offshore bar. In late December she moved to the forereef inside WSER.

Third seeding - February 2007 - 19 lobsters tagged (18 *P. argus* and 1 *P. guttattus*)

Principal movement patterns:
(1) None of the female lobsters tagged were reproductively active and none of these lobsters made movements towards deep water as in the summer.

(2) Large shifts in location, unlike the late fall, became common again as one third of the lobsters tagged in this seeding emigrated from the original location. Another small female (also 66 mm CL) trekked from Hawk Channel to the offshore bar between February 8th to March second. Two females from the forereef migrated to the offshore bar. One offshore bar male migrated to Hawk Channel and a forereef male migrated to the offshore bar then moved laterally along the forereef to the west sentinel receivers located approximately 2 km west of WSER.
(3) The single *P. guttatus* was detected fewer than 10 times by a Hawk Channel receiver closest to the release point. No other receivers detected this tag.

June 2007 - August 2007 forereef only deployment

Fourth seeding - June 2007- 24 lobsters tagged (29 *P. argus* and 1 *P. guttatus*). The forereef was an acoustically difficult place to track tagged lobsters but the very close positioning of the receivers within the grooves of the reef successfully revealed the movements of these lobsters.
Principal movement patterns:
(1) All ten reproductively active females made at least one deep water trip presumably to spawn (Table 4). Two of the ten made three detected trips (sample given in Figure 13). The reproductive migration typically lasts three to five days whereupon each lobster returns to its "home" groove on the forereef. When multiple trips are detected, the time between trips ranged between 23 and 32 days with a mode of 25 days.
(2) Daily movement patterns typically involved movement from a groove on the forereef beginning shortly after dusk. By midnight lobsters reach a foraging ground which is often the back reef but can also be another regional of the forereef. Lobsters rarely ventured near our deep reef receivers unless spawning. These daily movement patterns are reminiscent of daily movement patterns observed in Hawk Channel lobsters in studies conducted with closely packed sonic receivers (Bertelsen and Hornbeck, in review).

Fish Visual Surveys

All sites surveyed in 2007 are presented in Table 5. Data are presently being proofed and entered from these surveys.

Fish Sonic Tagging

Forty eight fish were successfully implanted with acoustic tags and released between June 2006 and June 2007 (Table 6). Catch per unit effort (CPUE) for tagged fish are reported for each quarter in Table 7. The majority of reef fish species acoustically tagged were seranids: twenty six red grouper, Epinephelus morio, five Nassau grouper, Epinephelus striatus, seven black grouper, Mycteroperca bonaci, two rock hind, Epinephelus adscensionis, one goliath grouper, Epinephelus itajara and one gag grouper, Mycteroperca microlepsis. In addition, two yellowtail, Ocyurus chrysurus,

one mutton snapper, Lutjanus analis, one gray snapper, Lutjanus griseus, one cobia, Rachycentron canadum, and one blacktip shark, Carcharhinus limbatus, were also tagged. Mean size of all snappers and groupers tagged is summarized in Figure 14.

A summary of frequency of signal detections by fish and by VR2s is presented in Tables 8,9. Preliminary analyses indicate that groupers that were captured on Hawk Channel patch reefs appeared to remain on patch reefs (see Report 1 for preliminary information on home range estimates). The large reserve design (30 km2) appears effective in providing adequate protection of patch reef habitat for these fish. However, fish captured in the fore reef zone and from the deeper offshore bar exhibited significant movement between these habitats. Fish that utilized the fore reef zone often moved across the southern reserve boundary to and from the open fishing area of the offshore bar.

Two examples of individual fish movements captured and released in the fore reef zone are presented below. The first case is a Nassau grouper (tag 868; 480 mm TL) tagged on February 8, 2007 and last detected on April 18, 2007. This fish was periodically detected on offshore bar receivers as indicated by the mean daily latitude position in Figure 15. Detections were generally within range of the fore reef receivers but occasionally this fish was also detected on offshore bar receivers, indicating movement to the south, across the southern reserve boundary. The second case is a black grouper (tag 1319; 760 mm TL) tagged on October 18, 2006 and last detected on February 15, 2007. This fish also exhibited movements outside the reserve boundary along the offshore bar (Figure 16). This fish was continuously present near the center of the fore reef and offshore bar receivers, with four receivers recording 92.1% of the total pings detected. However, approximately 6.2% of detections were recorded for a short period (November 9 - 15, 2007) on receivers to the west of the reserve along the north side of the offshore bar.

To improve resolution on habitat usage and fine scale details of movements, future work will focus on the spur and groove sections of the fore reef (see array design in Figures 2,3) and integrate these results with the broad-scale movements established in the WSER and offshore bar.

CONCLUSIONS and MANAGEMENT CONSIDERATIONS

Lobster Monitoring

The 10 small SPAs are partially effective reserves because legal-sized lobsters are larger and more abundant than in fishery, but there has been no increase in size or abundance over time. The small long-term LKS SPA is a partially effective reserve because legal-sized lobsters generally larger in reserve than in fishery but they are less abundant in reserve than in fishery, even after 25 years of protection. The medium-sized CAR SPA is a partially effective reserve because legal-sized lobsters larger in reserve than in fishery - but they are significantly less abundant there than in reserve than in fishery. Western Sambo Ecological Reserve is functioning as an effective

reserve for spiny lobsters as evidenced by the increase and abundance of legal-sized lobsters relative to the fishery. We have also observed evidence of "spillover" of large lobsters from reserve to the fishery.

Small and medium-sized reserves in FKNMS provide a small amount of protection to spiny lobsters. Increased reserve longevity (LKS) or reserve size when a single habitat is protected (CAR) does not provide increased lobster protection. WSER is an effective reserve because it encompasses a large area of diverse lobster habitats including patch reefs as well as forereef/backreef which lobsters utilize differently during different seasons and life stages. Effective reserves for spiny lobsters must protect habitat for multiple life-stages of lobsters and take into account lobster reproductive behavior in addition to foraging behavior.

Sonic Tagging

Lobster Sonic Tagging

Please note: In this last discussion and review of our work with sonic technology, spiny lobsters in the Western Sambo Ecological Reserve, I'm going to utilize some of the findings that come from our earlier study (2003, 2004) where sonic receivers were deployed in a close grid pattern in Hawk Channel that permitted us to track lobsters with a fairly high degree of precision but without knowing movement patterns that exceeded a kilometer or two (Bertelsen et al. 2000). In the current project, receivers were placed far apart which allow us to detect departures and arrivals over many kilometers but without knowing smaller scale movements. Both sets of studies provide essential but different views about how lobsters utilize WSER.

Our view of the spatial requirements, movement patterns, and how spiny lobsters use their environment has changed greatly since the nineteen twenties when *P. argus* was considered a "sluggish" animal but perhaps capable of long distant movements and likely incapable of returning to the same den "except by accident" (Crawford & de Smidt 1922). Perhaps one of the most important studies that began to change this view was the Tektite project of the late 1960's and early 1970's. In the Virgin Islands, a scientific team worked with the underwater habitat that now is located on Conch reef and they made extensive use of sonic tags. They found that lobsters had repetitive paths and timings that would lead individual lobsters on a journey of up to a kilometer away from their daytime den to feed, then the lobsters would unerringly return to the same den (Cooper & Herrnkind, 1971; Herrnkind & McLean, 1971; Herrnkind et al. 1975; Olsen et al., 1971). In the Tektite project, Herrnkind also made an first attempt to quantify emigration from their study site.

Daily movements:

Spiny lobsters in Hawk Channel and forereef have somewhat analogous daily patterns of movement basic on the earlier study in Hawk Channel and our last seeding in this project. In both the forereef and Hawk Channel, lobsters emerge from daytime

shelters after dusk and begin to travel toward foraging grounds. For forereef lobsters, this is typically the backreef zone as first described by Hunt et al., 1991 from large scale diver observation based project at Looe Key. We also found that lobsters sometimes travel laterally to forage and at other times they do not travel much at all. The finding, that sometimes lobsters stay near their den, supports Herrnkind's observations from Tektite where they observed some individuals remaining near their den sometimes. Hawk Channel lobsters also generally travel up to a kilometer at times to "favorite" foraging areas. Both forereef and Hawk Channel lobsters reach their foraging areas by midnight and around 3 am both return to the same forereef groove or patch reef to pick out a daytime shelter. That lobsters return to the same groove or patch reef is a tendency, not a "law" and as Herrnkind found during Tektite, we also found sudden unpredictable changes in denning preference and sometimes, lobsters left the area all together.

Because we did not have the resources and time to tightly pack receivers on the offshore bar, I cannot postulate on daily movement patterns for these lobsters. I have little doubt that these lobsters exhibit somewhat analogous daily movement patterns.

Reproductive migrations:

One principal new findings we made with these sonic studies is that egg bearing females in Hawk Channel and the forereef migrate to deeper waters south of the forereef to release eggs. I first speculated that female lobsters used deep water to spawn based on the incidence of late stage eggs found on egg bearing lobsters in deep water during a late 1990's fecundity study (Bertelsen et al., 2000).

Hawk Channel egg bearing females typically leave for deep water near midnight, suddenly turning south moving at nearly 500 m per hour. These trips generally take two days to complete. After 4-5 days, these lobsters typically return to their home patch reef. We found two occasions, however, where the female lobster stayed in the deep water then began to wander through the forereef or offshore bar. Another exception to this reproductive migration is that we found two or three egg bearing females (these data are not 100% definitive) that did not migrate but remained in Hawk Channel well beyond the time the eggs would have been released. I have speculated these non-migrating females are "naive" and that the clutch we observed may be their first.

Forereef egg bearing females also move to deeper water to spawn. During our final summer 2007 seeding, the overall number of tag detections by all receivers very nearly 50% female and 50% male. The receiver located in deep water near the offshore bar directly south of the seeding detected more than 95% female lobsters. One new finding we made with this project was that we detected three distinct migrations for two of the ten reproductively active tagged forereef females. We have observed three egg masses for lobsters kept in the laboratory (T. Matthews - FWC, pers. comm.) and this is the first field confirmation of that observation. Because weather and water conditions forced us to start tagging well into the spawning season, I

believe it likely that we could detect many more reproductive migrations if we could begin tagging in April or May rather than June.

I do not have data to allow a definitive statement regarding offshore bar reproductively active females. I believe it likely that these females simply spawn in their locale area.

Emigration

From the Tektite project, Olsen et al. (1971) reported daily emigration of between 0.6% to 2.6% and 2.7% in two separate sites. This extrapolates to approximately a 34% monthly rate of emigration of initial residents (i.e., excluding subsequent immigration). They also reported that approximately 12% of those tagged returned after extended periods of time (between 20 and 74 days). From our 2003 and 2004 studies we estimated net emigration of 25% of males after 54 days (Bertelsen and Hornbeck, in review). We could not venture an estimate of female emigration due to complications with reproductive migration.

In our large scale seedings (Summer 2006, Fall 2006, and Winter 2007), we find a wide range of emigration rates ("leaving" or "entering" WSER vs "remaining in tagged area") ranging between 6% (Fall 2006) to 38% (Summer 2006) for what is approximately a 60 day (3 month) period. Although we experienced a distinct lack of emigration during the winter seeding, the relatively small sample size and the lack of replicate winter seedings leaves this observation as interesting but without significance on its own.

Executive summary of findings

1. During the reproductive season, all mature female lobsters throughout WSER whether they reside in Hawk Channel, the forereef, or the offshore bar, are participating in egg production by traveling to (or residing in) deeper waters off the WSER forereef or offshore bar. Migrations may repeat up to three times with a 3.5 to 5 week interval between spawnings.

2. During the reproductive season, all mature male lobsters throughout WSER and the offshore bar tend to remain in their respective region and presumably mate with female lobster in those regions.

3. Emigration between the offshore bar and forereef or Hawk Channel appears to predominately occur during late summer or late winter seasons. Please note, however, that this is based on one year's observation. Variation among years is unknown. Long range migrations between the offshore bar and Hawk Channel do occur, however; data are insufficient to estimate a rate.

4. None of the sonic data collected during this project and two previous projects support a correlation between movement rates and moon phase. In addition, reproductive migrations by female lobsters is not influenced by moon phase. Spawning by different individuals occur at any lunar phase and when multiple spawning events are detected by an individual, these events typically occur at different lunar phases.

5. There is no evidence to suggest that WSER acts as a "magnet", concentrating lobsters from surrounding areas. Over the course of a year, for the lobsters we could track and identify a fate, five of 18 lobsters tagged on the offshore bar, left the offshore bar (27%) and nine of 38 WSER forereef and Hawk Channel lobsters left WSER (24%) (Table 4).

Fish sonic tagging

Understanding the spatial dynamics and habitat usage of fishes is critical to understanding the efficacy of marine reserves and their role in supporting fisheries. Recreational and commercial fishing pressure has depleted populations of large predatory reef fishes and caused unprecedented global changes in coral reef ecosystems (Starr et al., 2005). In the Florida Keys, recent population stock assessments have identified thirteen grouper, seven snapper and two grunt species as currently over-fished (Ault et al., 1998). Numerous species of groupers and snappers are particularly susceptible to over exploitation because they form large spawning aggregations at predictable times and locations. Targeted fishing effort by fishermen in these areas has resulted in the disappearance (10%) or decline (65%) of 280 known aggregations worldwide (Cornish, 2005).

The WSER provides protection for a variety of cross-shelf habitats, i.e. seagrass, hard bottom, patch reefs & fore reef, which theoretically provides protection for ontogenetic related habitat shift movements for fishes from settlement through the adult stage. Preliminary information from acoustic telemetry suggests that groupers captured and released on patch reefs, remained on patch reef habitat. However, the southern boundary of the WSER does not extend beyond 18 m depth and likely does not provide refuge for migratory spawning movements. Although the WSER and the adjacent offshore bar have not been documented as fish spawning habitat, nine probable spawning sites for four species of snappers have been identified in the vicinity of the WSER (9 – 98 m depth) (Lindemann et al., 2000). Analyses of acoustical data do not yet substantiate migratory movements related to spawning events. However, groupers that utilized the fore reef zone moved across the southern reserve boundary to and from the deeper offshore bar, including the endangered Nassau grouper *Epinephelus striatus*.

Although temporal and spatial patterns of spawning behavior of most snappers and groupers are not well documented in the Florida Keys, habitat near the WSER (the offshore bar south of Western Dry Rocks [12 – 37 m depth]) is a known aggregation site for gray snapper *Lutjanus griseus* and mutton snapper *L. analis* (Lindemann et al.,

2000). Effective conservation of exploited reef fishes requires that deeper reefs and the timing of spawning migration patterns be incorporated into fisheries management plans (Starr et al., 2005). Therefore, we recommend that the southern boundary of the WSER be extended to the south to protect the deeper offshore bar habitat. Additionally, placement of a marine reserve at Western Dry Rocks reef incorporating the offshore bar area should be reviewed and species specific seasonal spawning closures should be considered in future management plans.

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Table 1. Lobster Monitoring Sites. Sanctuary Zones (reserves) and their reference areas.

RESERVE	REFERENCE AREA
Western Sambo ER (WSER)	Pelican Shoal (PLS)
Carysfort/South Carysfort SPA (CAR)	Pacific Reef (PAC)
Eastern Sambo RO (ESB)	Middle Sambo (MSB)
Grecian Rocks SPA (GDR)	North North Key Largo Dry Rocks (NNDR)
Molasses Reef SPA (MOL)	Pickles Reef (PIC)
Conch Reef RO (CNR)	Little Conch Reef (LCON)
Alligator Reef SPA (ALL)	Alligator Reef West (ALLC)
Tennessee Reef RO (TNR)	Tennessee Reef Light (TNC)
Coffins Patch SPA (COF)	The Donut (COFC)
Sombrero Key SPA (SOM)	Delta Shoal (DEL)
Looe Key SPA (LKS)	Maryland Shoal (MAR)
Looe Key RO (LKR)	Looe Key West Patches (LKRC)
Sand Key SPA (SAN)	Western Dry Rocks (WDR)

Table 2. Lobster Monitoring Site Locations and Sampling Dates.

PROTECTED ZONES						REFERENCE AREAS					
Date	Site	Habitat	Rep	Latitude (N)	Longitude (W)	Date	Site	Habitat	Rep	Latitude (N)	Longitude (W)
6/23/2006	SOM	Forereef	1	24˚22.567	81˚06.595	6/23/2006	DEL	Forereef	1	24˚37.944	81˚05.397
6/26/2006	SAN	Forereef	1	24˚27.122	81˚52.706	6/26/2006	WDR	Forereef	1	24˚26.697	81˚55.575
6/30/2006	ESB	Forereef	1	24˚49.165	81˚66.256	6/30/2006	MSB	Forereef	1	24˚48.919	81˚67.293
7/3/2006	COF	Patch Reef	1	24˚68.538	80˚96.362	7/3/2006	COFC	Patch Reef	1	24˚69.120	80˚94.736
7/5/2006	TNR	Forereef	1	24˚76.390	80˚75.440	7/5/2006	TNC	Forereef	1	24˚74.553	80˚78.162
7/20/2006	ALL	Forereef	1	24˚50.060	81˚62.968	7/20/2006	ALLC	Forereef	1	24˚50.306	81˚62.196
7/21/2006	CAR	Forereef	1	24˚47.911	81˚71.687	7/17/2006	PAC	Forereef	1	25˚22.204	80˚08.354
7/21/2006	CAR	Forereef	2	24˚48.214	81˚91.746	7/17/2006	PAC	Forereef	2	25˚22.385	80˚08.428
7/21/2006	CAR	Forereef	3	24˚48.092	81˚71.928	7/17/2006	PAC	Forereef	3	24˚49.606	81˚64.931
7/18/2006	MOL	Forereef	1	24˚56.454	80˚28.449	7/18/2006	PIC	Forereef	1	24˚48.341	81˚70.782
7/14/2006	CNR	Forereef	1	24˚51.374	81˚71.429	7/14/2006	LCON	Forereef	1	24˚28.924	81˚42.234
7/19/2006	GDR	Forereef	1	24˚30.035	81˚37.712	7/19/2006	NNDR	Forereef	1	25˚22.106	80˚08.435
7/24/2006	LKR	Patch Reef	1	24˚30.522	81˚41.635	7/20/2006	LKRC	Patch Reef	1	24˚50.235	81˚63.264
7/20/2006	LKS	Forereef	1	24˚29.002	81˚42.213	7/21/2006	MAR	Forereef	1	24˚57.000	80˚27.257
7/10/2006	WES	Forereef	1	24˚50.791	80˚37.348	7/10/2006	PLS	Forereef	1	25˚00.563	80˚22.563
7/10/2006	WES	Forereef	2	24˚50.427	80˚37.680	7/10/2006	PLS	Forereef	2	24˚59.229	80˚24.872
7/12/2006	WES	Forereef	3	24˚56.307	81˚40.113	7/12/2006	PLS	Forereef	3	24˚50.228	81˚62.801
7/11/2006	WES	Back Reef	1	24˚54.617	81˚40.361	7/13/2006	PLS	Back Reef	1	25˚06.473	80˚18.358
7/13/2006	WES	Back Reef	2	25˚22.227	80˚20.974	7/17/2006	PLS	Back Reef	2	25˚08.196	80˚17.366
7/17/2006	WES	Back Reef	3	25˚22.025	80˚21.039	7/18/2006	PLS	Back Reef	3	24˚52.198	81˚63.237
7/11/2006	WES	Patch Reef	1	25˚21.177	80˚21.736	7/19/2006	PLS	Patch Reef	1	24˚52.424	81˚63.261
7/12/2006	WES	Patch Reef	2	24˚50.941	81˚56.927	7/19/2006	PLS	Patch Reef	2	24˚52.527	81˚63.027
7/19/2006	WES	Patch Reef	3	24˚56.672	81˚38.960	7/19/2006	PLS	Patch Reef	3	24˚50.478	81˚72.038
9/11/2006	ESB	Forereef	1	24˚29.503	81˚39.766	9/11/2006	MSB	Forereef	1	24˚29.298	81˚40.533
9/12/2006	LKS	Forereef	1	24˚32.753	81˚24.325	9/13/2006	MAR	Forereef	1	24˚30.668	81˚34.228
9/15/2006	WSB	Forereef	1	24˚28.752	81˚43.031	9/13/2006	PLS	Forereef	1	24˚30.011	81˚37.781
9/15/2006	WSB	Forereef	2	24˚28.818	81˚42.784	9/14/2006	PLS	Forereef	2	24˚30.011	81˚37.229
9/18/2006	WSB	Forereef	3	24˚28.924	81˚42.307	9/14/2006	PLS	Forereef	3	24˚30.288	81˚37.103
9/19/2006	WSB	Back Reef	1	24˚28.942	81˚42.787	9/13/2006	PLS	Back Reef	1	24˚30.086	81˚37.964
9/19/2006	WSB	Back Reef	2	24˚28.929	81˚42.974	9/20/2006	PLS	Back Reef	2	24˚30.165	81˚37.779
9/20/2006	WSB	Back Reef	3	24˚28.981	81˚42.318	9/20/2006	PLS	Back Reef	3	24˚30.247	81˚37.370
9/21/2006	WSB	Patch Reef	1	24˚30.338	81˚42.333	9/22/2006	PLS	Patch Reef	1	24˚31.325	81˚39.422
9/21/2006	WSB	Patch Reef	2	24˚29.711	81˚42.482	9/22/2006	PLS	Patch Reef	2	24˚31.608	81˚39.107
9/25/2006	WSB	Patch Reef	3	24˚30.658	81˚42.051	9/25/2006	PLS	Patch Reef	3	24˚31.378	81˚39.953

Table 3. Sonic tag seeding efforts by time, sex, and location.

		Location (# tagged)			Group statistics		
Time	Sex	Offshore bar	Forereef	Hawk Channel	Largest (mm CL)	Smallest (mm CL)	Number tagged
June 2006	M	2	6	5	113	75	13
	F	6	6	4	90	66	16
October 2006	M	3	1	3	101	76	7
	F	5	5	2	94	66	12
February 2007	M	3	4	3	118	66	10
	F	2	3	3	87	70	8
June 2007 (forereef only)	M	na	12	na	122	71	12
	F	na	12	na	100	68	12
Group totals		21	49	20	122	66	90

Table 4. Large scale movements of lobsters in and around WSER by season, sex, reproductive status, and location.

Location	Number tagged	Sex (reproductive) (females)	tagged area	Remained in WSER[1]	WSER[2]	Left fate	Entered UnknownMade deep water spawning trip[3]
Seeding 1 (June 2006)							
Offshore bar	2	M			1	1	
	6	F (4)	1		3	2	na
Forereef	6	M	1			5	
	6	F (6)	5	1			1?
Hawk Channel	5	M	4	1			
	4	F (4)	2	2			3
Seeding 2 (November 2006)							
Offshore bar	3	M	3				
	5	F (0)	5				
Forereef	1	M	1				
	5	F (0)	3			2	
Hawk Channel	3	M	3				
	3	F (0)	1	1		1	
Seeding 3 (February 2007)							
Offshore bar	3	M	2		1		
	2	F (0)	2				
Forereef	4	M	3	1		1	
	3	F (0)	1	2			
Hawk Channel	3	M	3				
	3	F (0)	2	1			

[1]Number of Forereef or Hawk Channel lobsters that moved to the offshore bar or left WSER sometime during a three month period following the seeding.

[2]Number of Offshore bar lobsters that moved into WSER forereef or Hawk Channel sometime during a three month period following the seeding.

[3]Number of female lobsters making spawning trips from Hawk Channel or forereef to deep water south of WSER. This category is not applicable for offshore bar females.

Table 5. Location of fish visual census sites surveyed in WSER in 2007.

Field No.	Month	Grid	Long. Deg.	Long. Min.	Lat. Deg.	Lat. Min.
FKV07050501	5	2241	81	42.237	24	33.044
FKV07050502	5	2240	81	41.219	24	33.173
FKV07050505	5	2593	81	42.822	24	28.193
FKV07050506	5	2531	81	42.354	24	29.115
FKV07050507	5	2532	81	43.078	24	29.477
FKV07060701	6	2240	81	41.408	24	33.104
FKV07060802	6	2530	81	41.919	24	29.101
FKV07060803	6	2463	81	41.697	24	30.029
FKV07060804	6	2464	81	42.637	24	30.360
FKV07060805	6	2532	81	43.344	24	29.265
FKV07070601	7	2241	81	42.200	24	33.048
FKV07070602	7	2465	81	43.243	24	30.100
FKV07070603	7	2532	81	43.136	24	29.991
FKV07070604	7	2531	81	42.301	24	29.743
FKV07070605	7	2594	81	43.047	24	28.765
FKV07080604	8	2463	81	41.657	24	30.044
FKV07080605	8	2530	81	41.922	24	29.824
FKV07080606	8	2531	81	42.132	24	29.128
FKV07080607	8	2464	81	42.632	24	30.383
FKV07080608	8	2532	81	43.199	24	29.513
FKV07090601	9	2465	81	43.237	24	30.105
FKV07090602	9	2532	81	43.247	24	29.508
FKV07090603	9	2531	81	41.966	24	29.125
FKV07090604	9	2594	81	43.522	24	28.808
FKV07090806	9	2392	81	41.473	24	31.552

Table 6. All acoustically tagged fish captured and released in the WSER between June 2006 - June 2007.

Species	Date	Region/Zone	Depth (ft)	Size (TL) (mm)	Code	Tag Type
Carcharhinus limbatus	6/15/2006	Patch	25	1350	1216	V16-4H
Epinephelus adscensionis	6/12/2007	Fore Reef	28	415	2195	V16-4H
Epinephelus adscensionis	6/12/2007	Fore Reef	28	440	2197	V16-4H
Epinephelus itajara	6/15/2006	Patch	25	760	1218	V16-4H
Epinephelus morio	2/9/2007	Fore Reef	34	642	863	V16-3H
Epinephelus morio	2/8/2007	Patch	18	580	864	V16-3H
Epinephelus morio	1/30/2007	Patch	24	510	866	V16-3H
Epinephelus morio	1/30/2007	Patch	24	550	867	V16-3H
Epinephelus morio	2/8/2007	Patch	18	600	869	V16-3H
Epinephelus morio	10/19/2006	Patch	25	435	882	V9-2L
Epinephelus morio	6/14/2006	Patch	25	530	1202	V13-1H
Epinephelus morio	6/14/2006	Patch	25	500	1203	V13-1H
Epinephelus morio	6/9/2006	Patch	25	520	1204	V13-1H
Epinephelus morio	6/9/2006	Patch	25	565	1205	V13-1H
Epinephelus morio	6/8/2006	Patch	25	597	1209	V13-1H
Epinephelus morio	6/9/2006	Patch	25	560	1213	V13-1H
Epinephelus morio	6/8/2006	Patch	25	483	1215	V13-1H
Epinephelus morio	2/8/2007	Patch	18	635	1217	V16-4H
Epinephelus morio	2/8/2007	Fore Reef	40	660	1219	V16-4H
Epinephelus morio	10/19/2006	Patch	25	570	1220	V16-4H
Epinephelus morio	6/14/2006	Patch	25	540	1274	V16-3H
Epinephelus morio	6/14/2006	Patch	25	610	1275	V16-3H
Epinephelus morio	10/18/2006	Fore Reef	35	550	1277	V16-3H
Epinephelus morio	6/14/2006	Patch	25	635	1278	V16-3H
Epinephelus morio	10/11/2006	Outer bar	78	620	1279	V16-3H
Epinephelus morio	10/19/2006	Patch	25	530	1321	V16-3H
Epinephelus morio	10/18/2006	Fore Reef	65	570	1322	V16-3H
Epinephelus morio	2/9/2007	Fore Reef	34	625	2158	V16-3H
Epinephelus morio	2/9/2007	Fore Reef	34	535	2159	V16-3H
Epinephelus morio	6/12/2007	Fore Reef	28	670	2196	V16-4H
Epinephelus morio	1/30/2007	Patch	24	560	Unknown	
Epinephelus stratus	2/8/2007	Fore Reef	40	480	868	V16-3H
Epinephelus striatus	10/12/2006	Outer bar	83	470	1280	V16-3H
Epinephelus striatus	10/18/2006	Fore Reef	65	410	1316	V16-3H
Epinephelus striatus	10/18/2006	Fore Reef	65	525	1317	V16-3H
Epinephelus striatus	10/18/2006	Fore Reef	65	480	1323	V16-3H
Lutjanus analis	10/18/2006	Fore Reef	35	555	1318	V16-3H
Lutjanus griseus	6/14/2007	Fore Reef	28	505	2156	V16-3H

Table 6. (continued)

Species	Date	Region/Zone	Depth (ft)	Size (TL) (mm)	Code	Tag Type
Mycteroperca bonaci	10/12/2006	Outer bar	83	720	865	V16-3H
Mycteroperca bonaci	10/19/2006	Patch	25	480	881	V9-2L
Mycteroperca bonaci	10/18/2006	Fore Reef	65	760	1319	V16-3H
Mycteroperca bonaci	10/19/2006	Patch	25	560	1320	V16-3H
Mycteroperca bonaci	6/14/2007	Fore Reef	28	590	2152	V16-3H
Mycteroperca bonaci	6/14/2007	Fore Reef	28	440	2157	V16-3H
Mycteroperca bonaci	6/12/2007	Fore Reef	28	470	4234	V13-1H
Mycteroperca microlepis	6/14/2006	Patch	25	640	1273	V16-3H
Ocyurus chrysourus	2/20/2007	Outer Bar	36	550	2155	V16-3H
Ocyurus chrysurus	10/11/2006	Outer bar	52	370	880	V9-2L
Rachycentron canadum	10/12/2006	Outer bar	65	780	1276	V16-3H

Table 7. CPUE for all fish tagged.

Tagged June 2006

ZONE	Effort (hrs)	GEAR	Catch (# fish)	CPUE (fish hr^{-1})
Patch	7.84	H&L	6	0.77
Patch	21.68	Trap	7	0.32
Fore reef	3.75	Trap	0	0.00
Outer bar	3.90	Trap	0	0.00
All Zones	37.17	both	13	0.35

Tagged fish Oct/Nov 2006

ZONE	HOURS (hrs)	GEAR	# of fish (# fish)	CPUE (fish hr^{-1})
Patch	0.80	H &L	5	6.25
Patch	2.78	Trap	0	0.00
Fore reef	2.50	H &L	2	0.80
Fore reef	4.05	Trap	5	1.23
Outer bar	5.70	H &L	2	0.35
Outer bar	33.27	Trap	3	0.09
All Zones	49.10	both	17	0.35

Tagged fish Jan/Feb 2007

ZONE	HOURS (hrs)	GEAR	# of fish (# fish)	CPUE (fish hr^{-1})
Patch	3.12	H&L	5	1.60
Fore reef	3.18	H&L	5	1.57
Outer bar	18.04	traps	1	0.06
Outer bar	4.75	H&L	0	0.00
All Zones	29.09	both	11	0.38

Table 8. Frequency of detections of tagged fish by individual VR2 listening stations for June 2006 – April 2007.

VR2	Frequency	Percent	Valid Percent	Cumulative Percent
2311	389	0.09	0.09	0.09
2312	881	0.20	0.20	0.29
2314	4899	1.11	1.11	1.40
2315	7661	1.74	1.74	3.14
2316	7323	1.66	1.66	4.80
2317	892	0.20	0.20	5.00
2318	12	0.00	0.00	5.01
2319	61707	14.01	14.01	19.01
2320	26	0.01	0.01	19.02
2323	439	0.10	0.10	19.12
2324	932	0.21	0.21	19.33
2325	15391	3.49	3.49	22.83
2326	1479	0.34	0.34	23.16
2327	128	0.03	0.03	23.19
2328	33722	7.65	7.65	30.85
2329	3740	0.85	0.85	31.69
2330	8011	1.82	1.82	33.51
2331	1909	0.43	0.43	33.95
2332	17	0.00	0.00	33.95
4207	109320	24.82	24.82	58.77
4209	123	0.03	0.03	58.79
5115	35685	8.10	8.10	66.89
5116	1346	0.31	0.31	67.20
5117	162	0.04	0.04	67.24
5118	105	0.02	0.02	67.26
5120	3048	0.69	0.69	67.95
5121	843	0.19	0.19	68.14
5123	67753	15.38	15.38	83.52
5124	8723	1.98	1.98	85.50
7149	5632	1.28	1.28	86.78
7151	46	0.01	0.01	86.79
7154	362	0.08	0.08	86.87
7155	10219	2.32	2.32	89.19
7160	28	0.01	0.01	89.20
7245	785	0.18	0.18	89.38
7246	3520	0.80	0.80	90.18
7247	153	0.03	0.03	90.21
7248	21550	4.89	4.89	95.10
7249	1939	0.44	0.44	95.54
7250	19627	4.46	4.46	100.00
Total	**440527**	**100**	**100**	

Table 9. Frequency of detections for individual tagged fish between June 2006 – April 2007.

Code	Frequency	Percent	Valid Percent	Cumulative Percent
863	558	0.13	0.13	0.13
864	3703	0.84	0.84	0.97
865	2286	0.52	0.52	1.49
866	4204	0.95	0.95	2.44
867	8737	1.98	1.98	4.42
868	18502	4.20	4.20	8.62
869	2438	0.55	0.55	9.18
880	2983	0.68	0.68	9.85
881	19	0.00	0.00	9.86
882	50	0.01	0.01	9.87
1202	1762	0.40	0.40	10.27
1203	46	0.01	0.01	10.28
1204	1352	0.31	0.31	10.59
1205	555	0.13	0.13	10.71
1209	285	0.06	0.06	10.78
1213	17078	3.88	3.88	14.65
1216	46	0.01	0.01	14.67
1217	1014	0.23	0.23	14.90
1218	67719	15.37	15.37	30.27
1219	13647	3.10	3.10	33.37
1220	172	0.04	0.04	33.40
1273	4680	1.06	1.06	34.47
1274	1473	0.33	0.33	34.80
1275	12025	2.73	2.73	37.53
1276	16	0.00	0.00	37.53
1277	37492	8.51	8.51	46.05
1278	1189	0.27	0.27	46.32
1279	68276	15.50	15.50	61.81
1280	13	0.00	0.00	61.82
1316	127	0.03	0.03	61.85
1317	52441	11.90	11.90	73.75
1318	178	0.04	0.04	73.79
1319	30408	6.90	6.90	80.69
1320	4678	1.06	1.06	81.75
1321	14877	3.38	3.38	85.13
1322	16096	3.65	3.65	88.79
1323	28455	6.46	6.46	95.25
2155	12186	2.77	2.77	98.01
2158	5669	1.29	1.29	99.30
2159	3092	0.70	0.70	100.00
Total	**440527**	**100**	**100**	

Figure 1. Lobster Monitoring Sites in Florida Keys National Marine Sanctuary

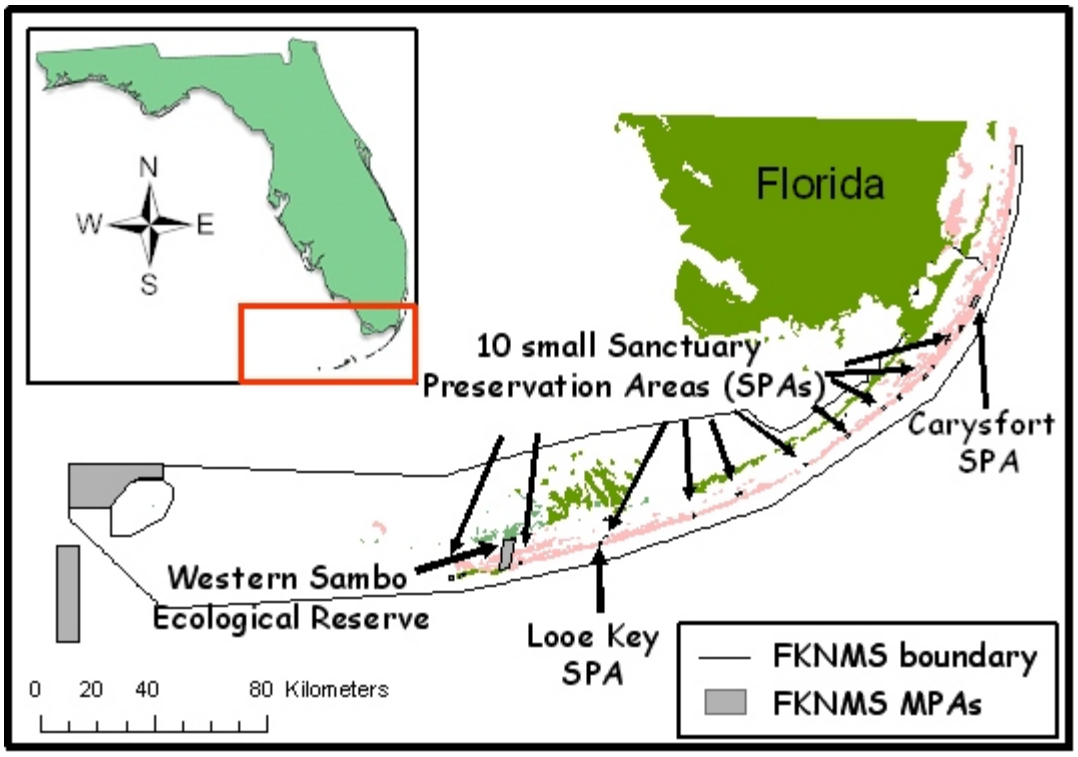

Figure 2. Sonic receiver deployment sites; first deployment; (June 2006 - April 2007) within and around Western Sambo Ecological Reserve. The circles around the deployment site indicate the approximate range of detection (~300 m) of VR2 receivers with V16 sonic tags. The sonic receivers were arranged into three interlocking rings or zones.

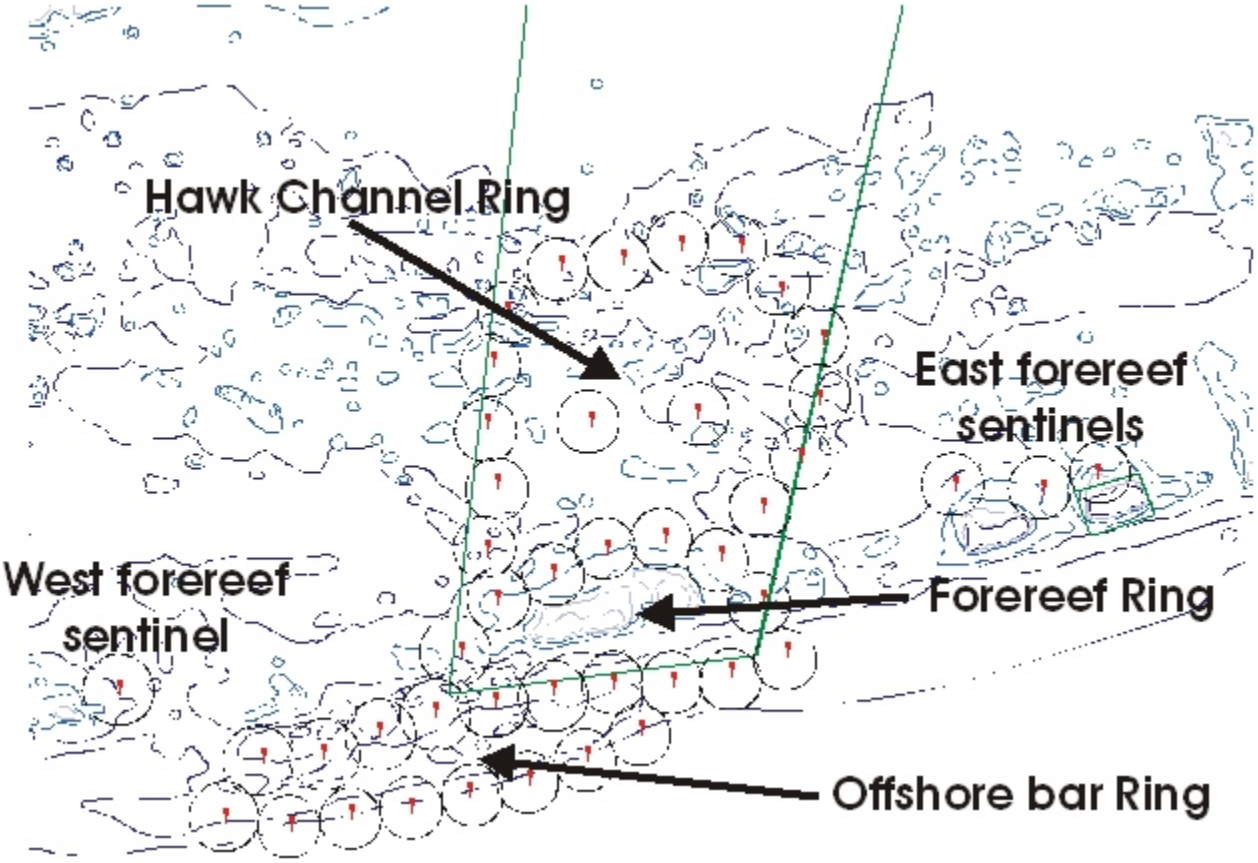

Figure 3. A detailed view of the forereef groove receivers; second deployment; (June - August 2007) and the two mooring balls where we based tagging operations.

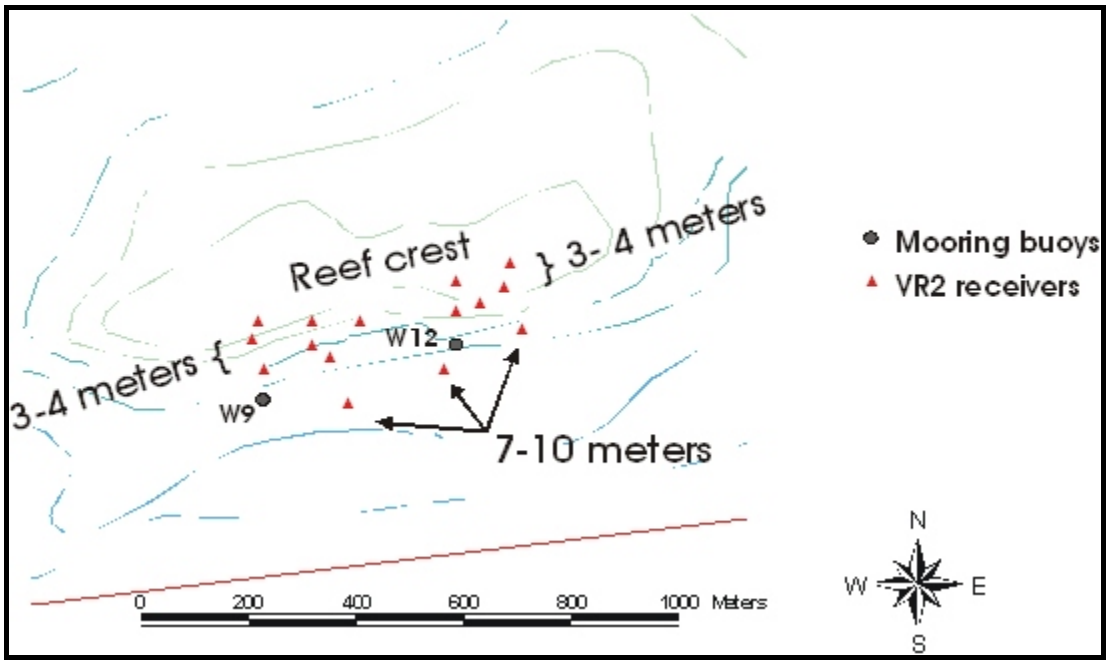

Figure 4. Wide view of the forereef receivers; second deployment; (June - August 2007).

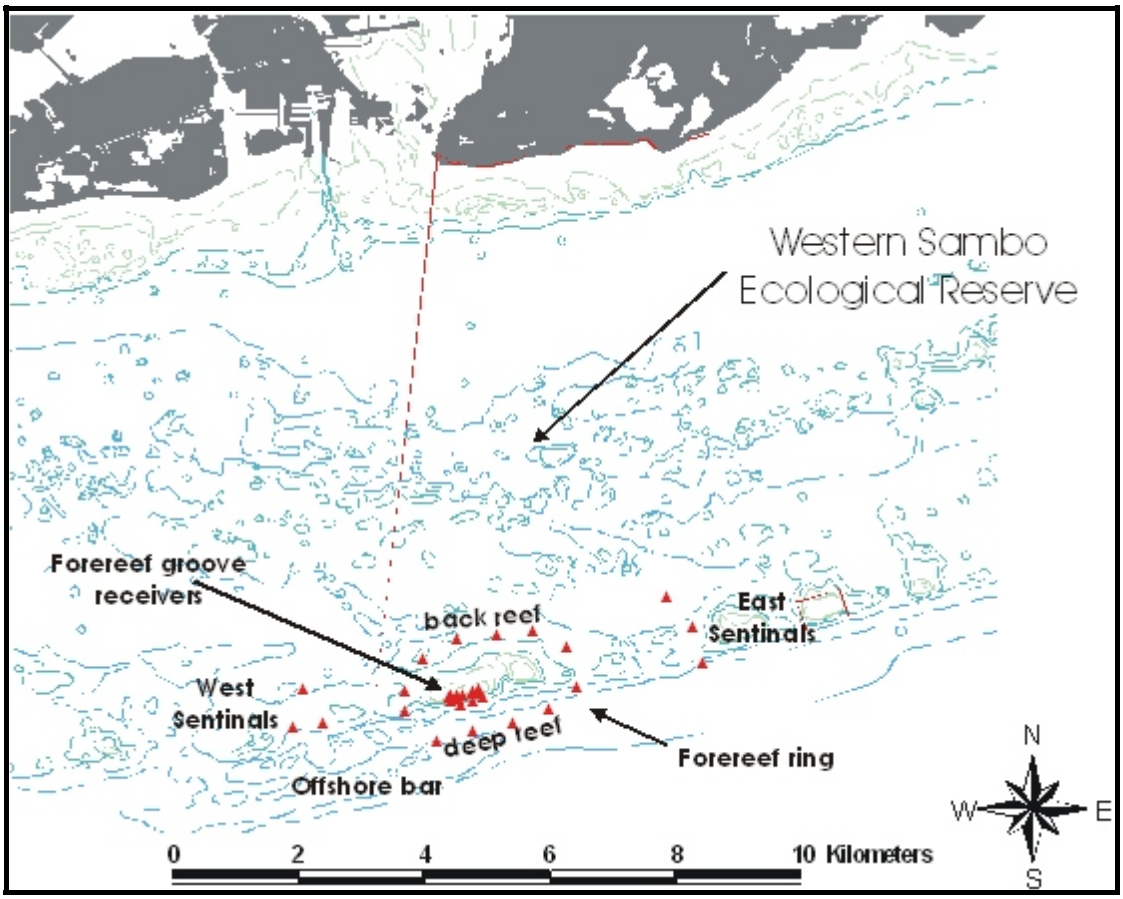

Figure 5. Study sites in Western Sambo Ecological Reserve (WSER) and Pelican Shoal (PLS). Habitat strata included forereef, backreef, and offshore patch reefs.

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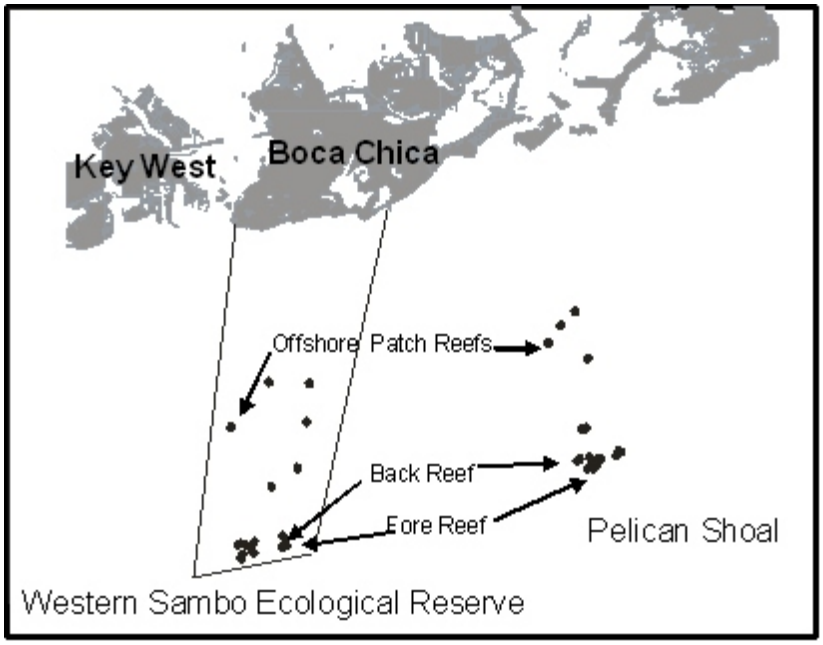

Figure 6. Size of legal-sized lobsters in Florida Keys National Marine Sanctuary, during the closed fishing season (July) 1997-2006. Reserves are shown in black; references are shown in gray.

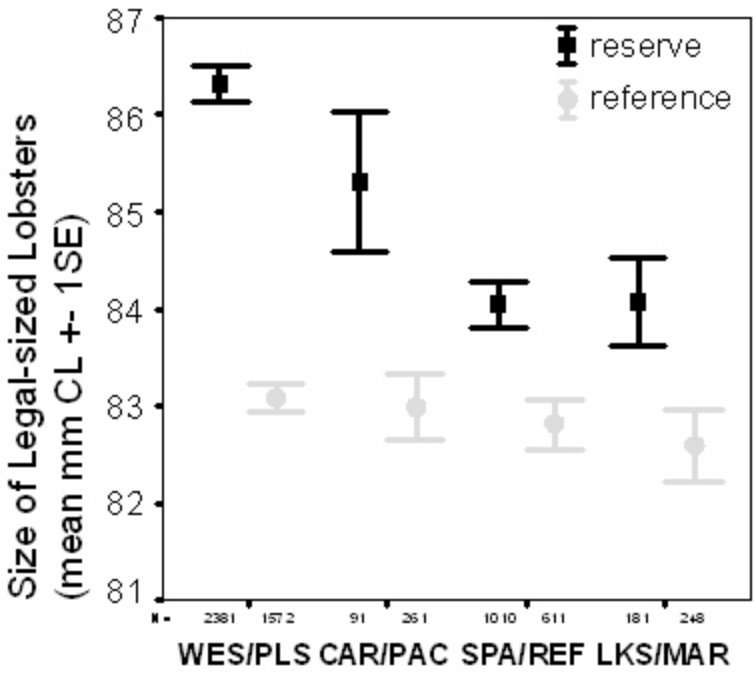

Figure 7. Size of legal-sized lobsters by year. a) 10 small SPAs; b) small long-term LKS reserve; c) medium-sized CAR SPA; d) large WSER reserve. Light bars = reserves; dark bars = references.

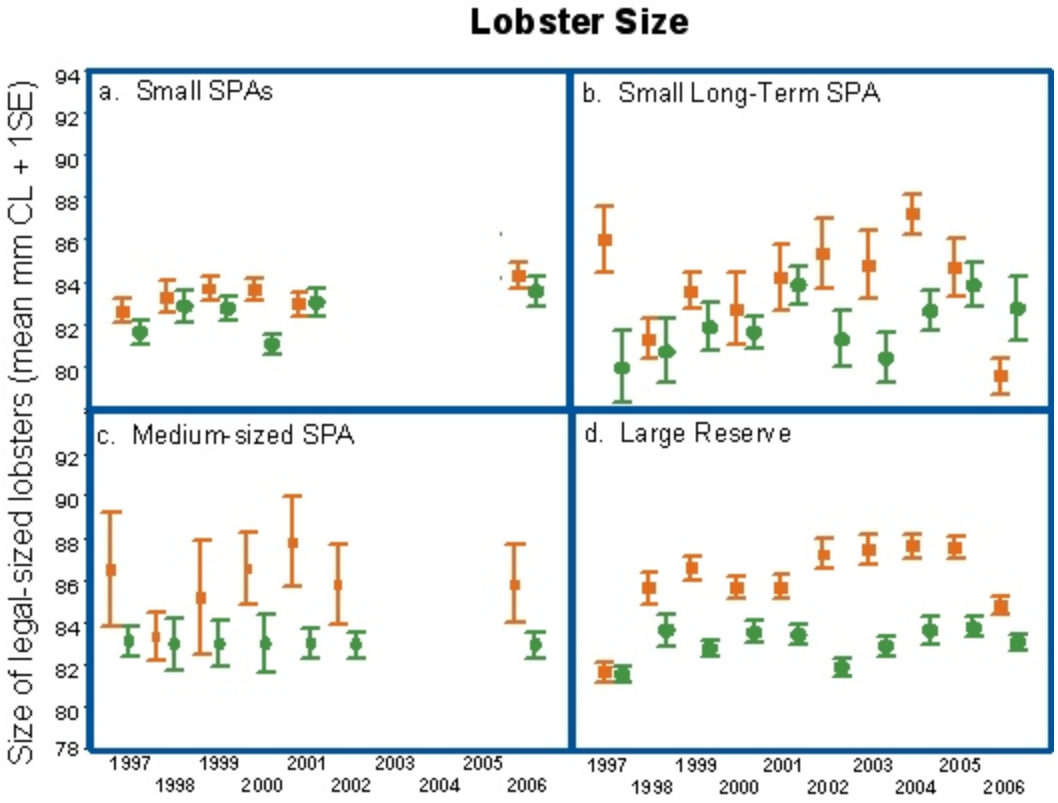

Figure 8. Size of legal-sized spiny lobsters collected in three reserves/references in Florida Keys National Marine Sanctuary, July 2007. WSER/PEL = Western Sambo Ecological Reserve/Pelican Shoal; ESB/MSB = Eastern Sambo/Middle Sambo; LKS/MAR = Looe Key SPA/Maryland Shoal.

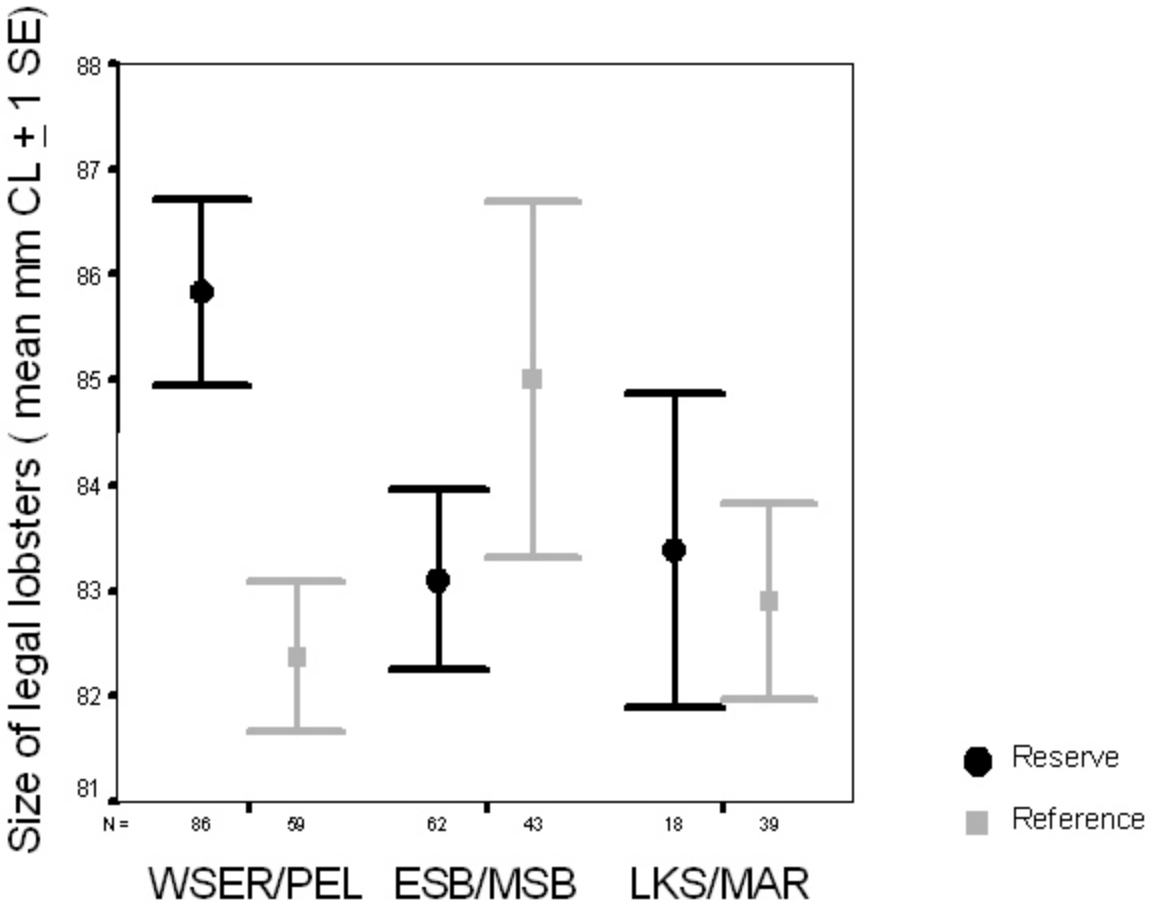

Figure 9. Abundance of legal-sized lobsters by year. a) 10 small SPAs; b) small long-term LKS SPA; c) medium-sized CAR SPA; d) large WSER reserve. Light bars = reserves; dark bars = references.

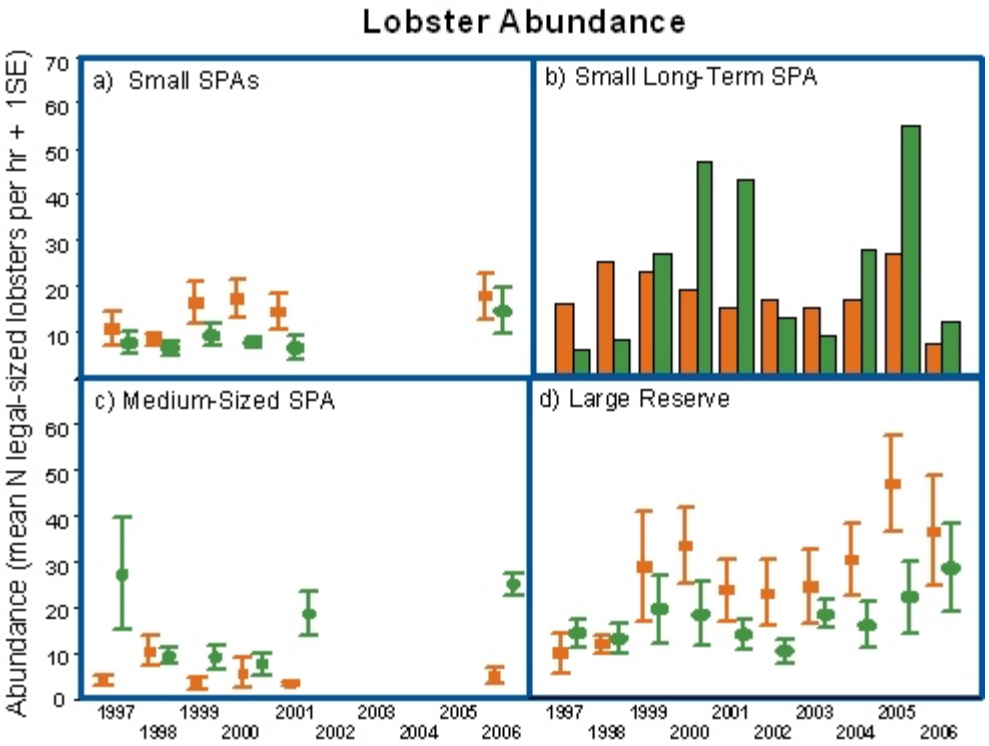

Figure 10. Area-based abundance estimates for legal-sized spiny lobsters in three reserves/references in Florida Keys National Marine Sanctuary, July 2007. WSER/PEL = Western Sambo Ecological Reserve/Pelican Shoal; ESB/MSB = Eastern Sambo/Middle Sambo; LKS/MAR = Looe Key SPA/Maryland Shoal.

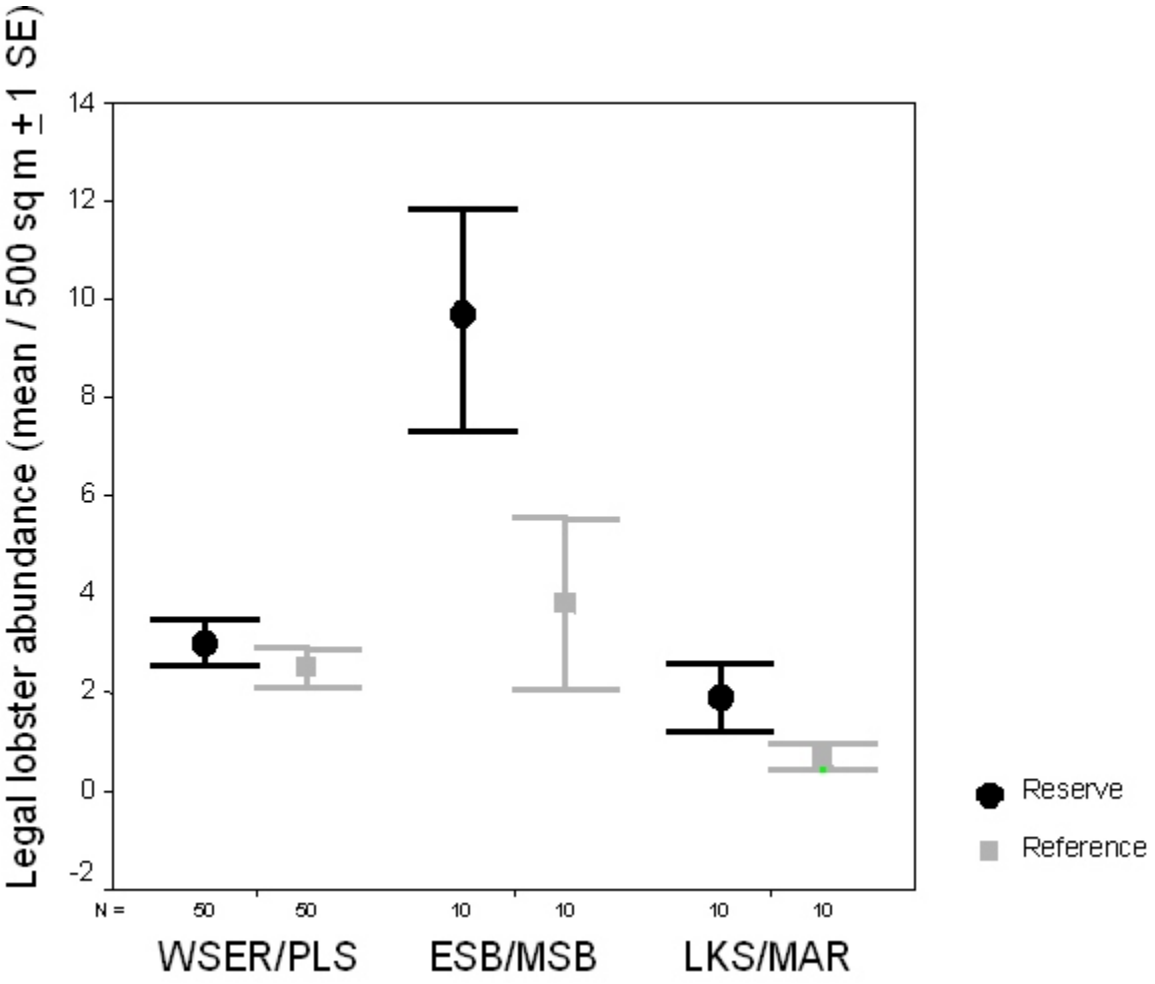

Figure 11. A typical movement pattern summary for a Hawk Channel reproductively active female during the summer spawning season. This female was 71 mm CL in size, with orange eggs and eroded spermatophore. She made a 6-7 day trip past the forereef late June and returned to Hawk Channel. Then in late July she left the Hawk Channel area again. Although forereef receivers did not detect this trip (only one receiver caught the first trip), the timing of the disappearance from Hawk Channel and length of disappearance is perfectly consistent with all the other spawning trips.

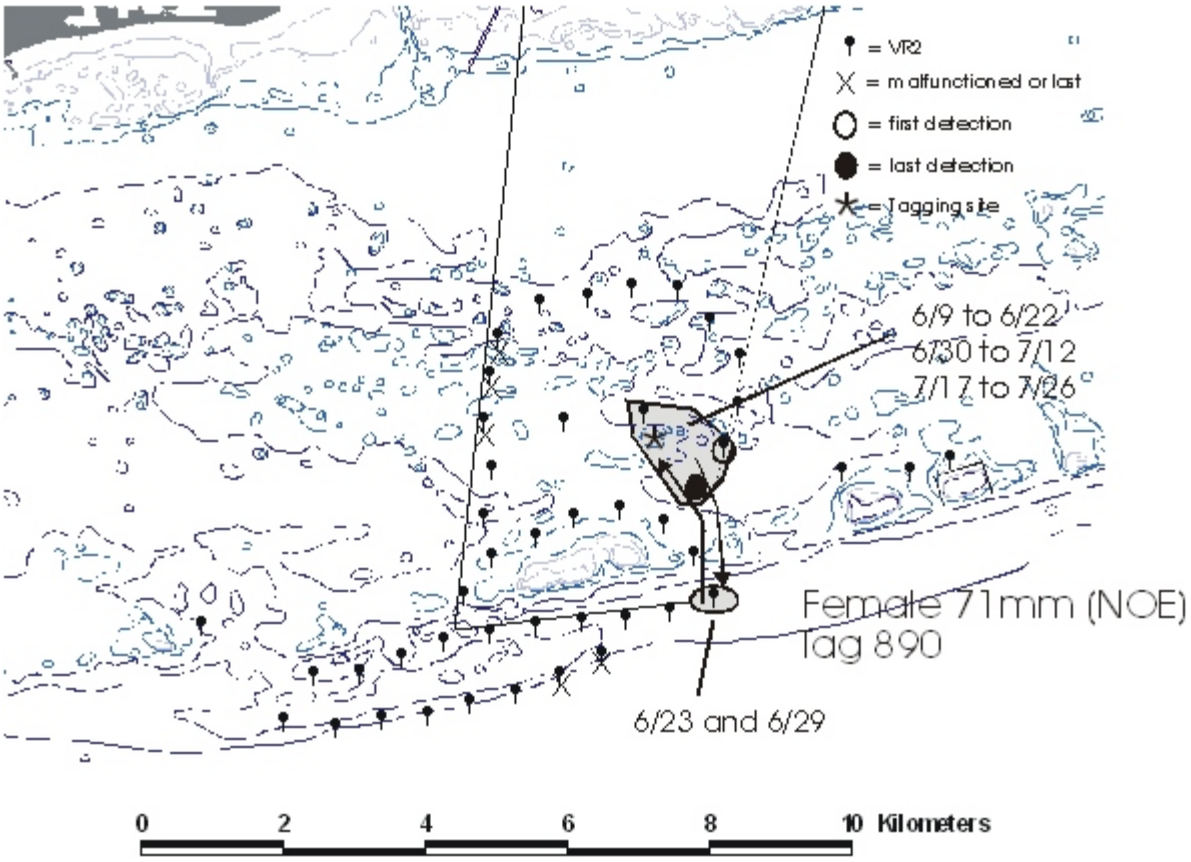

Figure 12. One of the tagged offshore bar females traveled through the entire deployment of sonic receivers from south to north. This migration took place presumably after all spawning had been completed This was a 75 mm CL female with orange eggs and eroded spermatophore at the time of tagging (6/9/06). The migration into Hawk Channel took place in the first week of August and covered more than 6 km.

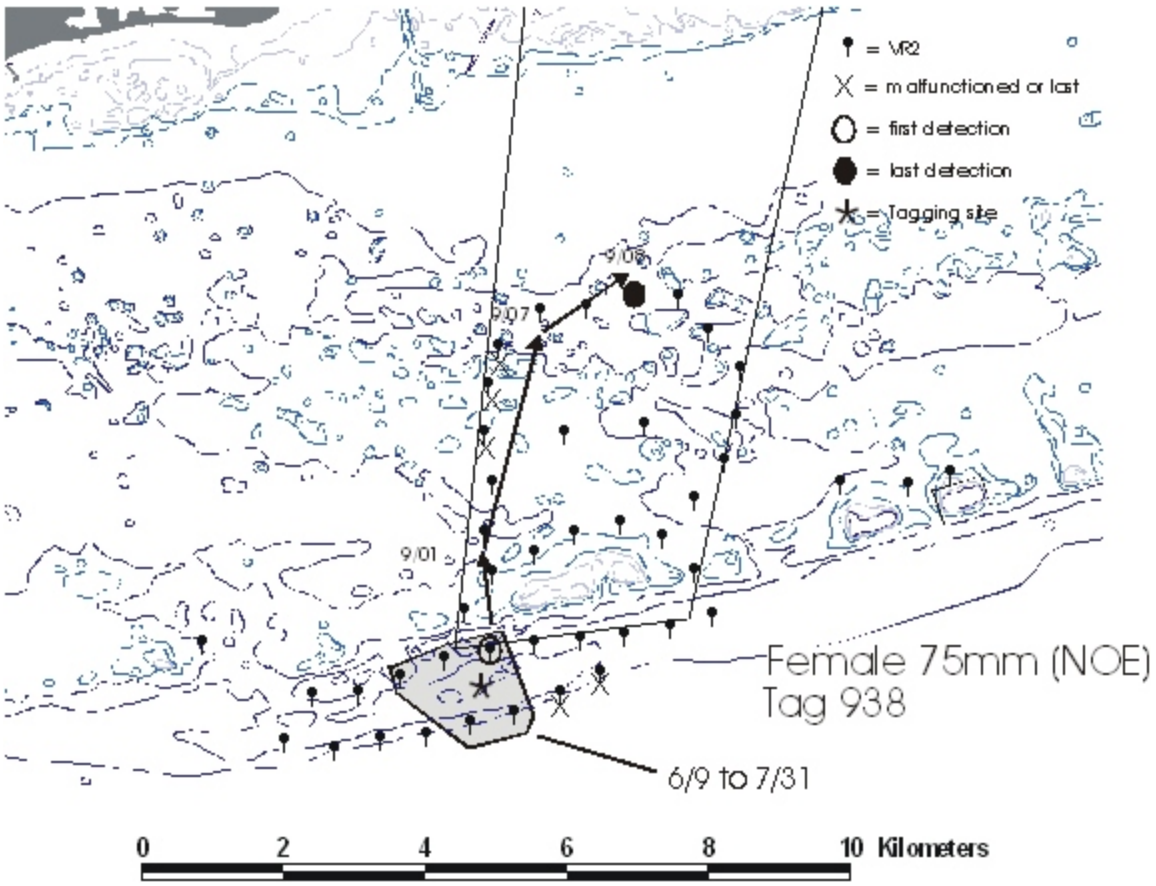

Figure 13. The estimated latitude of a female lobster (100 mm CL with brown eggs when tagged) by date and time. This female made three detected deep reef trips presumably to release eggs. Close inspection of the latitude by time reveals that when not releasing eggs, she often made trips to the back reef beginning just after dark and concluding around 3am.

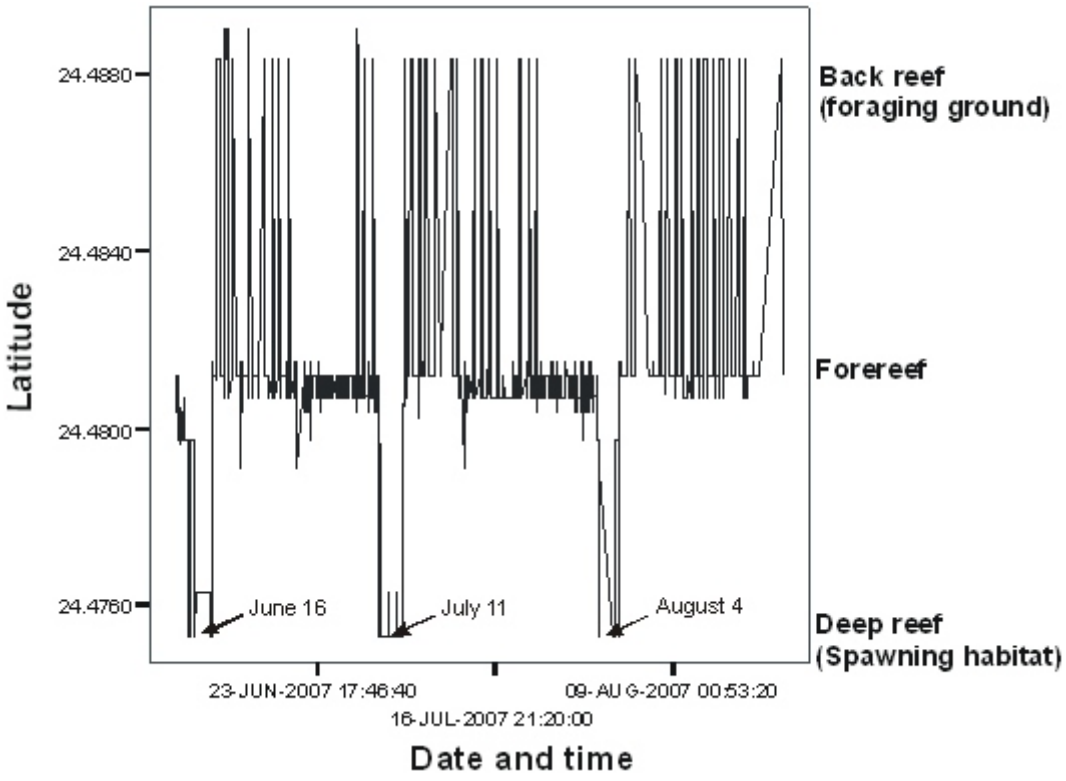

Figure 14. Mean total length (+/- 1 sd) of snapper and groupers tagged between June 2006 – June 2007 with the number (n) of fish per species.

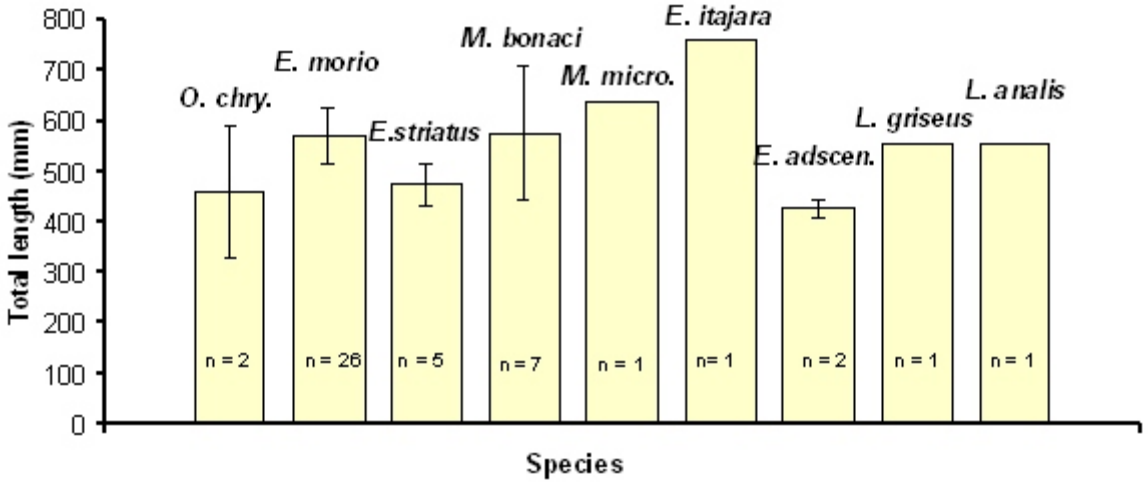

Figure 15. Mean latitude position per hour for tag 868 *E. striatus* (480 mm TL) tagged in the fore reef zone indicating movement across the WSER boundary into open fishing zone.

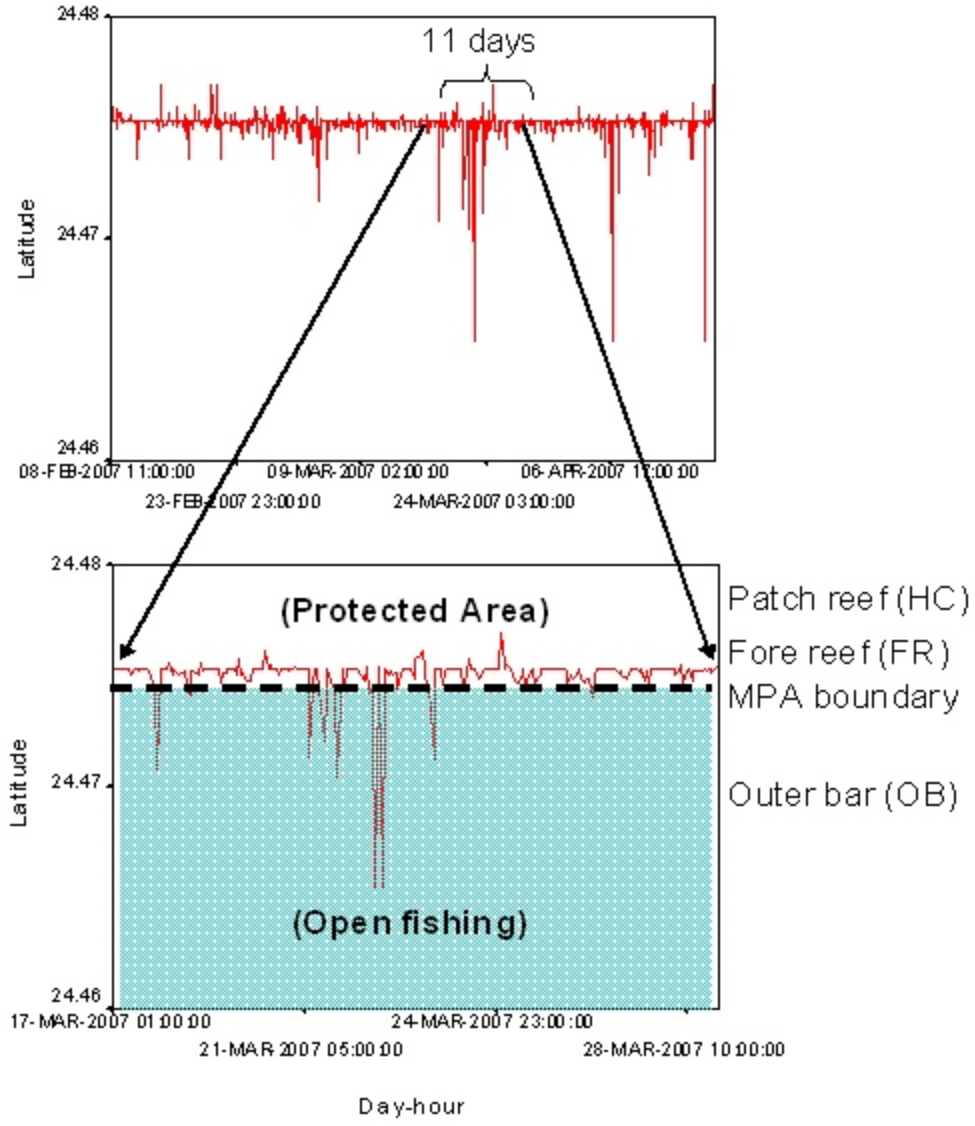

Figure 16. Estimated location of tag 1319 *M. bonaci* (760 mm TL) between October 2006 – February 2007 with frequency of detection by VR2 receivers in fore reef and offshore bar areas.