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Fine-scale Movements and Home Ranges of Red Snapper *Lutjanus campechanus* Around Artificial Reefs in the Northern Gulf of Mexico

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ABSTRACT

Few studies have examined fine-scale movement patterns of continental shelf marine fishes. For example, little is known about the fine-scale movement patterns of red snapper *Lutjanus campechanus*, an important marine species, around artificial reefs in the northern Gulf of Mexico. Such information could provide insight on habitat use and help answer persistent questions concerning the ecological function of these structures for red snapper. Thus, the present study examined fine-scale (~1 m accuracy) movements of red snapper (N = 17) with the VR2W Positioning System (VPS, Vemco Ltd, Nova Scotia). This system enabled the continuous monitoring of tagged fish over extended durations (68–500 d) on various temporal scales (daily and monthly). Red snapper showed a consistent close association with artificial reefs throughout the study (mean ± SD distance = 24.5 ± 28.5 m). Home ranges (95% kernel density estimates, KDE) were significantly larger during daytime than nighttime periods. Monthly home ranges and core areas (50% KDE) were significantly larger in summer and fall than in winter and spring, and were significantly larger in fall than in summer. Changes in water temperature were positively correlated with monthly area use (home range and core area size) suggesting colder temperatures reduced red snapper movement. Additionally, area use was positively correlated with fish size (508–719 mm total length). Red snapper showed a high degree of site fidelity to the studied artificial reefs on multiple temporal scales, and these habitats provided a "home base" from which fish expanded area use to the immediately surrounding unstructured habitat.

INTRODUCTION

Red snapper *Lutjanus campechanus*, a commercially and recreationally valuable species in the Gulf of Mexico, is closely associated with natural and artificial reefs (Szedlmayer 1997; Szedlmayer and Schroepfer 2005; Schroepfer and Szedlmayer 2006; Topping and Szedlmayer 2011a), and is often the most abundant species present on those structures (Lingo and Szedlmayer 2006; Gallaway et al. 2009; Dance et al. 2011). However, it is unclear if artificial reefs attract red snapper from surrounding areas and increase fishing mortality and stock depletion (Grossman et al. 1997; Cowan et al. 2011) or if they improve red snapper production and enhance fishery resources (Szedlmayer 2007; Gallaway et al. 2009; Shipp and Bortone 2009). Artificial reefs may increase fish biomass production by increasing food availability, feeding efficiency, and shelter from predation or fishes may be attracted to artificial reefs due to behavioral preferences (Bohnsack 1989). A better understanding of habitat use is required to clarify the ecological function of artificial reefs for red snapper.

Diet analyses have differed in the identification of red snapper foraging habitats. Ouzts and Szedlmayer (2003) reported diets with reef- and sand-associated prey, while other studies observed red snapper diets dominated by pelagic and sand-associated prey (McCawley et al. 2006; Wells et al. 2008). Also, diel shifts in foraging habitats were observed, wherein red snapper fed opportunistically on reef or pelagic organisms throughout the day before moving off reefs at night to exploit nocturnal benthic organisms (Ouzts and Szedlmayer 2003; McCawley et al. 2006). Seasonal diet shifts have also been reported, but identification of foraging habitats based on prey items was inconsistent between studies (Bradley and Bryan 1974; McCawley et al. 2003). Thus, these diet studies do not offer a clear understanding of the value of artificial reefs or surrounding open habitat as red snapper foraging habitats. Analysis of red snapper fine-scale movement patterns would provide indirect evidence of foraging habitats as diel and seasonal movement patterns may be closely associated with foraging activity (Snedden et al. 1999; Haertel and Eckmann 2002; Bellquist et al. 2008; Andrews et al. 2009).

In addition to improving understanding of the value of artificial reefs, analyses of fine-scale movements may also provide insight into the use of open habitats surrounding the reefs. For example, predation by red snapper and other reef fishes can alter the distribution and abundance of open habitat prey (Kurz 1995; Bortone et al. 1998). Also, as the distance between artificial reefs decreases, foraging areas of nearby reefs overlap, access to prey is reduced, and reef fish biomass may decline (Lindberg et al. 1990; Jordan et al. 2005; Strelcheck et al. 2005). An evaluation of fine-scale movements will contribute to defining the size of open habitat forage areas, and direct the placement of future artificial reefs as to optimize their use and increase reef fish biomass (Bortone et al. 1998; Strelcheck et al. 2005).

Fine-scale movement patterns of red snapper have been investigated in the northern Gulf of Mexico (Szedlmayer and Schroepfer 2005; McDonough 2009; Topping and Szedlmayer 2011); however, these studies were limited to short temporal scales (hours-weeks). Szedlmayer and Schroepfer (2005) manually tracked red snapper (N = 4) overnight (9 or 16 hr periods) using surface-operated detection equipment. All fish remained near the reef throughout the tracking period and were closer to the reef at dusk than during the night and dawn. Topping and Szedlmayer (2011) manually tracked red snapper (N = 12) from the surface for longer tracking periods (24 hr) and showed that red snapper stayed near the reef and were generally closer to the reef during the day than at night. McDonough (2009) monitored fine-scale movement patterns of red snapper around oil platforms for two 2-week periods with a real-time radio-linked acoustic positioning system (VRAP, Vemco Ltd, Nova Scotia). Fish showed diel periodicity related to distance from the platforms, but patterns were variable throughout the study. Many questions remain regarding diel movement patterns and habitat use of red snapper due to low sample sizes of tracked fish and short tracking durations. No previous studies monitored seasonal patterns of fine-scale movements by red snapper.

Recent advances in acoustic telemetry technology have greatly enhanced fine-scale tracking capabilities. The Vemco VR2W Positioning System (VPS) allows fine-scale (m), continuous, long-term, simultaneous tracking of multiple fish with greater accuracy than active manual tracking (Espinoza et al. 2011a). In the present study, the VPS was evaluated for use in the Gulf of Mexico, and was used to define red snapper home ranges, potential foraging distances, and diel and seasonal variations in movement patterns around artificial reefs. These data were then used to help clarify the ecological function and importance of artificial reefs for red snapper.

METHODS

Study site.—Red snapper were tagged and tracked in the Hugh Swingle General Permit Area in the northern Gulf of Mexico. Study sites were centered on steel cage artificial reefs (4.4 x 1.3 x 1.2 m; *N* = 3) labeled R1, R2, and R3. Reefs R1 and R2 were located 30 km south of Dauphin Island, Alabama at depths of 30 m, and R3 was 25 km south of Dauphin Island at a depth of 20 m (Figure 1). The reefs were deployed at unpublished locations and thus fishing mortality was limited.

Fish Tagging.—Adult red snapper (> 400 mm total length) were captured by hook and line, weighed, measured, and anesthetized onboard the research vessel in a 70 L container of seawater and MS-222 (150 mg tricaine methanesulfonate/L seawater for 2.5 min). Fish tagging procedures followed Topping and Szedlmayer (2011a). A uniquely coded acoustic transmitter (Vemco V16-6x-R64k; 69 kHz; transmission delay: 20–69 sec) was implanted within the peritoneal cavity through a vertical incision (20 mm) above the ventral midline, and the incision was closed with absorbable, sterile, surgical sutures (Ethicon 2-0 plain gut). For visual identification, all fish were also marked with individually numbered internal anchor tags (Floy®). Fish tagged between July 2010 and July 2011 were held at the surface or in a 185 L container of seawater after surgery for recovery prior to release. When fin and gill movements resumed, an inverted barbless hook was inserted through the lower jaw, and fish were returned to the reef on a weighted line and released at the bottom. Fish tagged in August 2011 were returned to depth in cylindrical cages (plastic-coated wire; one fish per cage; 40.6 cm height, 61 cm diameter). After ~2 hours, SCUBA divers opened cage doors on the bottom and released fish close (2–3 m) to the reef.

Fine-scale tracking.—Fine-scale movements of tagged red snapper were monitored from July 2010 to November 2011 using the Vemco VR2W Positioning System (VPS). Each study site included an array of omni-directional acoustic receivers ($N = 5$; Vemco VR2W) moored ~4.5 m above the seafloor on lines anchored to the bottom. Receiver positions were chosen to maximize detection ranges and assure continuous, simultaneous detection of each tagged fish by at least three receivers. Preliminary detection range tests of receivers showed 100% detection of transmitters at 400 m. Thus, a receiver was positioned adjacent to the artificial reef (20 m north) at each site, and four additional receivers were placed 300 m north, south, east, and west of center to maximize overlap of detection ranges (Figure 2). At each site, temperature loggers ($N = 2$; Onset HOBO® U22 Water Temp Pro v2) were attached to the center mooring line near the receiver and at the seafloor to monitor water temperature at 1 hr intervals.

Synchronization transmitters (sync tags; Vemco V16-6x; 69 kHz; transmission delay: 540–720 sec) were attached to the mooring lines 1 m above all receivers to synchronize the receiver clocks. Time synchronization was critical for accurate positioning with the VPS as transmitter positions were calculated with a 3-receiver time-difference-of arrival positioning algorithm (Espinoza et al. 2011a). A stationary control transmitter was moored within the R1 receiver array and its position was recorded using sonar and a Global Positioning System (GPS, latitude and longitude) onboard the research vessel. The accuracy of the VPS was evaluated by comparing VPS-calculated positions with the stationary control transmitter position. Fish detection data were downloaded from the receivers periodically (1–2 months), post-processed using Vemco VPS Software (Vemco Ltd, Nova Scotia), and reported as fish positions over time.

Data Analysis.—Area use was calculated in R using two-dimensional kernel density estimation (Venables and Ripley 2002). Kernel density estimates (KDE) describe a probabilistic area within which an animal may be located (Worton 1989; Seaman and Powell 1996). Red snapper home ranges were defined by 95% KDE (< 5% excursions) and core areas were defined by 50% KDE. The effect of reef site on area use (i.e., 95% and 50% KDE) was analyzed with a two-way mixed model repeated measure analysis of variance (rmANOVA) with fish as a random factor and month as a repeated measure. The effect of month on area use was tested using a one-way mixed model rmANOVA with fish as a random factor and month as a repeated measure. The effect of diel period (day and night), on area use was analyzed using a two-way mixed model rmANOVA with fish as a random factor and month as a repeated measure. When significant differences were detected Tukey-Kramer multiple comparison tests were used to show specific differences in area use over time. The effect of water temperature on area use by red snapper was analyzed by linear regression and diel area use patterns periods were compared to water temperature with a two-way rmANOVA with month as a repeated measure. Linear regression was used to compare fish length and monthly area use from September–November 2011, the time period when the majority of tagged fish were present on the reefs. Distances between the artificial reef and red snapper positions (latitude, longitude) were calculated with the haversine formula (Sinnott 1984):

$$a = \sin^2(\Delta\text{latitude}/2) + \cos(\text{latitude}_1) \bullet \cos(\text{latatitude}_2) \bullet \sin^2(\Delta\text{longitude}/2)$$

$$c = 2\arctan2(\sqrt{a}, \sqrt{(1-a)})$$

$$d = Rc,$$

where R is the earth's radius (mean radius = 6,371 km). The haversine formula was also used to calculate distances between the known and VPS-calculated positions of the stationary control transmitter. Fish distance from the reef was compared to area use with linear regression.

RESULTS

Tagging Efforts and Outcome

Adult red snapper (N = 46) were tagged with acoustic transmitters and released on steel-cage artificial reefs (N = 3) in the northern Gulf of Mexico. All red snapper were grouped into three categories based on the status of the tagged fish after 2 d at liberty: tracked, lost, or stationary (Table 1). Tracked fish (N = 17) were monitored with the VPS for 68–500 d between July 2010 and November 2011. Lost fish (N = 16) left the receiver array, and most (N = 14) were not detected again after this initial loss. However, two of the lost fish were detected intermittently ~80 m south of the R1 receiver array. Fish status (i.e., active or stationary) and movements of these two fish could not be analyzed due to low accuracy of VPS-calculated positions outside the receiver array. Stationary transmitters (N = 13) were defined as red snapper mortalities and showed zero movement immediately after the fish's release (N = 9) or within 90 min (N = 3) or 2 d (N = 1) of release. Divers recovered most stationary transmitters (N = 10) from the seafloor using VPS-calculated positions (latitude, longitude), while the others (N = 3) could not be recovered due to low visibility conditions, or inability of divers to locate transmitters within the reef structure.

Fine-scale Movements

A stationary control transmitter was used to examine the accuracy of VPS-calculated positions. The mean ± SD distance between the known position and VPS-calculated positions (N = 42,652) of the control transmitter was 0.98 ± 0.66 m. Fish distance from the reef was positively correlated with area use (home range: P<0.0001, r^2=0.51; core area: P<0.0001, r^2=0.48), suggesting tracked fish were farther from the reef when larger area use (KDE) was observed. Area was used to describe red snapper habitat relative to artificial reefs, rather than distance, because KDE are robust to autocorrelation and are not sensitive to outlying positions (Worton 1989; Seaman and Powell 1996). Reef site did not significantly affect monthly area use (home range: P=0.84; core area: P=0.61), thus tagged fish from all sites were pooled for all further analyses.

Home ranges were significantly larger July–August 2011 than December 2010 – April 2011 and significantly larger September–November 2011 than November 2010 – July 2011 (P < 0.05). Similarly, core areas were significantly larger September–November 2011 than November 2010 – June 2011 and August 2011. Core areas were also significantly larger July–August 2011 than April 2011 and significantly larger July 2011 than December 2010 – February 2011 (P < 0.05). Additionally, home ranges and core areas were significantly larger in September 2011 and November 2011 than in July 2010 (P < 0.05; Figure 3). Red snapper area use was positively correlated with mean daily water temperature at R1 (home range: P < 0.0001,

r^2 = 0.16; core area: P < 0.0001, r^2 = 0.14; Figure 4), R2 (home range: P < 0.001, r^2 = 0.09; core area: P < 0.0001, r^2 = 0.17), and R3 (home range: P < 0.0001, r^2 = 0.07; core area: P < 0.005, r^2 = 0.03).

Diel patterns in red snapper area use were analyzed with the effect of month removed. Home ranges were significantly larger during the day than the night (P < 0.01; Figure 5), but no significant differences in core area size were detected between day and night periods (P = 0.42). Water temperatures were not significantly different between day and night periods (P = 0.65). Fish size (508–719 mm total length) was positively correlated with area use (home range: P < 0.0001, r^2=0.66; core area P < 0.0001, r^2=0.33; Figure 6).

DISCUSSION

VPS Accuracy

VPS estimates of the stationary control transmitter position showed up to sub-meter accuracy. This high degree of accuracy was further verified by our ability to recover stationary transmitters (N = 10) on the seafloor from apparent red snapper mortalities by diving on VPS-calculated positions. The accuracy of the VPS was first validated in a southern California estuary (< 4 m depth), where the mean ± SD distance between known positions and VPS estimates of stationary transmitters was 2.13 ± 1.31 m (Espinoza et al. 2011a). The VPS was then applied to gray smooth-hound sharks *Mustelus californicus* (N = 22; 5–145 d) in the estuary and successfully identified fine-scale patterns in habitat use, including diel movement patterns (Espinoza et al. 2011). The present study showed the VPS is also highly applicable for monitoring fine-scale movements of fishes in open waters in the Gulf of Mexico, and the frequency and accuracy of red snapper positions achieved with the VPS exceeded that of manual tracking (Topping and Szedlmayer 2011).

Residence and Site Fidelity

Past studies of red snapper movement patterns, site fidelity, and residence around artificial reefs in the Gulf of Mexico reported varying results. Several mark-recapture studies suggested red snapper showed little site fidelity to artificial reefs (Watterson et al. 1998; Patterson et al. 2001; Patterson and Cowan 2003) and moved extensively (mean distance 29.6 km; Patterson et al. 2001). Strelcheck et al. (2007) used similar methods, but reported less movement from release sites (mean distance 2.1 km) than other mark-recapture studies. Ultrasonic telemetry studies of red snapper around the same oil-gas platforms off Louisiana concluded red snapper had high short-term site fidelity and low long-term site fidelity (Peabody 2004), or low short-term site fidelity (McDonough 2009). In contrast, high site fidelity and long-term residence was reported in ultrasonic telemetry studies of red snapper around smaller artificial reefs, with median residence times of 373 d and 542 d (Szedlmayer and Schroepfer 2005; Schroepfer and Szedlmayer 2006; Topping and Szedlmayer 2011a). The present study supports the contention of high site fidelity and close association of red snapper with artificial reefs, based on new methods of fine-scale tracking with the VPS. Red snapper showed high site fidelity and long-term residency on artificial reefs, after excluding early emigrations and mortalities that were likely a tagging artifact. After 2 d (recovery period) most tagged fish (94%) were present up to the last day of tracking, while one fish emigrated from the receiver array after 68 d of continuous residency.

Seasonal Movements

This study was the first to continuously monitor fine-scale movement patterns of red snapper for extended durations (68–500 d). Red snapper remained relatively close to artificial reefs throughout the study (mean ± SD distance = 24.5 ± 28.5 m) and showed seasonal changes in habitat use. Movement patterns were significantly correlated with water temperature such that home ranges and core areas were larger during spring and summer months than fall and winter months. Patterns of smaller area use during colder months may reflect changes in red snapper metabolism as metabolic rate is positively related to temperature (Gillooley et al. 2001) and food intake decreases at lower water temperatures (Hidalgo et al. 1987). Seasonal changes in movement and home range size have not been reported previously for red snapper, as long-term telemetry studies with this species were not capable of detecting such fine-scale changes in proximity to a reef (Szedlmayer 1997; Szedlmayer and Schroepfer 2005; Topping and Szedlmayer 2011a).

Seasonal changes in area use may also result from seasonal prey availability. Red snapper stomach contents contained the greatest variety of prey during summer, and the least during winter (Bradley and Bryan 1975). Consistent with this pattern, species diversity on artificial reefs in the northern Gulf of Mexico was highest during the summer, and was affected by fluctuations in the epifaunal community and forage base (Dance et al. 2011). Additional studies of seasonal diets are needed to clarify red snapper foraging behavior during months of reduced movement.

Diel Movements

In the present study, red snapper home ranges were significantly larger during the day than the night, while previous manual tracking indicated patterns of larger area use at night compared to day periods (Szedlmayer and Schroepfer 2005; Topping and Szedlmayer 2011).

Though all studies had low sample sizes of tracked fish, the present study examined fine-scale movement patterns over longer time periods (9–24 hr compared to 68–500 d) with greater accuracy (~1 m) and frequency of locations than these previous studies. Even so, differences in study design may have resulted in differing movement patterns among these studies. For example, compared to the present study, previous manual tracking of red snapper was over larger reefs (army tank and concrete pyramid) and only during summer periods (Szedlmayer and Schroepfer 2005; Topping and Szedlmayer 2011). Further, research vessel noise and movement may have altered fish behavior during manual tracking (Slabbekoom et al. 2010).

Diel changes in home range observed in this study may indicate changes in foraging habitats as diel movement patterns of predatory fishes are often closely related to foraging activity (Snedden et al. 1999; Haertel and Eckmann 2002; Bellquist et al. 2008, Andrews et al. 2009). Studies of red snapper feeding periodicity suggested red snapper fed opportunistically on pelagic and reef-associated organisms during the day, and moved over open sand at night to consume nocturnal benthic organisms (Ouzts and Szedlmayer 2003; McCawley et al. 2006). These foraging behaviors were the opposite of habitat use patterns observed in this study, where home range expanded during the day to include larger areas of open habitat. Diel movement patterns of marine fishes are also commonly associated with shifts between foraging and refuge habitats (Emery 1978). The smaller nocturnal home ranges observed in this study suggest artificial reefs may be used for refuge under low light conditions.

Emigration and Mortality

Initial rates of emigration (35% within 2 d) observed in this study were higher than previously reported by other red snapper telemetry studies (16% within 3 d, Szedlmayer and Schroepfer 2005; 17% within 6 d, Topping and Szedlmayer 2011a). Early emigrations in these previous studies reportedly occurred during an initial recovery period and were attributed to abnormal behavior caused by tagging stress (Szedlmayer and Schroepfer 2005; Topping and Szedlmayer 2011a). While a portion of early emigrations in the current study may have been a tagging artifact, exceptionally high early emigration rates suggest additional factors contributed to the observed behavior. For example, McDonough (2009) reported 30% of tagged red snapper left the receiver array or were not detected within 2 d of tagging, and suggested predation by a migratory predator may have contributed to the initial loss of tagged fish. Transmitters from lost fish in this study may have been consumed by predators that subsequently moved out of the receiver array. In addition, red snapper lost from the receiver arrays in this study may have moved to nearby artificial reefs outside the receiver detection ranges. Szedlmayer (1997) relocated the majority of red snapper that emigrated from the release site at other artificial reefs 88–760 m away. Seasonal and directed movements among artificial reefs have also been reported previously, where red snapper moved to different structures for extended periods and returned to the original release site (Topping and Szedlmayer 2011a). Future work is needed to improve understanding of movement patterns and habitat use of tagged red snapper after emigrating from a release site.

A large number (28%) of transmitters showed no movement within 2 d of releasing tagged red snapper onto artificial reefs. The short time between fish tagging and no movement suggests tag loss was unlikely and stationary transmitters were the result of fish mortality. Predation may have contributed to high rates of early mortality as sharks (spinner shark *Carcharhinus brevipinna*, Atlantic sharpnose shark *Rhizoprionodon terraenovae*, and other unidentified species) and bottlenose dolphins *Tursiops truncatus* were observed while fishing and diving at the study sites during tagging and tracking periods. Also, red snapper were captured by spinner sharks and bottlenose dolphins during sampling trips at nearby sites. Beginning immediately after release, one tagged fish showed large, erratic movements throughout the receiver array for 2 d before the transmitter became stationary. These movement patterns were inconsistent with those of other red snapper, indicating the transmitter may have been swallowed by a predator and excreted after 2 d.

All fish tagged in August 2011 (N = 12) were held in cages on the seafloor for ~2 hr prior to release in an effort to reduce emigration and mortality rates of tagged fish. In November 2011, all fish released in cages were alive and showed continuous residency on the reefs. One fish emigrated from the reef immediately after release, but returned to the same reef after 12 days and remained there until the end of the study. The lack of emigration and mortality observed for fish released in cages supports the hypothesis that high initial rates of emigration and mortality were a result of the tagging procedure and did not reflect natural red snapper behavior.

Conclusions

Overall, this study showed red snapper were closely associated with specific artificial reefs and relatively small surrounding areas on multiple temporal scales, and these structures were an important habitat for this species. This study was the first to report seasonal changes in fine-scale proximity to artificial reefs, where red snapper used smaller areas in colder months than warmer months, suggesting movements were affected by water temperature. Diel patterns in habitat use were the opposite of previous studies with smaller home ranges observed during the night than the day in the present study. The immediately surrounding open habitat around reefs was also used regularly, and may be an important forage area for red snapper. If forage areas from nearby reefs overlap, reef fish abundance, richness, and biomass, may be inhibited by a decline in open habitat prey availability (Lindberg et al. 1990; Bortone et al. 1998; Jordan et al. 2005). Therefore, fine-scale area use estimates from this study may be used in defining the size of potential forage areas, and in providing management efforts with information that could optimize artificial reef placement.

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Table 1: Summary of tagging effort and outcome of red snapper *Lutjanus campechanus* tagged with ultrasonic transmitters and released on three artificial reefs in the northern Gulf of Mexico. Tagged fish were tracked with the VPS, lost (left the receiver array within 2 d of release), or transmitters became stationary (fish mortality) within 2 d of release.

		Outcome		
Reef	Tagged	Tracked	Lost	Stationary
R1	25	6	10	9
R2	14	4	6	4
R3	7	7	0	0
Total	46	17	16	13

Table 2: Summary of acoustic telemetry data for red snapper *Lutjanus campechanus* tracked around artificial reefs in the northern Gulf of Mexico. P: fish was present at the tagging site on the last day of tracking, E: fish emigrated from the receiver array prior to the last day of tracking.

Tag ID	Site	TL (mm)	Wt (kg)	Tag date	No. days tracked	Cage	Status
3	R1	539	2.0	9-Jul-2010	500	N	P
14	R1	578	2.8	23-Nov-2010	363	N	P
16	R1	719	5.9	10-Dec-2010	346	N	P
19	R1	689	4.8	14-Apr-2011	68	N	E
25	R2	570	2.6	24-Jun-2011	150	N	P
34	R3	508	2.0	16-Aug-2011	98	Y	P
35	R3	622	3.5	16-Aug-2011	98	Y	P
36	R3	544	2.2	16-Aug-2011	98	Y	P
37	R3	571	2.6	16-Aug-2011	98	Y	P
38	R1	524	2.2	18-Aug-2011	95	Y	P
39	R1	565	2.5	18-Aug-2011	95	Y	P
40	R3	572	3.0	18-Aug-2011	96	Y	P
41	R3	524	2.4	18-Aug-2011	96	Y	P
42	R3	662	4.4	18-Aug-2011	96	Y	P
43	R2	532	2.4	23-Aug-2011	90	Y	P
44	R2	598	3.0	23-Aug-2011	90	Y	P
46	R2	515	3.0	23-Aug-2011	90	Y	P

Figure 1: Northern Gulf of Mexico and the Hugh Swingle General Permit Area; circles indicate study sites at reefs R1, R2, and R3. (Missing figure)

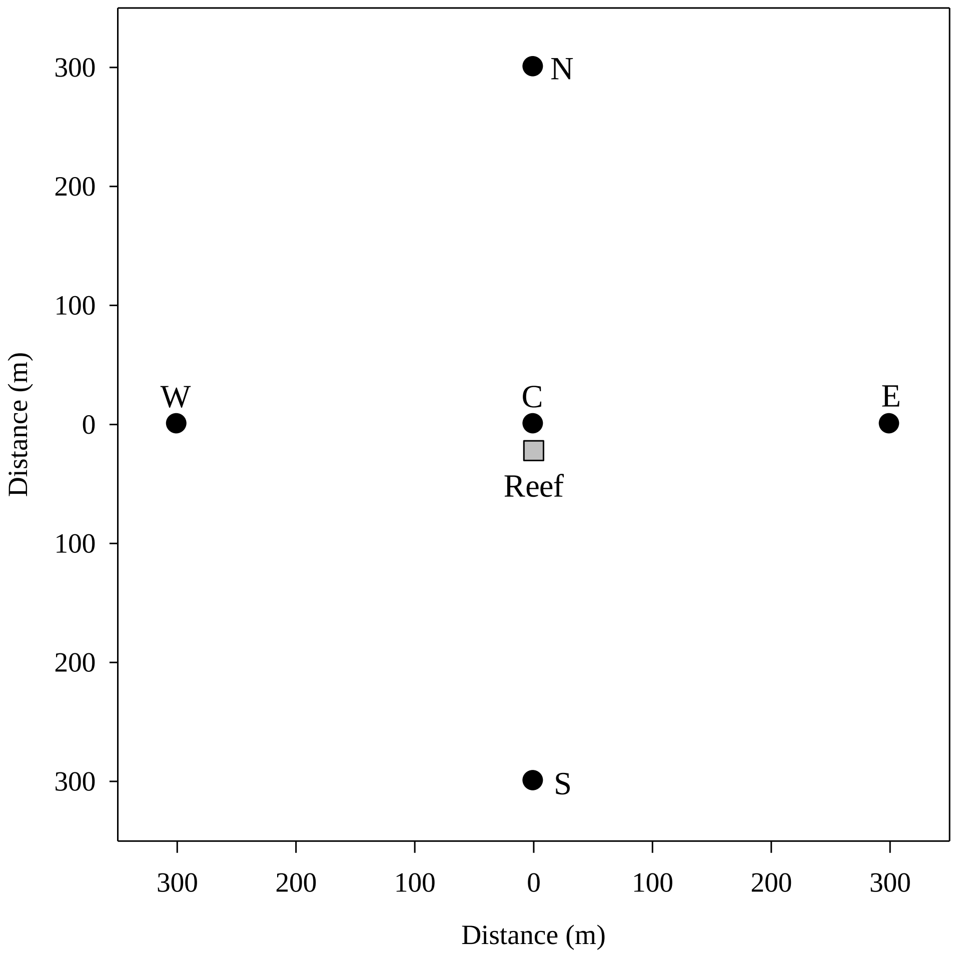

Figure 2: Receiver array used to examine fine-scale movements of red snapper *Lutjanus campechanus* around artificial reefs in the northern Gulf of Mexico. The same receiver array design was used at all sites. Circles: receivers and co-located synchronization transmitters; square: artificial reef.

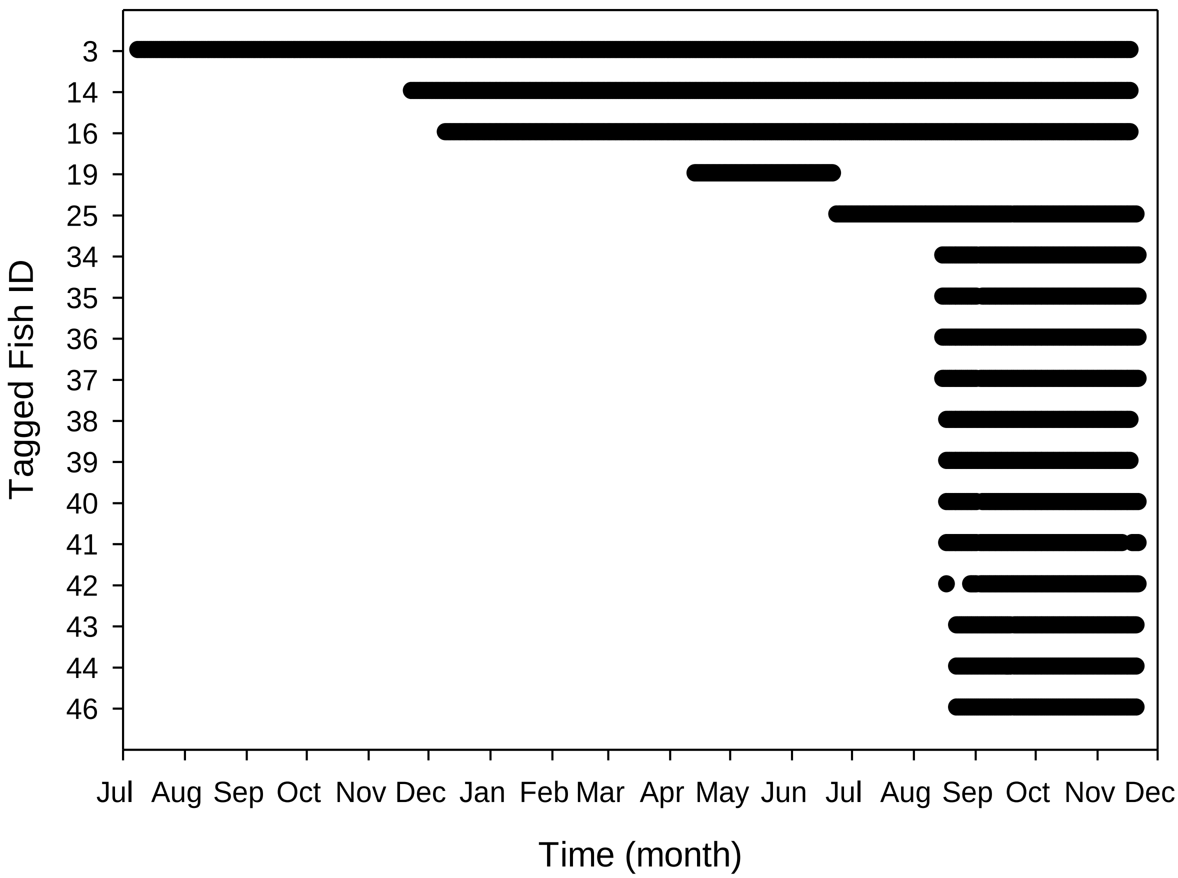

Figure 3: Daily presence of tagged red snapper *Lutjanus campechanus* released on three artificial reefs in the northern Gulf of Mexico.

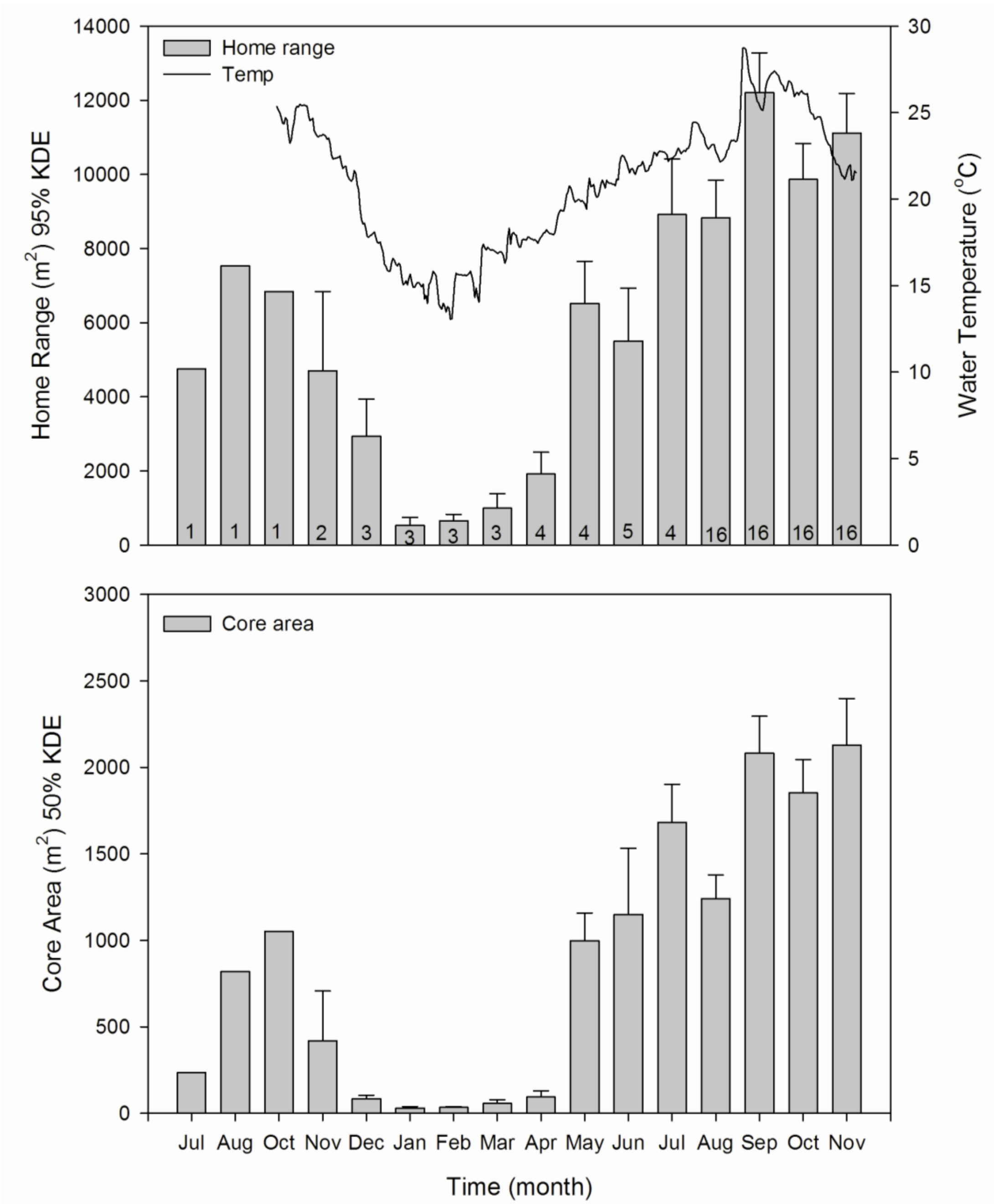

Figure 4: Mean monthly home ranges (95% KDE + SD) and core areas (50% KDE + SD) of red snapper *Lutjanus campechanus* around artificial reefs in the northern Gulf of Mexico. Numbers within bars indicate monthly sample sizes of tracked fish and the black line indicates mean daily water temperature at a depth of 26 m.

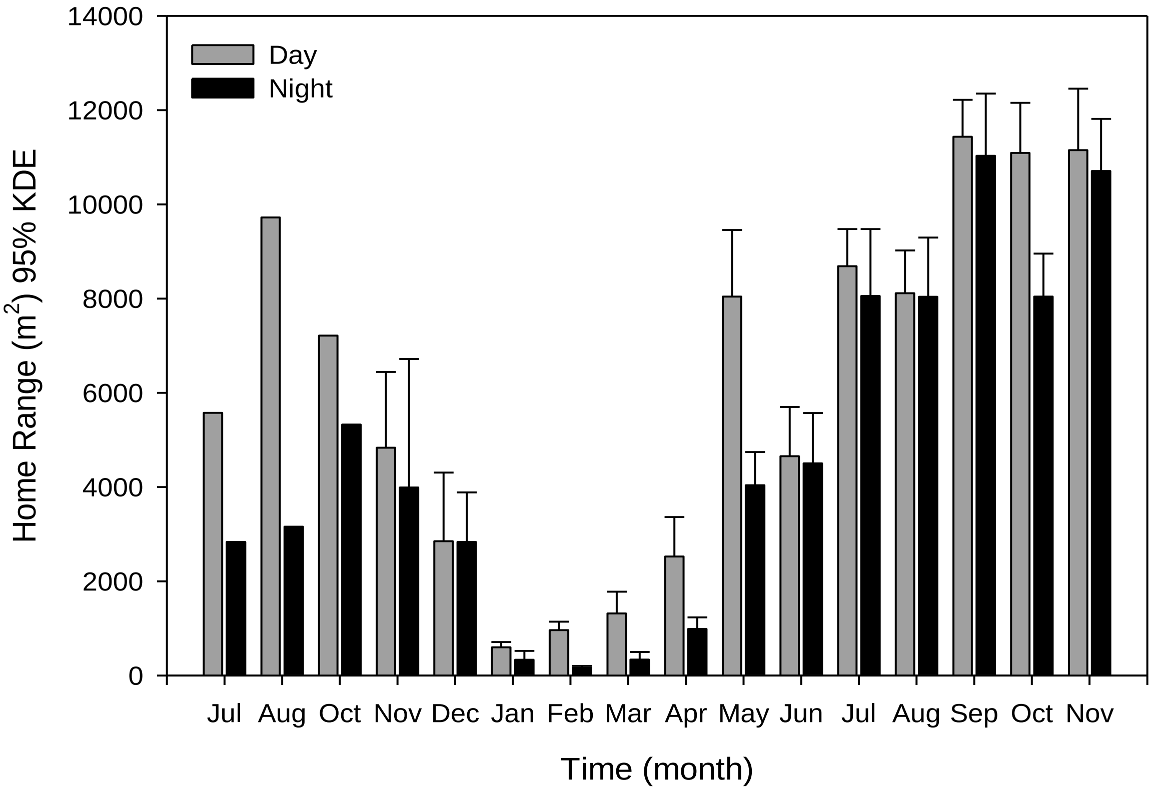

Figure 5: Comparison of mean monthly diurnal (gray bars) and nocturnal (black bars) home range estimates (95% KDE + SD) for red snapper *Lutjanus campechanus* around artificial reefs in the northern Gulf of Mexico. Overall, home ranges were significantly larger during the day than at night ($P < 0.01$). Day and night core area sizes (50% KDE, not shown) were not significantly different ($P = 0.42$).

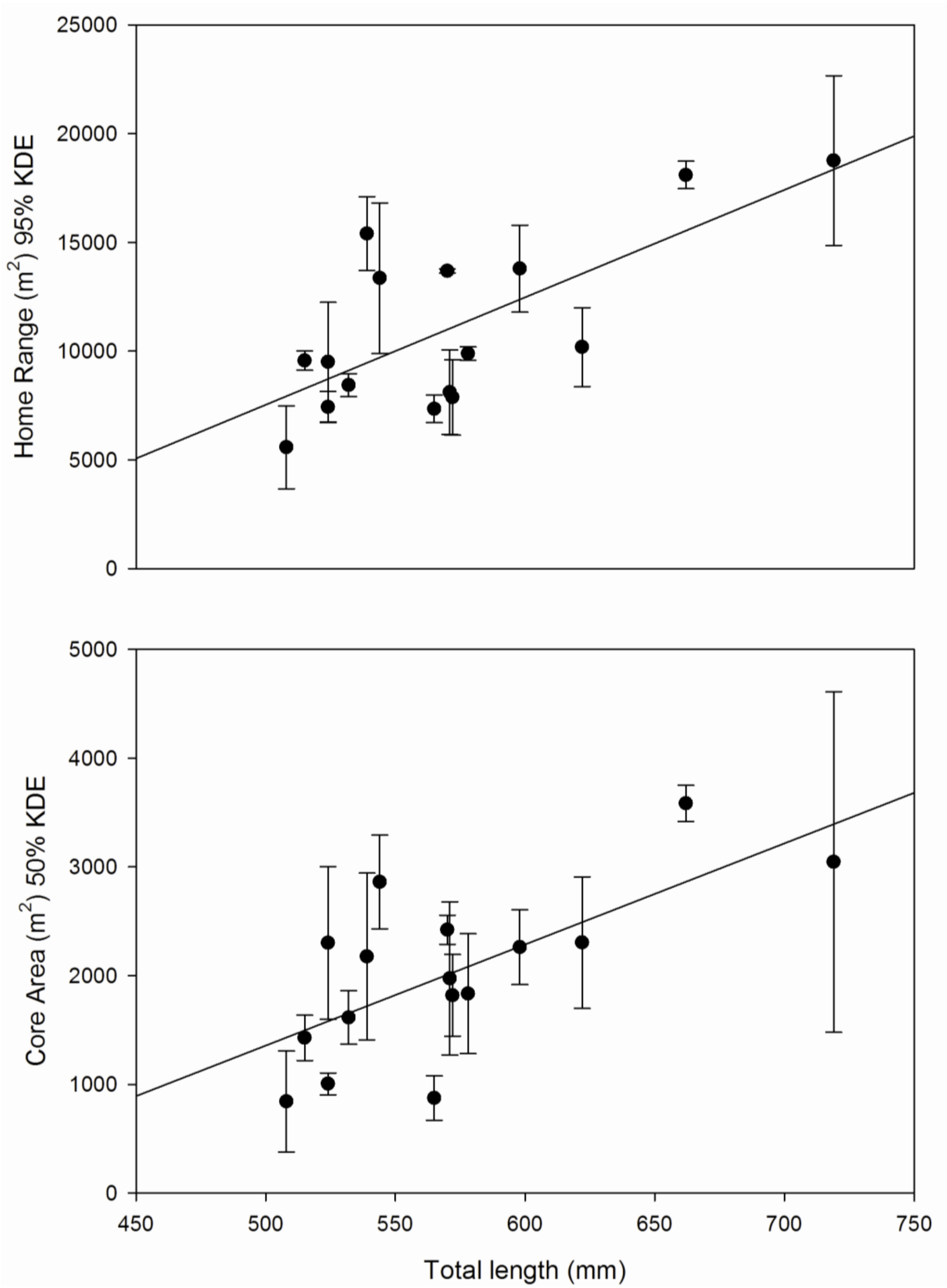

Figure 6: Relation between the total length (mm) of tagged red snapper *Lutjanus campechanus* and mean ± SD (A) home ranges and (B) core area used September–November 2011.