Red snapper (*Lutjanus campechanus*) movement patterns based on acoustic positioning around oil and gas platform in the northern Gulf of Mexico

by

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Abstract

Offshore oil and gas platforms provide habitat for many marine fish species in the northern Gulf of Mexico. By law, the owning company is required to remove obsolete platforms. The most economical method is explosive removal, but such removals usually result in high mortalities of economically important red snapper (*Lutjanus campechanus*). The present study used telemetry methods to examine the movement patterns and residency of red snapper (n = 54) around three oil and gas platforms in the northern Gulf of Mexico from March 2017 to May 2018. Site fidelity was 30% yr^{-1} and residency time was 11 months. Water temperature and dissolved oxygen (DO) had a significant effect on fine-scale area use patterns (home range = 95 % kernel density estimates (KDE)). Salinity showed little change and was well within the tolerance range for Lutjanidae. Seasonal area use increased in the summer and fall ($F(3, 257) = 27.22$, $P < 0.0001$). Diel area use significantly differed among sites ($F(23, 4255) = 8.42$ $P < 0.0001$). Red snapper at the lighted-manned East and Center sites showed no diel area use patterns, however fish at the unlighted-unmanned West site had larger area use during the day. Fish in the present study displayed homing behavior with frequent short-term forays away from their home reef from August through November (n = 19, 88% < 4-d). Fish also showed a high affinity for platform structure (98% of all positions within or near platform structure) suggesting that offshore platforms provide important habitat for red snapper in the

Gulf of Mexico. Fishing mortality was high on platforms (*F* = 0.75 (0.35 - 1.36, 95% confidence limit)). Natural mortality was low with only two natural mortalities during the study (*M* = 0.06 (0.01 - 0.22)). The present study indicated that the optimum time for explosive removal would be in August and September after fishers have removed many of the resident red snapper during the intensive fishing effort in June and July.

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Introduction

Oil and gas platform removal

Oil and gas platforms provide both ecological and economical value to the northern Gulf of Mexico. Addition of platforms has added about 20 km^2 of artificial substrate to the naturally unstructured seafloor (Reynolds et al. 2018). Platforms act as artificial reefs by increasing the amount of vertical hard substrate available. This increase in structured habitat is valuable to a number of species ranging from encrusting organisms to economically important reef fishes (Gallaway and Lewbel 1982; Schroeder and Love 2004; Gallaway et al. 2009).

In 2017 there were around 2,000 oil and gas platforms in the Gulf of Mexico. This number has been reduced from a peak of around 4,000 and will continue to decline as removals exceed installations (Pulsipher et al. 2001; Kaiser and Pulsipher 2003). Platforms and all associated structure must be completely removed to 15 feet below the substrate one year after lease termination (30 C.F.R. § 250.1701 2017). Removals are required to minimize safety hazards, harm to the environment and prevent conflict.

Total removal by explosives is the most cost effective and preferred method for platform removal (Gitschlag et al. 1997; Kaiser and Pulsipher 2003; Barkaszi et al. 2016). Underwater explosives generate shock wave and acoustic energy that result in substantial fish mortalities (Gitschlag et al. 1997; Gitschlag et al. 2000, Schroeder and Love 2004). Hundreds to thousands of fish are killed during a platform explosion with variations due to structure, water depth and removal schedule (Gitschlag et al. 1997). Atlantic spadefish

Chaetodipterus faber), blue runner (*Caranx crysos*), red snapper (*Lutjanus campechanus*) and sheepshead (*Archosargus probatocephalus*) account for nearly 85% of the total fish mortality from explosive removals in the northern Gulf of Mexico (Gitschlag et al. 2000).

Red Snapper on oil and gas platforms

A substantial portion of the red snapper population in the Gulf resides on oil and gas platforms (Gallaway et al. 2009). Red snapper live near platforms most likely for increased shelter and food resources (Render 1995; Stanley and Wilson 2003; Gallaway et al. 2009; Simonsen et al. 2015). Relative biomass estimates show that red snapper are often a dominant species on standing platforms suggesting that platforms successfully act as artificial reefs (Reynolds et al. 2018).

Platforms provide valuable habitat for red snapper, however they may make fish more susceptible to fishers. Red snapper recruit to platforms around age-2, which is the same time they begin entering into the fishery (Gitschlag et al. 2003; Gallaway et al. 2009). Oil and gas platforms are popular fishing sites that are easily assessable by both commercial and sport fishers. Platforms have been estimated to attract nearly 87% of all boating activity and bring in hundreds of millions USD to the local economies for fishing related activities (Gallaway and Lewbel 1982; Hiett and Milon 2002). Fisher surveys at popular boat launch locations off Louisiana reported that most fishermen fished around 6.5 platforms per trip (Gordon Jr. 1993). Platforms showed a higher total mortality (Z) for red snapper ($Z = 0.54$) compared to both published (locations available to public) and unpublished reefs (locations limited; $Z = 0.39$ to 0.48; Gitschlag et al. 2003; Gallaway et al. 2009; Topping and Szedlmayer 2013; Williams-Grove and Szedlmayer 2016b).

Telemetry studies on platforms

Advances in telemetry have enhanced habitat use studies of fish species by allowing continuous monitoring of presence-absence and accurate positional data. Telemetry has been applied in many offshore platform studies and provided important insight on the movement patterns of several species (Jorgensen et al. 2002; Lowe et al. 2009; Brown et al. 2010; Mireles 2010; Anthony et al. 2012; Reubens et al. 2013). In contrast to the Gulf of Mexico's platforms, where fishing is permitted, most other areas limit access to platforms and thus they act as de-facto marine reserves (Schroeder and Love 2004; Lowe et al. 2009). For example, tracking studies on reef fishes (e.g. rockfishes (*Sebastes spp.*), cabezon (*Scorpaenichthys marmoratus*), lingcod (*Ophiodon elongates*) and California sheephead (*Semicossyphus pulcher*)) off California showed the importance of platforms as habitat to many economically important species (Lowe et al. 2009; Mireles 2010; Anthony et al. 2012). Fishing pressure is also limited on platforms in the North Sea creating refuge from fishing pressure for tagged Atlantic cod (*Gadus morhua*) during seasonal migrations from feeding to nursery grounds (Jorgensen et al. 2002; Reubens et al. 2013).

Several studies have used telemetry to examine red snapper movement patterns on other types of artificial reefs (Szedlmayer 1997; Szedlmayer and Schroepfer 2005; Topping and Szedlmayer 2011a, b, 2013; Piraino and Szedlmayer 2014; Williams-Grove and Szedlmayer 2016a, b, 2017). However only two previous telemetry studies attempted to estimate red snapper movement patterns on standing platforms (Peabody 2004; McDonough 2009). Peabody (2004) deployed a single receiver on each of eight platforms in the northern Gulf of Mexico off the coast of Louisiana. Detection frequency data were collected on 97 transmitter tagged red snapper for 200 days. Red snapper showed low site fidelity with only a < 10% probability of being present on their release site after approximately 130 days (Peabody 2004). These conclusions were based on the percentage of detected tagged red snapper within the range of the platform receivers at each release site. Red snapper displayed diel patterns with largest movement away from platforms at night. However, detection ability was likely reduced due to transmitter failure and thermocline interference. These difficulties lead Peabody (2004) to conclude that that site fidelity on platforms should be re-examined in future studies. Peabody (2004) also estimated a high fishing mortality ($F = 0.36 – 6.7$) using varying reporting rates and natural mortality estimates.

In the second platform study in the northern Gulf of Mexico, a VEMCO Radio Acoustic Positioning (VRAP) system was deployed around two platforms off the coast of Louisiana, one in 2005 and the other in 2006 (McDonough 2009). However, this VRAP study was of limited duration with deployment for <1 week in May 2005 due to equipment loss and a second week in August 2005. Sixteen red snapper were originally tagged in May 2005, with five still present after the August 2005 study period. In May 2006, the VRAP array was deployed on another platform for two weeks. Twenty red snapper were tagged at the beginning of the 2006 study and five remained after two weeks at the end of the study. Tagged red snapper displayed both diel movements away from the reef during the day and night. This VRAP study also concluded low site fidelity "< 50% chance of a fish remaining 8.3 days after release" on a site and that platforms were only attracting devices (McDonough 2009).

In contrast, the telemetry studies on smaller artificial reefs reported high site fidelity for red snapper (72% to 88% yr^{-1}; Topping and Szedlmayer 2011b; Piraino and Szedlmayer 2014; Williams-Grove and Szedlmayer 2016a). The different results on site fidelity between platform and smaller artificial reef studies were difficult to compare due to the complications encountered in the previous platform studies and the limited study duration (7 to 200-d; Peabody 2004; McDonough 2009). Thus, little information was available on red snapper habitat use around oil and gas platforms.

The present study examined red snapper habitat use patterns around platforms with the VEMCO Positioning System (VPS) technology. This technology provided major advances in accuracy (± 2 m), frequency of positions (~ 10 min interval fish positions) and study periods (e.g., months to years) compared to previous tracking technology, and at the time of the study was the best method for the study of red snapper movement patterns (Andrews et al. 2011; Piraino and Szedlmayer 2014; Williams-Grove and Szedlmayer 2016a, b, 2017). As removal of platforms continues in the northern Gulf of Mexico with little construction of new platforms, it is important to estimate if this loss of habitat will affect the red snapper stock in the future. To help in this evaluation, movement patterns were quantified by measuring residency time, site fidelity and home range around platforms. Red snapper positions were examined for diel and seasonal patterns, and compared to environmental parameters (dissolved oxygen (DO), salinity, temperature). The present study also estimated instantaneous natural (M) and fishing (F) mortality independent of fisher reporting, which are critical parameters for red snapper stock assessments. An important practical aspect of the present study may be the use of red snapper movement patterns around platforms in scheduled removal plans, with the intent of minimizing red snapper mortalities from explosive removals. For example, are there predicted time periods when red snapper are farther away from platforms, thus potentially reducing mortalities from explosive removal?

Materials and Methods

Study sites

Three VPS telemetry arrays were deployed on platforms off the coast of Alabama and Louisiana (Fig. 1). Study sites were randomly selected from over 2,000 platforms in the northern Gulf of Mexico. The “East site” was located 25 km (13 nautical miles) southeast of Dauphin Island, Alabama, USA. The East site was a large gas producing complex of three connected platforms with 14 legs attached to the seafloor located over sand substrate in 17 m depths and had a total area of 442 m^2. The “Center site” and “West site” were located south of coastal Louisiana, USA. The Center site was an oil and gas producing platform 86 km (46 nautical miles) southeast of Pecan Island, LA, over mud-silt substrate in 30 m depths and had an area of 263 m^2. The West site was a gas producing platform located 106 km (57 nautical miles) southwest of Pecan Island, LA, on sand substrate at 23 m depths and had an area of 148 m^2. Both Center and West sites were single platforms with four legs attached to the seafloor. Information regarding platform production was provided by the Bureau of Ocean Energy Management (BOEM; https://www.data.boem.gov/Production/ProductionData/Default.aspx).

Array design

Array design was similar to previous studies (Piraino and Szedlmayer 2014; Williams-Grove and Szedlmayer 2016a, b, 2017), but adapted for the larger size of platforms (Fig. 2). Each array includes six VEMCO VR2Tx receivers. A center receiver

(C) was placed 20 m north of each platform. Surrounding receivers were placed 300 m to the northeast (NE), northwest (NW), southeast (SE) and southwest (SW) of the C receiver. A south receiver (S) was placed 415 m south of the C receiver. Receivers were spaced for maximum detection efficiency of transmitter tagged red snapper around the platforms. Prior range testing of similar model receivers (VEMCO VR2W) showed 100% detection at 400 m (Piraino and Szedlmayer 2014). The VEMCO Receivers (VR2Tx) deployed in the present study had an additional noise sampling capability set to record every 10 minutes. This noise sampling was used to help clarify accurate fish detections during analyses. The East VPS array was deployed on 28 March 2017 and the Center and West VPS arrays were deployed on 4 and 7 July 2017.

All receivers were painted with copper based antifouling paint to help prevent the loss of detections from biofouling on the hydrophones (Topping and Szedlmayer 2011a, b). At the East site, receivers were attached to a mooring line 1.5 m above the seafloor with a float above the receiver (Topping and Szedlmayer 2013; Piraino and Szedlmayer 2014). The receiver position above the seafloor at the East site was less than the Center or West sites (4.5 m) due to the shallower depths at the East site (17 m) compared to Center (30 m) and West (23 m) sites. Mooring lines were attached to the seafloor with 1-m ground anchors.

A control transmitter (V16-6x) was placed 1.5 m above the seafloor on a mooring line 50 to 100 m north of the center receiver at each site. Receivers were collected and replaced every four months by SCUBA divers. Receiver detection data of transmitter tagged red snapper was post processed by VEMCO for fish positions based off the time differential of a transmitted signal at ≥ 3 receivers (VEMCO Ltd. Nova Scotia).

Environmental monitoring

Environmental meters (DO, temperature and salinity) were attached to the center receiver line at each site. Copper antifouling caps and copper mesh were used to prevent biofouling on meter sensors. Dissolved oxygen meters (U26-001, Onset Incorporated) were placed 40 cm above the seafloor and salinity meters (U24-002-C, Onset Incorporated) were attached 1 m below the VEMCO receivers on the mooring line. These Onset remote meters sampled at 10-minute intervals, with data retrieved and meters replaced at four-month intervals. Temperature, salinity and DO were also measured from a surface vessel operated YSI meter (Model 6920, YSI Incorporated) at each platform during all field site visits.

Tagging procedure

Tagging procedures follow previous protocols (Piraino and Szedlmayer 2014; Williams-Grove and Szedlmayer 2016a, b). Red snapper (n = 65) were tagged with acoustic V16-6x transmitters (69 kHz, 20-69 s signal interval, 5-yr battery life) on each of the VPS platform sites. Prior to fish tagging, DO was measured at the maximum depth with the surface operated YSI meter and if DO was < 2.5 mg/L, tagged fish were not released. Only fish > 430 mm total length (TL) were tagged and released in the present study. Fish were captured hook and line, anesthetized in 150 mg/L MS-222 (tricaine methanesulfonate) for 90 s, weighed (0.1 kg), measured (mm) and transmitters surgically implanted into the peritoneal cavity. Each fish was also injected with 0.4 ml/kg oxytetracycline dehydrate (OTC) in the epaxial muscle and tagged with an internal anchor tag (Floy® FM-95W) for external identification of tagged fish by fishers and on return tagging efforts. After recovery, fish were released with remotely opening predator protection cages at depth (Piraino and Szedlmayer 2014; Williams-Grove et al. 2015; Williams-Grove and Szedlmayer 2016a, b). Fish that did not leave the cage on their own initiative after a minimum of 15 min submersion in the cage were not released. At the start of the study, 12-15 transmitter tagged fish were released at each VPS site. During the study period as fish emigrated or were caught, additional fish were tagged and released to maintain the number of tagged fish near 10 fish per site.

Fine scale tracking

Fish positions were analyzed with the R program for home range area estimates (95 % KDE; Venables and Ripley 2002; Calenge 2006; Piraino and Szedlmayer 2014; Williams-Grove and Szedlmayer 2016a, b). Area use was compared over diel and seasonal time periods with generalized linear mixed models (GLMM) with fish as the random factor in the SAS 9.4 program using repeated measures (i.e. a fish was repeatedly measured over time; Venables and Dichmont 2004; Seavy et al. 2005; Bolker et al. 2008). After significant differences were detected with the mixed models, a Tukey-Kramer test was used to show specific differences. Diel periods were combined into three-hour intervals and then defined as day (0800 - 1700), night (2000 - 0500), dawn (0500 - 0800) and dusk (1700 - 2000). Dawn and dusk were defined based on sunrise and sunset times throughout the year from the U.S. Naval Observatory website (http://aa.usno.navy.mil/data/docs/RS_OneYear.php). Seasons were divided into summer (June through August), fall (September through November), winter (December through

February) and spring (March through May). Fish size (TL) was compared to area use by linear regression in SAS software.

Fish positions (easting and northing) were measured as distances (m) from the platform structure with ArcMap 10.4.1 proximity analysis tools (Environmental Systems Research Institute (ESRI); McKinzie et al. 2014). Distances from reef were calculated based on the distance between a fish position and the closest reef structure when fish were outside the platform legs. Positions inside the platform structure were defined as a distance value of 0 m. Fish were considered near platform structure if positions were located < 136 m from the platform. This distance (< 136 m) was based on the mean radius of all 95% KDE areas plus one standard deviation (SD) of the 95% KDE for each site, fish and month (n = 310, for 95% KDE areas; Williams-Grove and Szedlmayer 2016a). Fish positions that were ≥ 136 m were considered not associated with platform structure. After fish positions were assigned as located inside (0 m), near (< 136 m) or away (≥ 136 m) from the platforms, percent frequencies of positions were compared among these three locations.

Environmental Analyses

Mean environmental measures of DO, salinity and temperature were calculated by date for each VPS site. Effects of environmental factors on fish home range were analyzed with linear regression in SAS software (Williams-Grove and Szedlmayer 2016a).

Residency and site fidelity

Fish were categorized as active resident (continuous detections), caught (sudden loss of detections, fishing mortality), emigrated (detections gradually moving away from platform then disappearing) and deceased (stationary detections; Williams-Grove and Szedlmayer 2016a, b). A known fate model in the 'MARK' program was used to estimate residence time and site fidelity for tagged red snapper assuming a common start date (Kaplan and Meier 1958; Schroepfer and Szedlmayer 2006; Topping and Szedlmayer 2011a; Williams-Grove and Szedlmayer 2016b). Fish that died or were caught were right censored (removed) from the model. Residence time was the time when 50% of the tagged fish remained at their release site over the study period (Schroepfer and Szedlmayer 2006; Topping and Szedlmayer 2011a; Williams-Grove and Szedlmayer 2016b). Site fidelity was the maximum likelihood survival of fish remaining at the release site after one year at liberty (Schroepfer and Szedlmayer 2006; Topping and Szedlmayer 2011b; Williams-Grove and Szedlmayer 2016b).

Natural and fishing mortality

A known fate model was used to estimate mortalities (*F*, *M, Z*) in the MARK program with a staggered entry start date and conditional probabilities. Annual estimates were based on monthly time intervals for the study period (March 2017-May 2018; Edwards 1992; Topping and Szedlmayer 2013; Williams-Grove and Szedlmayer 2016a, b). Instantaneous annual mortality rates were based on total survival adjusted to 12 months (Klein and Moeschberger 2003; Starr et al. 2005; Topping and Szedlmayer 2013; Williams-Grove and Szedlmayer 2016b).

Results

Tagging and VPS events

Red snapper movements were tracked on three platforms in the northern Gulf of Mexico. All fish were greater than the Gulf of Mexico federal recreational length minimum of 406 mm total length (TL). Fish ranged from 439 to 753 mm TL (mean ± SD = 558 ± 85 mm TL, *n* = 65). Eleven fish were removed from further analyses due to tagging mortality and emigration within a six day tagging recovery period (Topping and Szedlmayer 2011b; 2013; Piraino and Szedlmayer 2014; Williams-Grove and Szedlmayer 2016a, b). Following the six day recovery period, 54 fish survived and were tracked for extended periods of time (96% > 30-d; Fig. 3).

Emigrations, tagging effects and mortality events were based on VPS positions and varied among the three platforms. Twenty-seven fish were tagged and released on the East site (439 - 753 mm TL; 559 ± 99 mm TL). One fish was removed from further analyses due to a tagging mortality. Among the 26 tracked fish, 10 fish emigrated and did not return, five were caught by fishers, and 11 were still active at the end of the study. Fish were tracked on the East site from March 2017 to May 2018 with time at liberty ranging from 12 to 402 days.

Seventeen fish were tagged and released on the Center site (440 - 690 mm TL; 606 ± 72 mm TL). Six fish were removed from further analyses due to tagging effects. Tagging effects included one fish that emigrated two days after released and five that died shortly after release (≤ 4-d). Reviews of video taken during each cage release indicated that tagging mortalities were caused by fish sinking into fine silt sediment. After removal of tagging effects, only one fish emigrated after 123 days residence and did not return. At the Center site no fishing mortalities were detected, but two natural mortalities occurred. Fish were tracked on the Center site from July 2017 to April 2018 with time at liberty ranging from 12 to 296 days.

Twenty-one fish were tagged and released at the West platform (455 - 684 mm TL; 520 ± 56 mm TL). Tagging effects were detected in four fish that emigrated in < 1 day and did not return. After removal of tagging effects, three fish emigrated and did not return and eight were caught by fishers. Fish were tracked on the West site from July 2017 to April 2018 with time at liberty ranging from 57 to 291 days.

Fine scale tracking

A total of 764,515 accurate (± 7 m) positions were continuously (~5 min) collected and analyzed from all sites. Least square mean (LSM) home range (95% KDE) differed significantly among sites ($F(2, 52) = 14.26$, $P < 0.0001$). Mean LSM home range was highest at the West site and lowest at the East site (West = 35,026 m^2; East = 15,199 m^2; Fig. 4). Fish TL was not significantly related to home range (Linear regression, $r^2 = 0.0019$, $F(1,51) = 0.10$, $P = 0.7553$). Fish remained close to the platforms (mean ± SD = 20.2 ± 17.8 m, $n = 54$) with 11% of positions within the platform structure, 87% near the platform structure and 2% away from platform structure (Table 1).

Diel area use

Red snapper showed significant differences in area use over diel periods among sites ($F(23, 4{,}255) = 8.42$ $P < 0.0001$). Fish at the East site showed no significant differences among any diel periods (Fig. 5a). Fish at the Center site showed significantly smaller area use during dawn (0500 – 0700) compared to midday (1100 – 1600) and night (2000 – 0400; Fig. 5b). Area use did not differ among midday (1100 – 1600), dusk (1700 – 1900) and night (2000-0400). However, area use during early day (0800 – 1000) was significantly smaller than late day (1400 – 1600). Fish at the West site showed significantly increased area use during the midday (1100 – 1600) compared to night (2000 - 0400), dawn (0500 – 0700) and dusk (1700 – 1900; Fig 5c).

Seasonal area use and environmental measures

Area use differed significantly by season ($F(3, 257) = 27.22$, $P < 0.0001$; Fig. 6). Area use was largest in the summer (mean ± SE = 19,530 ± 1,677 m^2) and fall months (19,446 ± 1,424 m^2) and smallest in the winter months (8,205 ± 1,427 m^2). Significant differences in area use were detected among study sites by season ($F(11, 251) = 27.84$, $P < 0.0001$). Differences were likely due to location and environmental variation among sites as area use was significantly effected by water temperature and DO for all sites (East temperature: $r^2 = 0.23$, $F(1, 223) = 64.61$, $P < 0.001$; East DO: $r^2 = 0.17$, $F(1, 223) = 46.5$, $P < 0.001$; Center temperature: $r^2 = 0.08$, $F(1, 265) = 24.65$, $P < 0.001$; Center DO: $r^2 = 0.03$, $F(1, 265) = 8.89$, $P = 0.003$; West temperature: $r^2 = 0.23$, $F1, 249 = 74.65$, $P < 0.001$; West DO: $r^2 = 0.05$, $F(1, 249) = 12.26$, $P < 0.001$). For example, fish at the East site showed the largest area use in summer as temperatures increased and DO decreased (13,504 ± 1,348 m^2; Fig. 7a; Fig. 8a, b). Summer area use was significantly larger than the smallest area use in spring (7,778 ± 749 m^2). Fish at the Center site showed largest area use in the fall (23,710 ± 3,368 m^2; Fig 7b). Area use was smallest in winter (7,787 ± 3,551 m^2) as temperatures decreased and was significantly smaller than fall area use (Fig. 9a, b). Fish at the West site showed the largest area use in summer (32,954 ± 2,292 m^2; Fig. 7c). Area use was significantly smaller as temperatures declined and DO increased into the winter (7,946 ± 2,031 m^2; Fig. 10a, b).

Mean monthly salinities at the present study sites were well within the upper and lower thresholds for Lutjanidae (Huff and Burns 1980; Moran 1988; Castillo-Vargasmachuca et al. 2013). Salinity varied little by month and showed little relation to area use at the West site ($r^2 = 0.01$, $F(1, 227) = 2.87$, $P = 0.092$; Fig. 10a) and Center site ($r^2 = 0.02$, $F(1, 244) = 4.71$, $P = 0.031$; Fig. 9a). At the East site the salinity meter malfunctioned from March to November 2017, and was not used in the analysis during this time period. However, salinity varied little from December 2017 to May 2018 and also showed little relation to area use ($r^2 = 0.0862$, $F(1, 109) = 10.28$, $P = 0.002$; Fig. 8a).

Site fidelity and residency

Emigrations

Many fish in the present study made short-term emigrations ($n = 19$). Short-term emigration events were defined as absences from the study site for ≤ 3 days with subsequent returns. Fish that emigrated for ≤ 3 days were still considered resident to their original tagging location, whereas fish that left for > 3 days were considered emigrants. This emigration criterion was based on the time duration of absence for fish that showed multiple emigrations and returns (i.e., 88 % of emigration events were < 4-d). Most (93%) short-term emigration events occurred in the late summer and fall months (August to November) and during the night (77% left and returned). Fish at the Center site (*n* = 6) and at the West site (*n* = 13) showed multiple short-term emigrations. For example, fish (F223) left and returned to the Center site 78 times, and remained active at the site for 296 days until the end of the study (Fig. 3). This fish was considered resident for the entire tracking period as 92 % of the movements away from the platform were < 1 day and 100 % were ≤ 3 days. Several fish (*n* = 9) that showed multiple short-term emigrations also showed longer-term emigrations that varied from 4 to 17 days with subsequent returns to the original tagging site (Fig. 3). No fish at the East site displayed short-term emigration behavior, but some (*n* = 3) showed longer-term emigrations with returns over periods of 15 to 178 days away. Also, the East site was the only site where fish (*n* = 9) showed permanent one-time emigrations (no returns) ranging from 33 to 157 days after tagging.

Site fidelity and residency

Site fidelity on platforms was 30% yr $^{-1}$ (total *S* = 0.27, 0.05 - 0.73, 95% CL; Fig. 11). Many (*n* = 22, 41 %) transmitter tagged red snapper emigrated. Among fish that emigrated, many (*n* = 9, 41 %) showed homing behavior and returned to their original release site. Residency time (50% of fish still present) was 11 months. Site fidelities and residency times varied among platforms (Table 2). Fish at the East site showed the lowest site fidelity at 27% yr^{-1} (total *S* = 0.25, 0.05 - 0.69) and residency time was 11 months. Fish at the Center site showed the highest site fidelity at 65% yr^{-1} (total *S* = 0.7, 0.38 - 0.90) and residency time was greater than the study period of 10 months. Fish at the West site showed an intermediate site fidelity at 48% yr^{-1} (total *S* = 0.54, 0.29 - 0.11) and residency time was also greater than the study period of 10 months.

Fishing and natural mortality

Fishing mortalities were detected in 13 out of 54 transmitter tagged red snapper. All VPS determined fishing mortalities were validated by fisher reported recaptures (100% reporting rate). Fish were returned by both commercial and sport fishers. In 2017, the original three day federal recreational fishing season was reopened for 39 weekend days (50 C.F.R. part 622). All fish returned by private fishers were caught during the fishing season ($n = 7$). More fish were returned during the extended season (57%) than during the original three-day season (43%). Time between tagging and capture ranged from 57 to 254 days. Total survival from F on platforms was $S_F = 0.44$ (0.23 - 0.68; 95% CL). Survival adjusted to an annual rate was $S_F^{(12/13)} = 0.47$ (0.26 - 0.70) and instantaneous annual F for all fish at all sites was $F = -\log(0.47) = 0.75$ (0.35 - 1.36; Fig. 12). Variations in F occurred among the sites (Table 3). Fish at the East site had a $S_F = 0.45$ (0.17 - 0.77) and $F = 0.73$ (0.24 - 1.64). Fish at the West site had a $S_F = 0.35$ (0.15 - 0.63) and $F = 1.26$ (0.56 - 2.30). No tagged red snapper were caught ($F = 0$) at the Center site during the study period.

Only two natural mortalities occurred over all platforms, with $S_M = 0.94$ (0.79 - 0.98) and $M = 0.06$ (0.01 - 0.22; Fig. 13). Natural mortality was only detected at the Center site, and for this site alone $S_M = 0.78$ (0.42 - 0.94) and $M = 0.30$ (0.07 - 1.04; Table 3). These natural mortalities were detected after tagged fish were at liberty for 12 and 145 days.

Discussion

The present study successfully tracked red snapper on three platforms in the northern Gulf of Mexico (*n* = 54). Over 76,000 accurate fish positions (± 7 m) were recorded continuously (about every 5 min) over the 13 month study period and provided a greater understanding on how red snapper use platforms as habitat. Red snapper had a high affinity for platform structure (98% of all positions associated with platform structure) and indicated that platforms provided important habitat for this species, similar to studies on other artificial reef structures in the northern Gulf of Mexico (Topping and Szedlmayer 2011a, b; Piraino and Szedlmayer 2014; Williams-Grove and Szedlmayer 2016a, 2017).

Diel patterns

Significant diel differences have been reported for red snapper on artificial reefs with different patterns depending on the study. For example, there were greater areas during the night (Topping and Szedlmayer 2011a, b), greater areas during the day (Piraino and Szedlmayer 2014), or both that depended on location (Williams-Grove and Szedlmayer 2016a). The present study showed both significant and none significant diel patterns depending on site.

Fish at the East and Center sites showed similar area use during day and night. One difference of platforms to submerged artificial reefs is that platforms are required to have floodlights when manned and navigation lights when unmanned (Keenan et al. 2007). Light intensity varies among platforms, but can penetrate into the water beyond 20 m and illuminate an area >200 m away from the source (Keenan et al. 2007). This variation in artificial light intensity could explain the diel differences observed among the present platform study sites. For example, the East and Center were manned platforms with extensive illumination (24 h). In contrast, the West site, where fish area use was largest during the day, was unmanned and only displayed small navigation lights. Previous studies have linked larger day area use patterns to red snapper behaving like prey species with fish becoming more cryptic at dawn and dusk (Piraino and Szedlmayer 2014; Williams-Grove and Szedlmayer 2016a). Fish at the Center site had the smallest area use at dawn when large pelagic predators were likely more active, but was the only site to show this crepuscular behavior (Piraino and Szedlmayer 2014; Williams-Grove and Szedlmayer 2016a).

Red snapper are an opportunistic species that feed on a variety of reef and open habitat associated prey items (Ouzts and Szedlmayer 2003; Szedlmayer and Lee 2004; Wells et al. 2008; Schwartzkopf 2014; Simonsen et al. 2015). Standing platforms aggregate large number of fish species including small schooling fish (e.g., antenna codlet (*Bregmaceros atlanticus*)) that have been found in red snapper diets (Stanley and Wilson 1997; Simonsen et al. 2015; Reynolds et al. 2018). Platform lights tend to attract prey items to the illuminated surface waters and likely enhance the ability for visually oriented red snapper to locate prey at night (Simonsen et al. 2015). This creates foraging opportunities during both day and night and could explain the lack of diel area use patterns observed on the East and Center platforms.

Most (77%) short-term emigration events in the late summer and fall months occurred at night (both left and returned). These short-term events were likely foraging forays to nearby open habitat and reef structures. Several previous studies support increased foraging at night by red snapper (Szedlmayer and Schroepfer 2005; Topping and Szedlmayer 2011a; 2011b; Williams-Grove and Szedlmayer 2016a). It is possible that red snapper forage away from platforms at night to take advantage of temporal shifts in prey availability (Diagle 2015). For example, some benthic and infaunal species, like conger eels (*Conger oceanicus*), burrow in the substrate during the day, but become active and available over open habitat at night (Levy et al. 1988). Previous diet studies on red snapper showed higher percentages of demersal crustaceans (e.g. crabs, *Squilla empusa* and *Sicyonia spp*.) in gut contents collected at night compared to day (Ouzts and Szedlmayer 2003; McCawley et al. 2006). Diet studies on platforms have reported both fish and bottom-associated species in red snapper diets (Schwartzkopf 2014; Simonsen et al. 2015).

Seasonal movements

Seasonal differences in red snapper area use were correlated with environmental changes. In the present study, area use decreased during the winter months, as temperature decreased and DO concentrations increased. This was consistent with previous observations that red snapper congregated near oil and gas platforms during winter (Stanley and Wilson 1997). Metabolic rates in most fish are lower in the winter, thus fish need less prey and forage over smaller areas compared to warmer summer months (Johnston and Dunn 1987). Red snapper area use was larger in the summer and fall months and coincided with most (93%) short-term emigration events (August to November). During the summer and fall there were higher temperatures and lower DO, and red snapper likely expanded their foraging area to meet increased metabolic rates. Previous red snapper studies have observed the same higher summer area use in relation to temperature (Piraino and Szedlmayer 2014; Williams-Grove and Szedlmayer 2016a).

In the present study fish showed an increase in area use during periods of low DO (< 1 mg/L) in the late summer and early fall (July to September). Many fish, for example: Atlantic croaker (*Micropogonias undulates*), pinfish (*Lagodon rhomboids*), bay anchovy (*Anchoa mitchilli*), spot (*Leiostomus xanthurus*), summer flounder (*Paralichthys dentatus*), and mudminnows (*Umbra limi*), have also been reported to respond to low DO by stratifying higher in the water column or leaving affected areas (Fry 1971; Priede 1985; Johnston and Dunn 1987; Rabaliais et al. 2001; Rahel and Nutzman 1994; Bell and Eggleston 2005; Craig and Crowder 2005). It is possible that red snapper use larger areas during times of low DO as well as move up in the water column above hypoxic bottom conditions. Previous hydroacoustic surveys on platforms reported similar patterns with red snapper moving higher up in the water column when DO levels were low near the seafloor (Stanley and Wilson 2004). Gray triggerfish (*Balistes capriscus*), also showed this pattern of moving up in the water column when DO was lower near the seafloor in the summer (McKinzie 2018). Future platform studies should tag red snapper with depth transmitters and deploy remote environmental meters to better understand vertical responses to abiotic variables.

Homing behavior

Forty-one percent of fish in the present study displayed homing behavior with both long-term and many short-term movements away from a site with subsequent returns to their home platform (*n* = 22). Homing behavior has been well documented in many fish species ranging from pelagic fishes to reef-dwelling fishes, and has been related to reproduction, shelter and foraging (Matthews 1992; Yoshiyama et al. 1992; Ogura and Ishida 1995; Robichaud and Rose 2001; Kolm et al. 2005; Doving et al. 2006; Loher 2008; Lowe et al. 2009; Mitamura et al. 2009; Rooker et al. 2014; Thyssen et al. 2014; Lewandoski et al. 2018). Tracking studies have observed homing behavior in rockfishes and lingcod on oil platforms with movements among platforms and natural reefs (Lowe et al. 2009; Anthony et al. 2012). For example, when rockfishes and lingcod were translocated from oil platforms to natural reefs, they moved back to the platforms over 11 to 19 km distances in <24 h, indicating that platforms provided preferred habitat over natural reefs for these species (Anthony et al. 2012).

Homing behavior has also been previously reported for red snapper in the northern Gulf of Mexico with fish returning to their original tagging site after extended time periods (Topping and Szedlmayer 2011b; Piraino and Szedlmayer 2014; Williams-Grove and Szedlmayer 2016a). Red snapper moved from their original reef sites to other reef sites and typically stayed on these other sites for 23 - 90 days, then returned to the original site (Williams-Grove and Szedlmayer 2016a). Red snapper in the present study returned to their original site after both short (< 4-d) and long periods away (6 – 157-d). Short-term movements (1 – 4-h) have previously been documented in red snapper on gas pipelines with frequent movements outside the receiver range (Szedlmayer and

Schroepfer 2005). Movement outside the receiver array in the present study was likely to nearby open habitat or reef structures for foraging purposes. Benefits from using these secondary sites likely outweighed the risk associated with large movements by increasing the foraging opportunities and prey availability. How red snapper navigate between reefs is still unknown, however it is possible that each platform has its own unique noise or odors associated that aid in homing (Lowe et al. 2009). Also similar to the present study, gray triggerfish (*Balistes capriscus*) showed both short excursions and longer term emigrations away from their tagging reef site (Herbig and Szedlmayer 2016; McKinzie 2018).

Residency and site fidelity.

Red snapper site fidelity (30% yr^{-1}) and median residency time (11 months) were lower than other telemetry-based estimates on smaller artificial reefs (Szedlmayer and Schroepfer 2005, Topping and Szedlmayer 2011b, Piraino and Szedlmayer 2014, Williams-Grove and Szedlmayer 2016a). The first long-term (5-yr) tracking study of red snapper on artificial reefs indicated a median residency time of 18 months and a site fidelity of 72% y^{-1} (Topping and Szedlmayer 2011b). Later studies also observed high site fidelity of 82 to 88% yr^{-1} and residency of 10 to 23 months (Piraino and Szedlmayer 2014; Williams-Grove and Szedlmayer 2016a).

In contrast, lower red snapper site fidelity estimates were reported on a ship artificial reef (27% after 200-d) and a complex of culverts and a tugboat (58 % after 200-d; Garcia 2013). Larger reefs, like platforms and ships, are complex habitats that support high abundances of large fish (Stanley and Wilson 1996, 1997, 2000; Reynolds et al.

2018). This can create both intraspecific and interspecific competition for limited resources, causing red snapper to make short-term foraging emigrations for increased prey at other sites as indicated on the Center and West sites.

Fish at the East site had the lowest site fidelity (27%) and did not show short-term emigrations. However, three fish made long-term emigrations with subsequent returns to the tagging location. The East site was located in close proximity to many smaller artificial reefs. Small artificial reefs are typically dominated by red snapper and thus interspecific competition may be reduced compared to larger platforms (Mudrak and Szedlmayer 2012). Fish at the East site may have emigrated and taken up residence on nearby smaller artificial reefs because of competitive pressure at the platform. Residence on smaller artificial reefs after leaving the East platform was collaborated by two fisher red snapper returns from a small artificial reef in close proximity to the East site and thus it was also likely that fish were not able to return to the East site due to being captured by fishermen.

Mortality

High fishing mortality (F = 0.75) in the present study led to high total mortality (Z = 0.81; Table 3). These estimates were much higher in comparison to estimates of Z on smaller artificial reefs (Z =0.39-0.54; Szedlmayer 2007; Topping and Szedlmayer 2013; Williams-Grove and Szedlmayer 2016b). Likewise, total mortality in the present study was greater than age based methods of total mortality on platforms (Z = 0.54; Gitschlag et al. 2003). Higher F on platforms compared to smaller submerged artificial reefs (F = 0.27 – 0.44; Topping and Szedlmayer 2013; Williams-Grove and Szedlmayer 2016b) was most likely due to platforms taking less effort to locate compared to submerged reef habitats (Gordon Jr. 1993). Fishing mortality in the present was also much higher than the maximum fishing mortality threshold observed in previous stock assessments (F_{MFMT} = 0.0588; SEDAR 2018).

Fishing mortality was not detected at the Center site. The Center site was located at the greatest distance from access ports and thus fishing effort was likely less than the other platforms in the present study. The Center site was the only site were natural mortality was detected (M = 0.06). It is well known that larger predators reside around platforms, for example, greater amberjack (*Seriola dumerili*), great barracuda (*Sphyraena barracuda*), goliath grouper (*Epinephelus itajara*), and sharks (*Carcharhinus spp.*; Ajemian et al. 2015; Reynolds et al. 2018). All of these species could prey on red snapper. After initial detection of natural mortalities (stationary transmitters), detections rates dropped indicating that transmitters became buried in sediment.

Natural mortality estimates in the present study were less than reported by Topping and Szedlmayer (2013; M = 0.11 (0.06-0.20)) and those used in previous stock assessments (M = 0.10, SEDAR 2013; M = 0.094, SEADAR 2018). Williams-Grove and Szedlmayer (2016b) also reported a low natural mortality (M = 0.04) rate similar to the present study. The low natural mortality observed on the platforms was probably due to the high fishing mortality (i.e., fish were caught before they had a chance to die) along with the high life expectancy of red snapper (> 40 yr; Szedlmayer and Shipp 1994; Wilson and Nieland 2001; Williams-Grove and Szedlmayer 2016b).

Implications for removal schedule

Decommissioning methods for oil and gas platforms range from toppling to complete removal (Continental Shelf Associates, Inc. 2004). Explosive removal is the method of choice based on safety, economics and simplicity (Kaiser and Pulsipher 2003; Barkaszi et al. 2016). However, explosive removals can result in substantial mortality of resident fishes (Continental Shelf Associates, Inc. 2004). The safe range for red snapper from the detonation point is 230 m (Young 1991; Continental Shelf Associates, Inc. 2004). Almost all red snapper positions (99%) in the present study were within the affected 230 m zone with a mean distance of 20.2 m from platform structure, thus most red snapper would not survive explosive removals. However, if explosive removals are applied, the present study suggests that removals during the late summer after the red snapper season would be the optimum time to reduce red snapper mortalities. Fishing mortality on platforms was high ($F = 0.75$), and this fishing mortality may create a time period of lower red snapper densities prior to immigration of new fish (Stanley 1994; Nieland and Wilson 2003; Szedlmayer and Lee 2004; Gallaway et al. 2009). Also, area use was greater and movements away from platforms were more frequent during the summer and early fall when DO was low, again suggesting that late summer would be an optimal time to carry out explosive removals to reduce red snapper mortality.

Other removal options may be viable for the northern Gulf of Mexico. Toppling or partial removal should be considered to maintain red snapper populations residing on platforms. Platforms that are converted to artificial reefs for fish stock enhancements have an estimated lifespan of >300 years and have proven to be suitable habitat for red snapper and other sport fishes (Schroeder and Love 2004; Ajemian et al. 2015; Reynolds et al. 2018). The conversion of platforms to artificial reefs would potentially keep red snapper populations at their present levels, in contrast to removals that likely would reduce red snapper stocks (Dauterive 2000; Gallaway et al. 2009; Lowe et al. 2009).

Conclusions

Platforms were important habitat for red snapper in the northern Gulf of Mexico, as red snapper were closely associated to platform structures (98% of positions within or near structure). Fish showed similar area use during both day and night for the East and Center sites, whereas fish at the West site showed larger area use during the day. These diel patterns were likely related to both foraging behavior and platform lights. Seasonal patterns were related to changes in both temperature and DO. Fish in the present study showed the largest area use and homing behavior in the late summer and early fall, which again were most likely linked to foraging behavior. Red snapper had site fidelity of 30% yr^{-1} and a median residency time of 11 months that were lower than previous telemetry studies on smaller submerged artificial reefs. However, site fidelities and residency times are known underestimates as it is unknown how long a fish was present at each platform before the study (Williams-Grove and Szedlmayer 2016a). Fishing morality was high ($F = 0.75$) and natural mortality was low ($M = 0.06$). This suggests that platforms may make red snapper more vulnerable to the fishery. However, Gallaway et al (2009) indicated that platforms overall increased stocks. Thus, the question still remains, do platforms increase red snapper stocks or make then more susceptible to fishing mortality, and unfortunately the question cannot be addressed in the present study.

Considering practical application when scheduling platform removals, area use patterns, fishing mortality and environmental factors should be evaluated to reduce red snapper mortalities. The present study indicated an optimum time for explosive removal would be in late summer after the red snapper fishing season is completed.

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Table 1 Percent of red snapper (*Lutjanus campechanus*) positions associated with platform structure. Percentages were estimated based on mean radius plus one standard deviation (SD) from platform structure

Platform	In (%)	Near (%)	Away (%)
East	16	83	1
Center	11	87	2
West	7	91	2
All	11	87	2

Table 2 Site Fidelity and residency of red snapper (*Lutjanus campechanus*) on oil and gas platforms in the northern Gulf of Mexico

Platform	Survival	Site Fidelity (% yr^{-1})	Residency (months)
East	0.25	27	11
Center	0.70	65	>10
West	0.54	48	>10
All	0.27	30	11

Table 3 Instantaneous mortality rates for red snapper (*Lutjanus campechanus*) on oil and gas platforms in the northern Gulf of Mexico. Instantaneous mortality rates (*F*, *M*, *Z*) were estimated for each platform (Ricker 1957). Values in parentheses are 95% confidence intervals. The number of fish that underwent a mortality event at each site = *n*

Platform	*n*	*F*	*M*	*Z*
East	5	0.73 (0.24-1.64)	0	0.73 (0.24-1.64)
Center	2	0	0.30 (0.07-1.04)	0.30 (0.07-1.04)
West	8	1.26 (0.56-2.30)	0	1.26 (0.56-2.30)
All	15	0.75 (0.35-1.36)	0.06 (0.01-0.22)	0.81 (0.39-1.45)

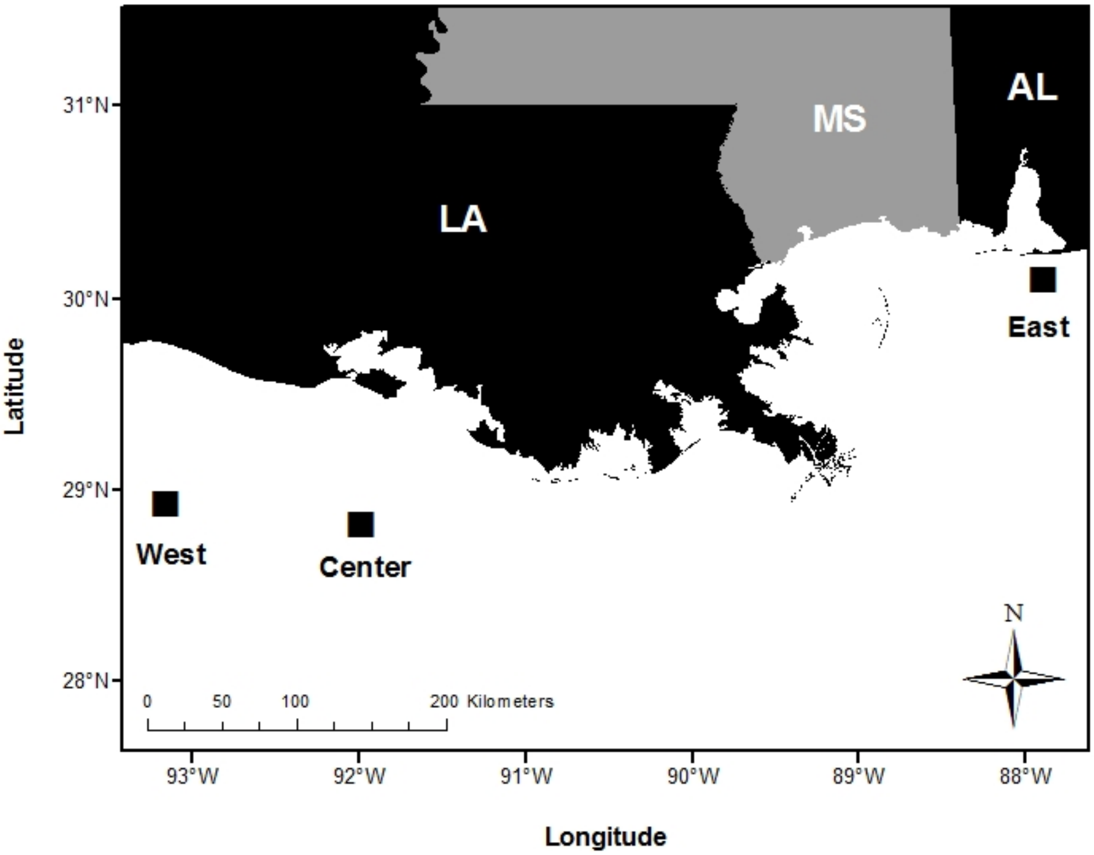


Fig. 1 Study platform locations in the northern Gulf of Mexico

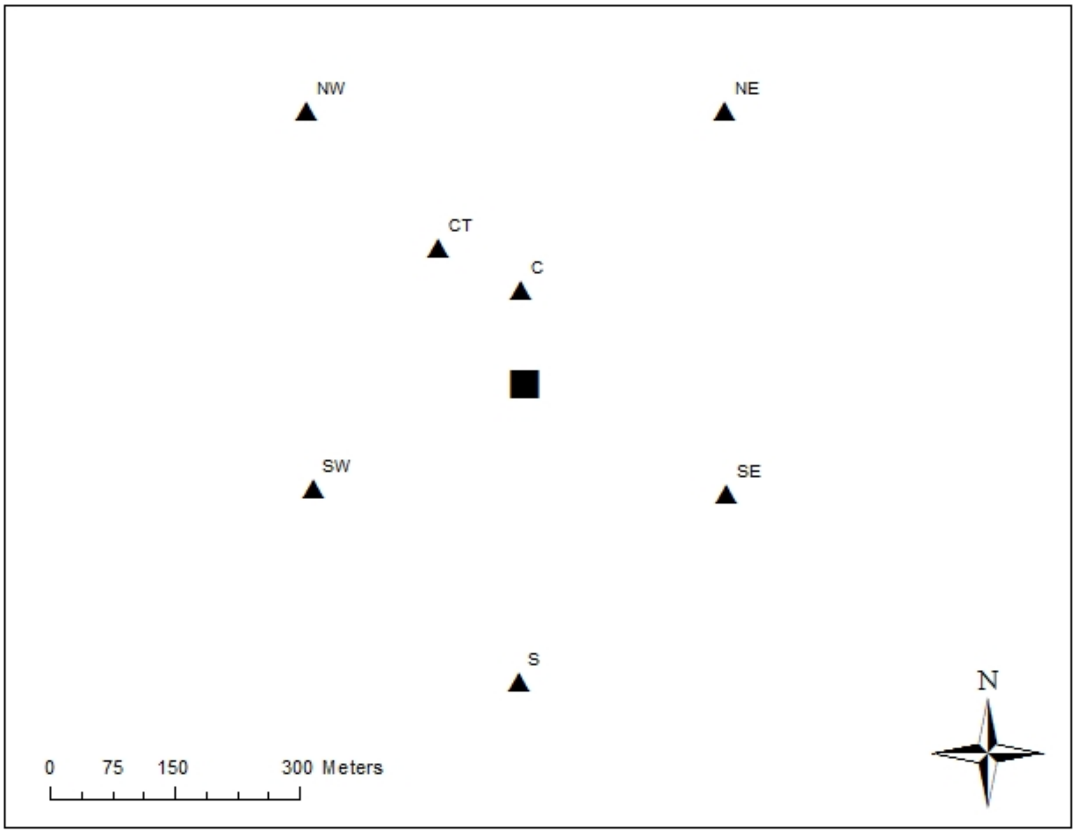


Fig. 2 Positions of VR2Tx receivers around a platform. Four receivers (NW, NE, SE, SW) were placed 300 m from the platform, one receiver (C) was placed near the platform (20 m) and one receiver (S) was placed (415 m) south of the platform. A control transmitter (CT) was placed approximately 50 m north of the platform. Triangles = receivers and control transmitter, square = platform.

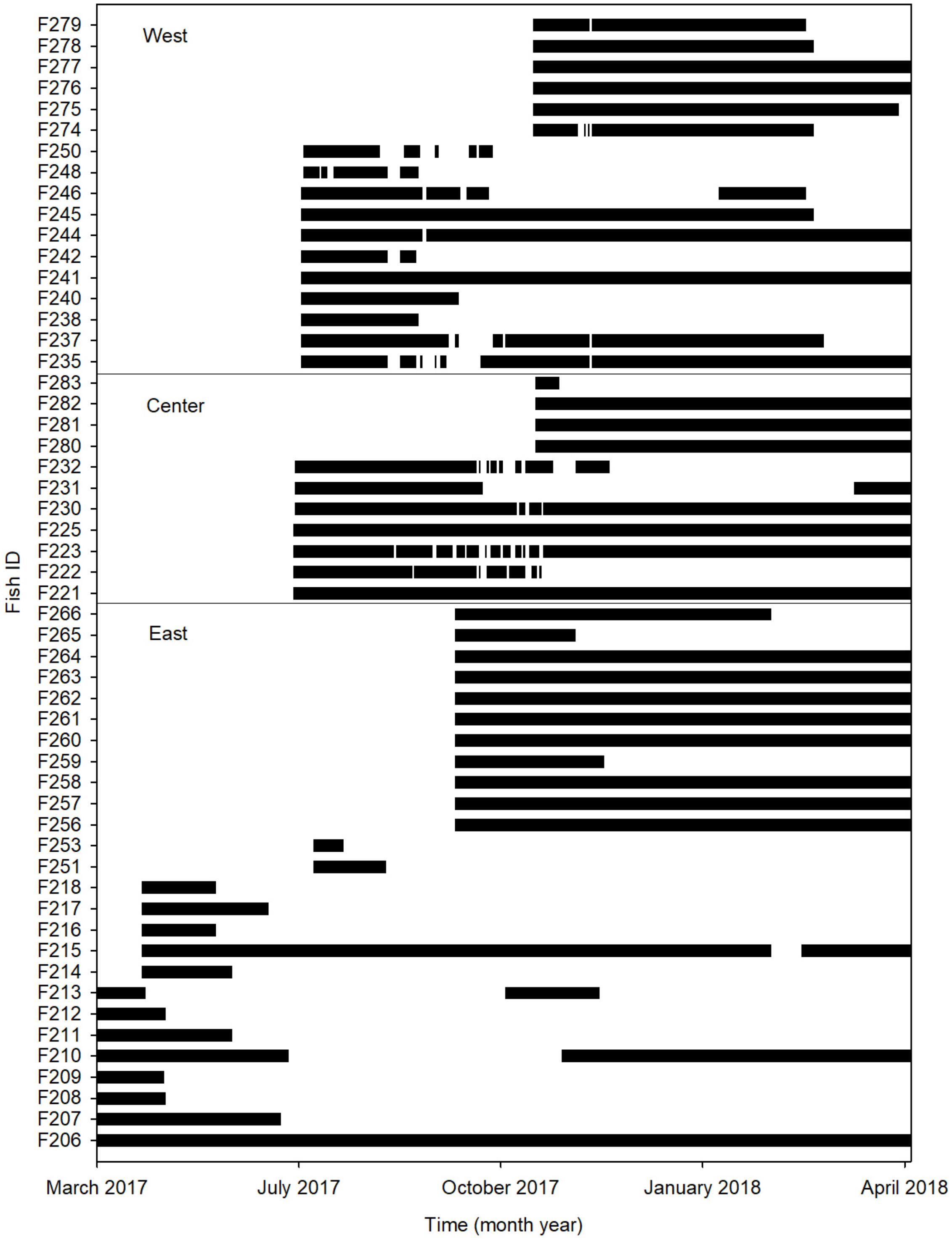
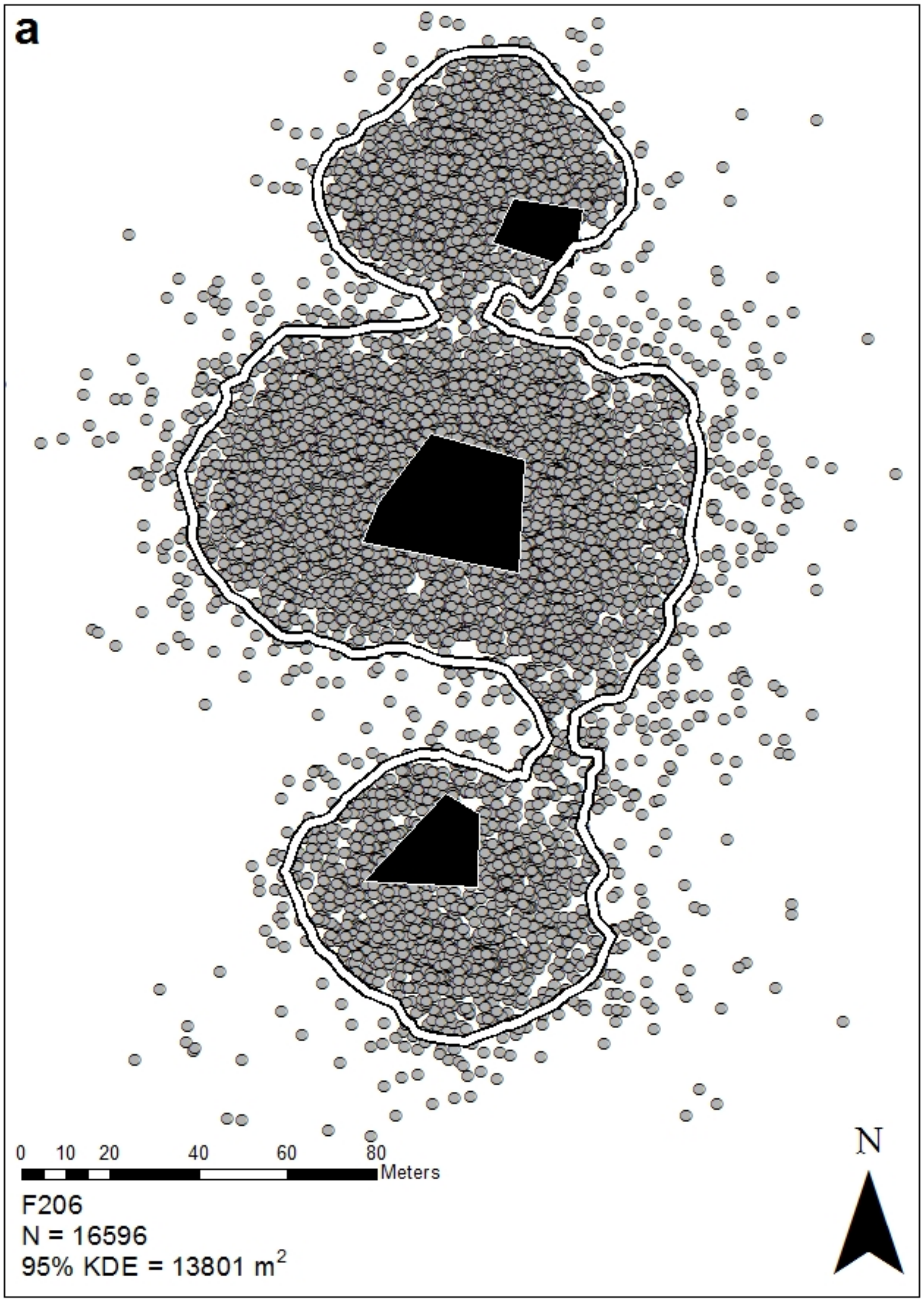
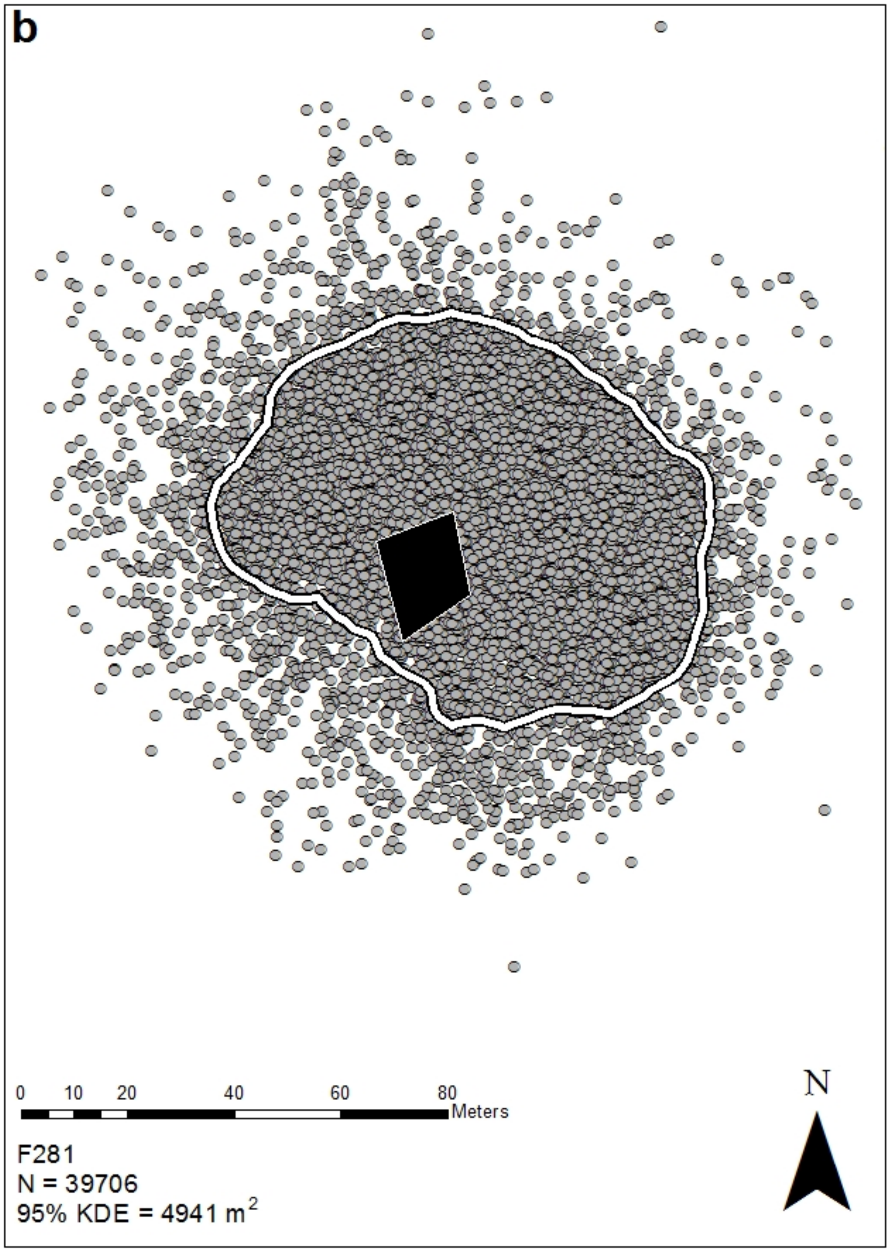


Fig. 3 Tracking periods for red snapper (*Lutjanus campechanus*; *n*=54) on oil and gas platforms in the northern Gulf of Mexico. Black bars = active on platform


a
0
10
20
40
60
80
Meters
F206
N = 16596
95% KDE = 13801 m2
N


b
0
10
20
40
60
80
Meters
N
F281
N = 39706
95% KDE = 4941 m2

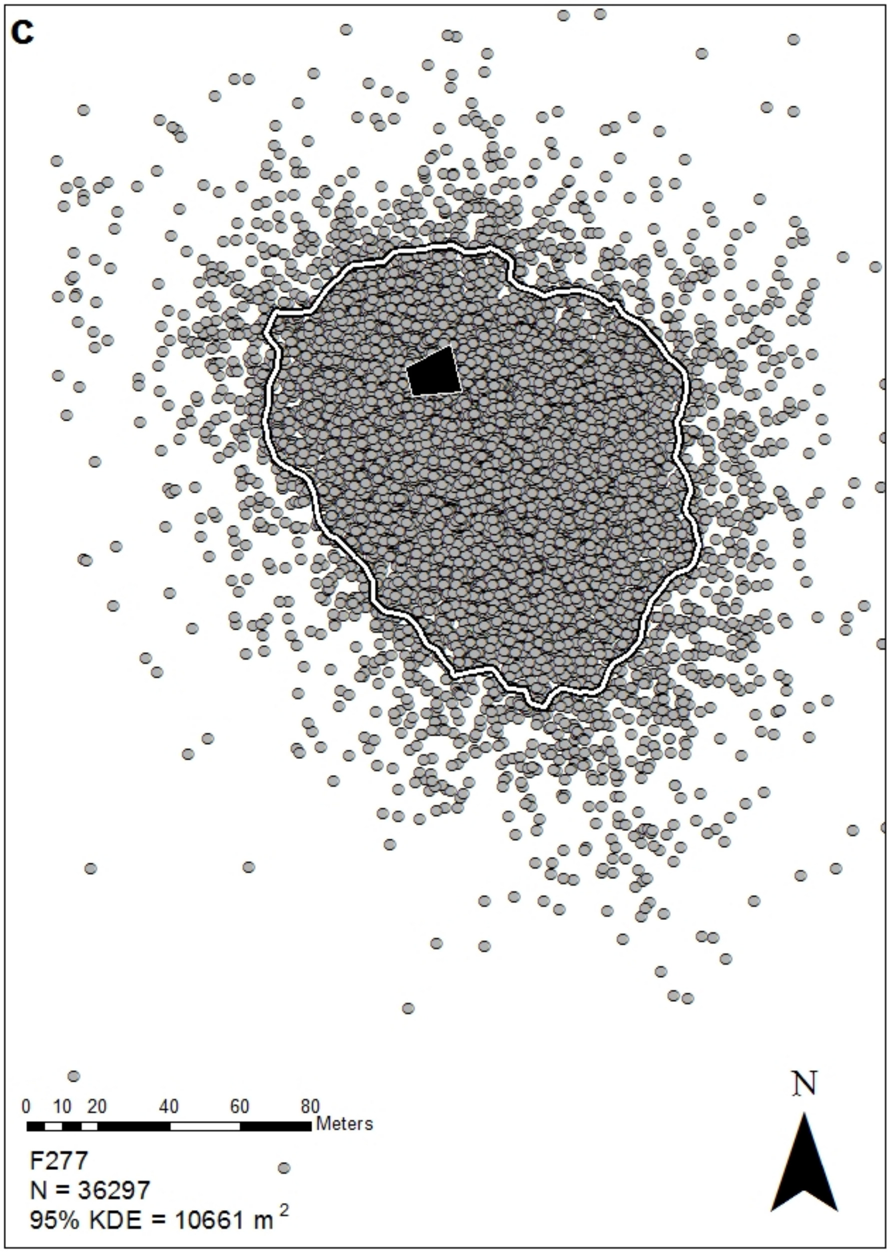


Fig. 4 Home range (95% KDE) of red snapper (*Lutjanus campechanus*) on three oil and gas platforms. Gray dots = VPS calculated positions, white lines = home range, black polygons = platform. (a) Home range for fish F206 at the East site; (b) Home rang for fish F281 at the Center site; (c) Home range for fish F227 at the West site

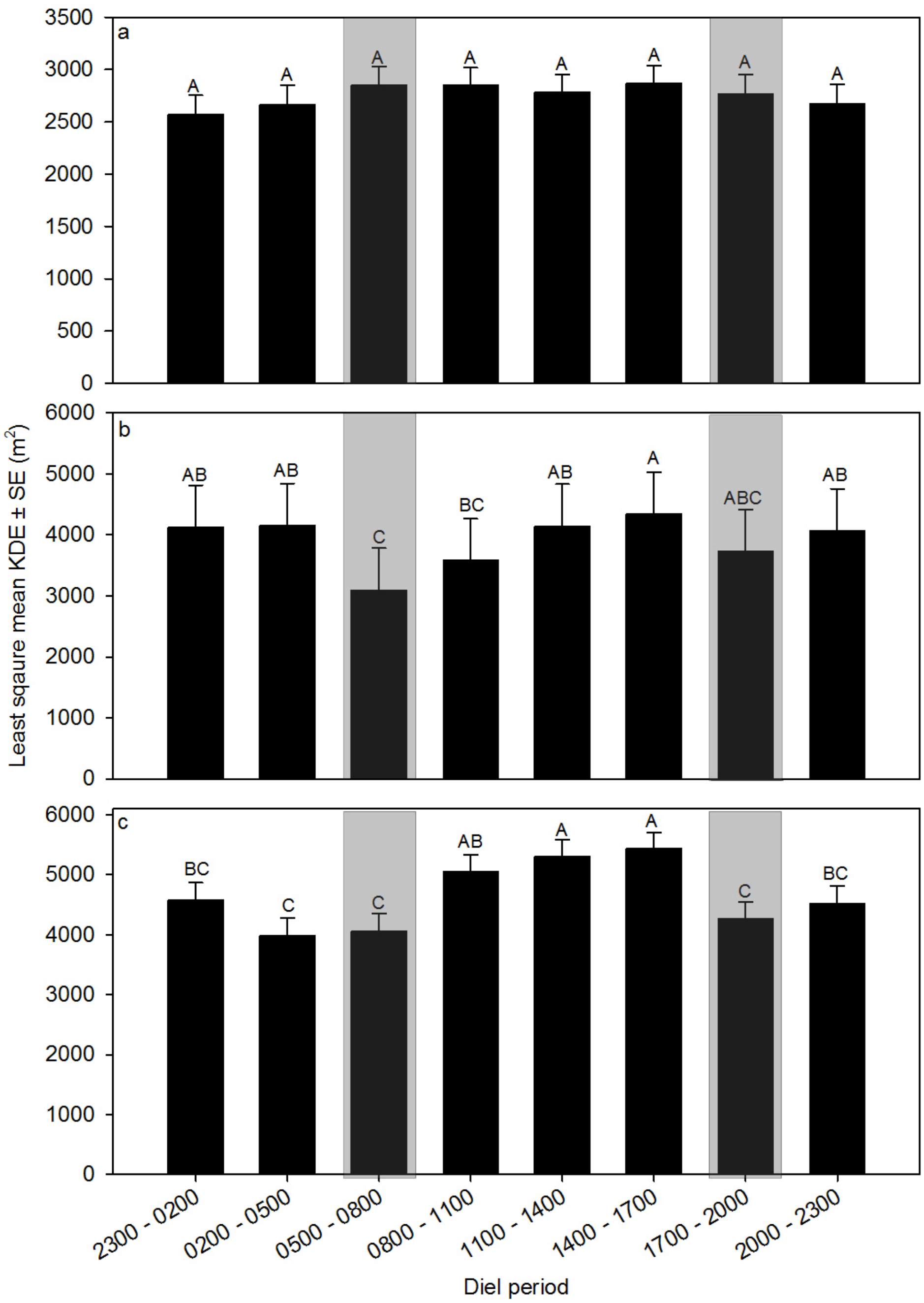


Fig. 5 Diel area use differences for red snapper (*Lutjanus campechanus*) on oil and gas platforms in the Gulf of Mexico. Black bars = home range (95% KDE); error bars = SE, Gray bars = dawn and dusk. Different letters indicate significant differences ($P \leq 0.05$). a) East site; (b) Center site; (c) West site

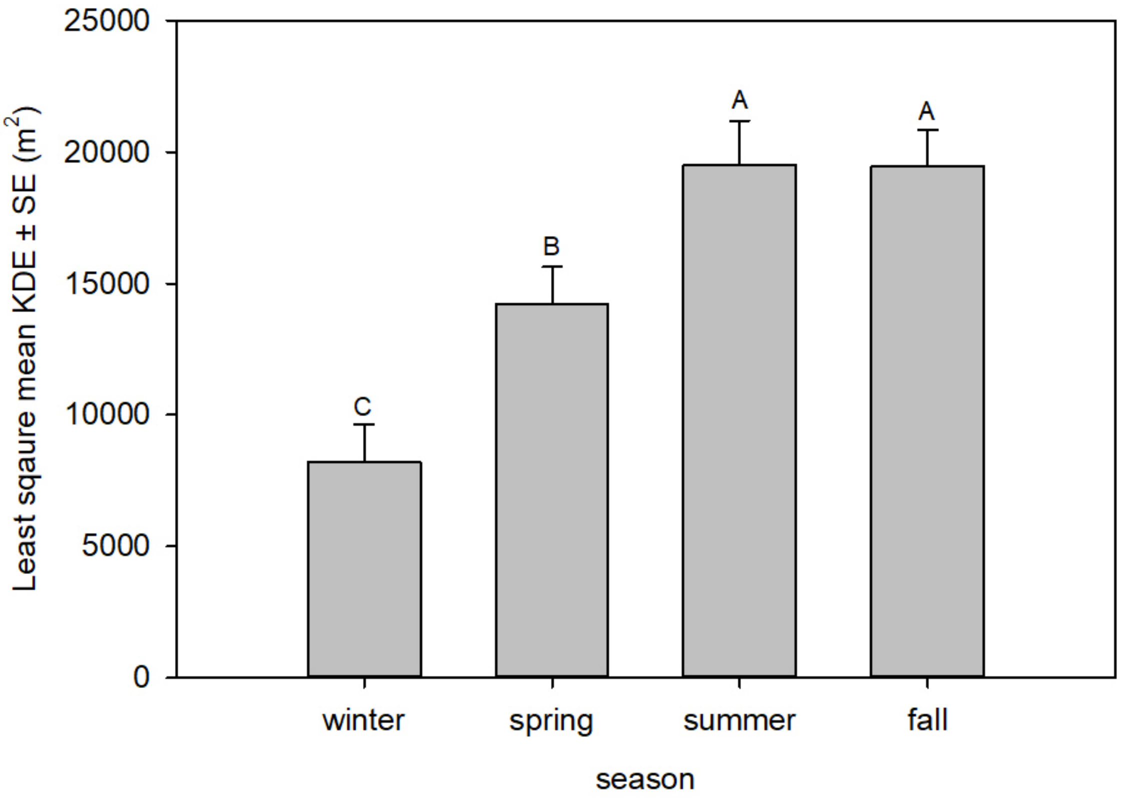


Fig. 6 Seasonal area use differences for red snapper (*Lutjanus campechanus*) on oil and gas platforms in the Gulf of Mexico. Gray bars = home range (95% KDE); error bars = SE. Different letters indicate significant differences ($P \leq 0.05$)

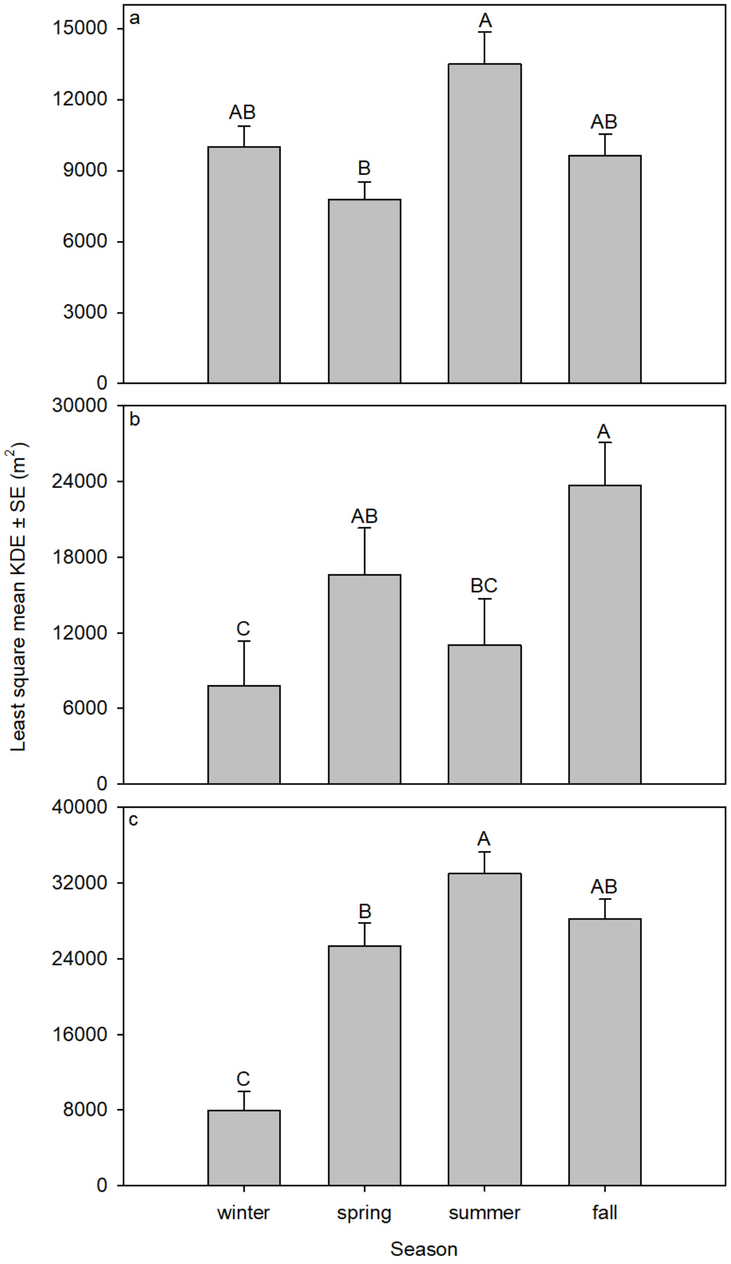


Fig. 7 Seasonal area use differences of red snapper (*Lutjanus campechanus*) on three oil and gas platforms in the Gulf of Mexico. Gray bars = home range (95% KDE); error bars = SE. Different letters indicate significant differences ($P \leq 0.05$). (a) East site; (b) Center site; (c) West site

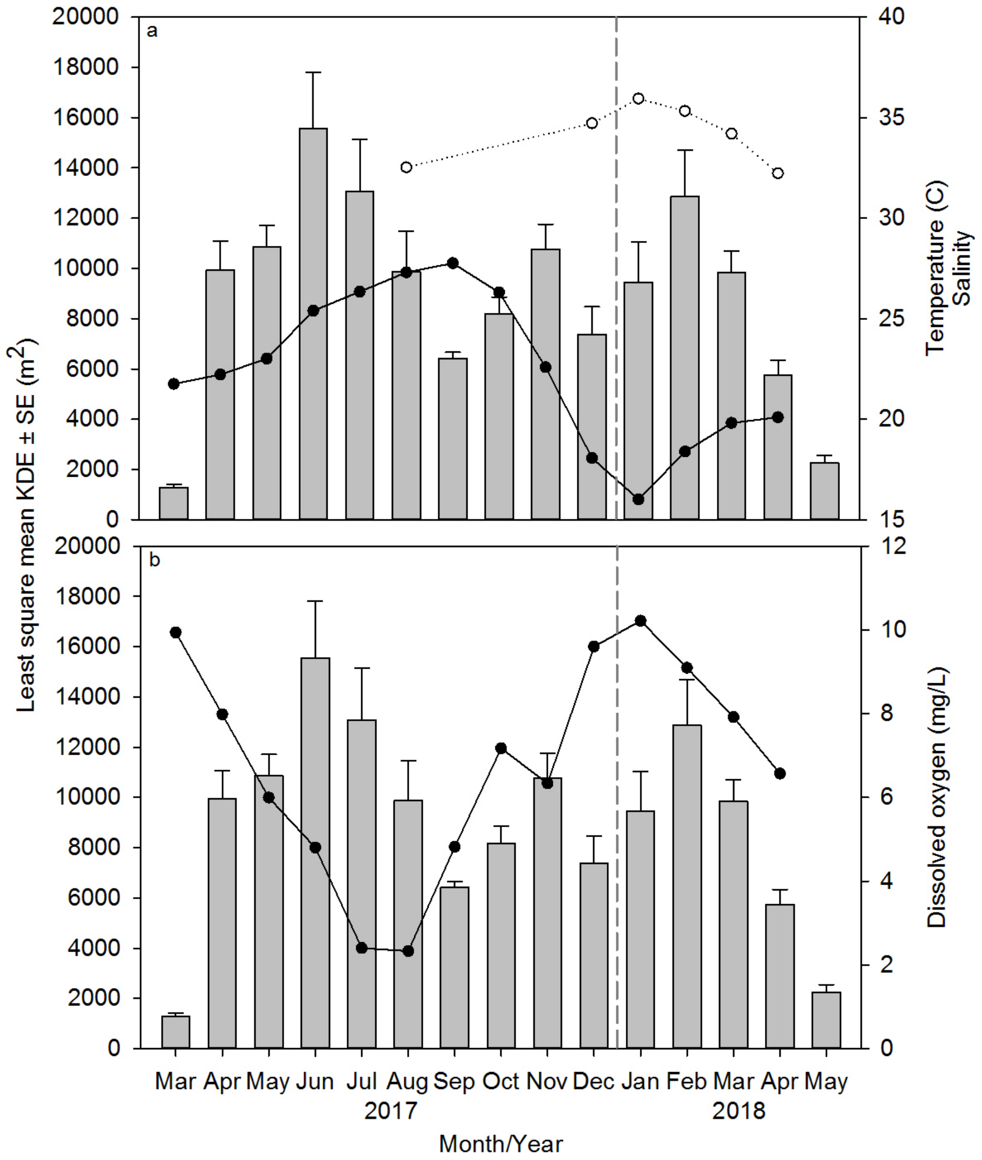


Fig. 8 Comparison of monthly area use for red snapper (*Lutjanus campechanus*) to environmental measures (temperature, dissolved oxygen (DO) and salinity) at the East site. Gray bars = home range (95% KDE); error bars = SE. (a) Area use vs. temperature and salinity; black circles = temperature; white circles = salinity; (b) Area use vs. DO; black circles = DO

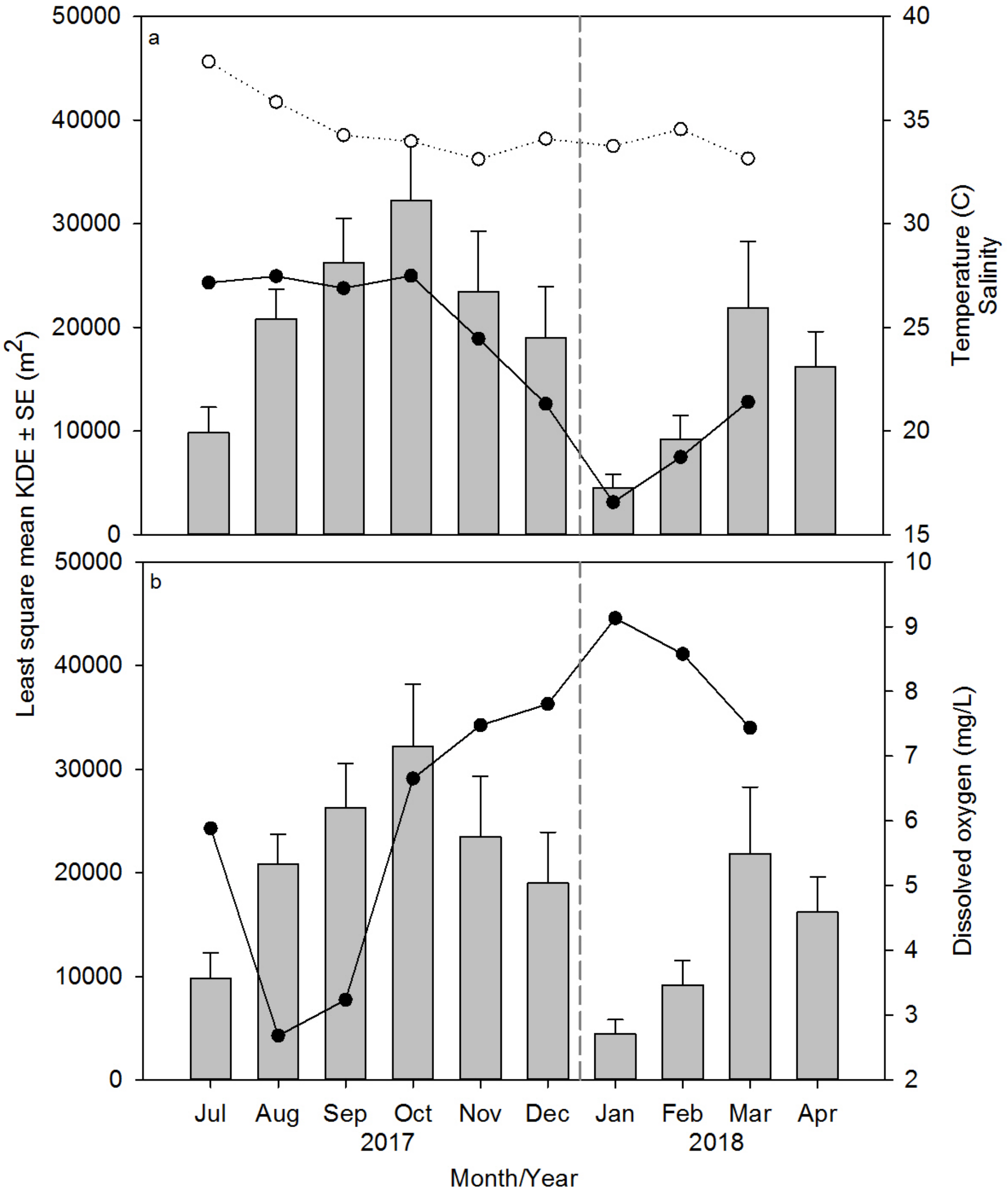


Fig. 9 Comparison of monthly area use for red snapper (*Lutjanus campechanus*) to environmental measures (temperature, dissolved oxygen (DO) and salinity) at the Center site. Gray bars = home range (95% KDE); error bars = SE. (a) Area use vs. temperature and salinity; black circles = temperature; white circles = salinity; (b) Area use vs. DO; black circles = DO

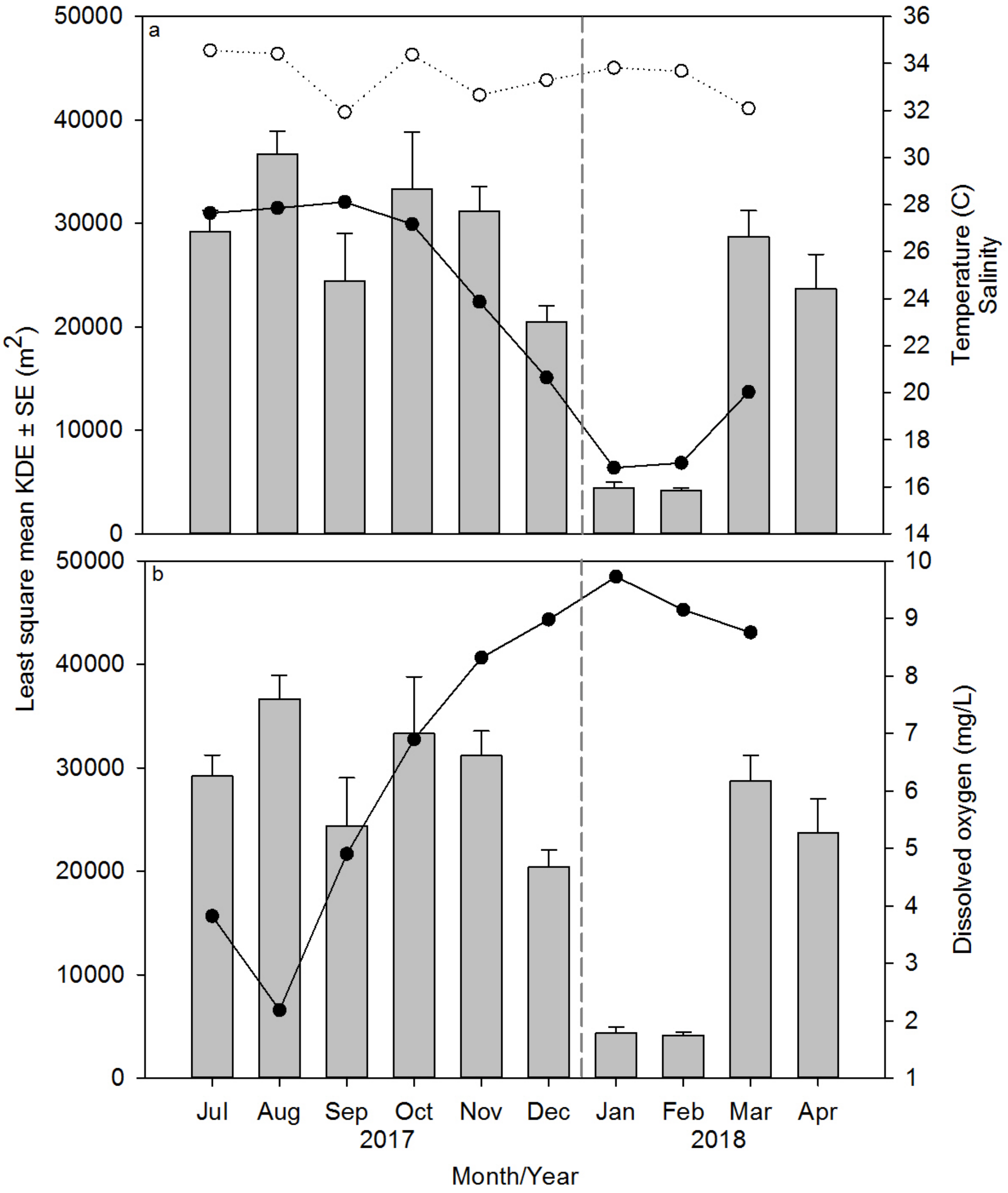


Fig. 10 Comparison of monthly area use for red snapper (*Lutjanus campechanus*) to environmental measures (temperature, dissolved oxygen (DO) and salinity) at the West site. Gray bars = home range (95% KDE); error bars = SE. (a) Area use vs. temperature and salinity; black circles = temperature; white circles = salinity; (b) Area use vs. DO; black circles = DO

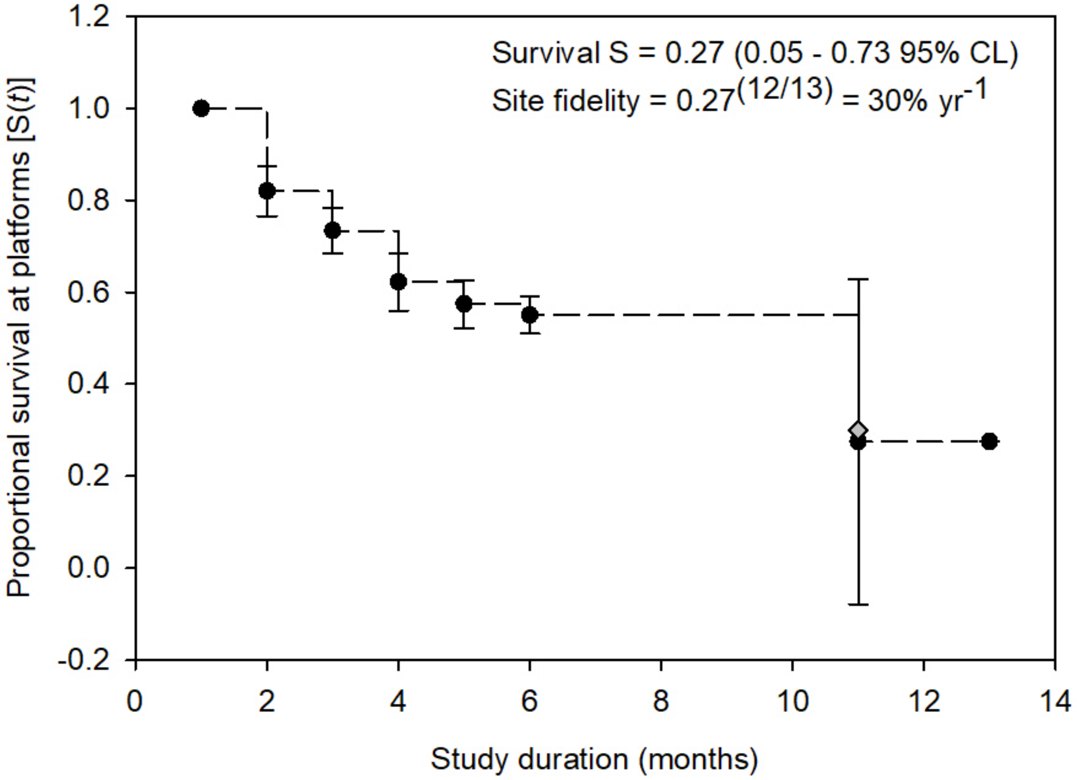


Fig. 11 Red snapper (*Lutjanus campechanus*) survival on oil and gas platforms in the northern Gulf of Mexico. Dashed lines are the proportion of fish that were resident after each monthly interval. Points and error bars (SE) are estimates of *S* for each monthly emigration event. Gray diamond = median residence time (11 months)

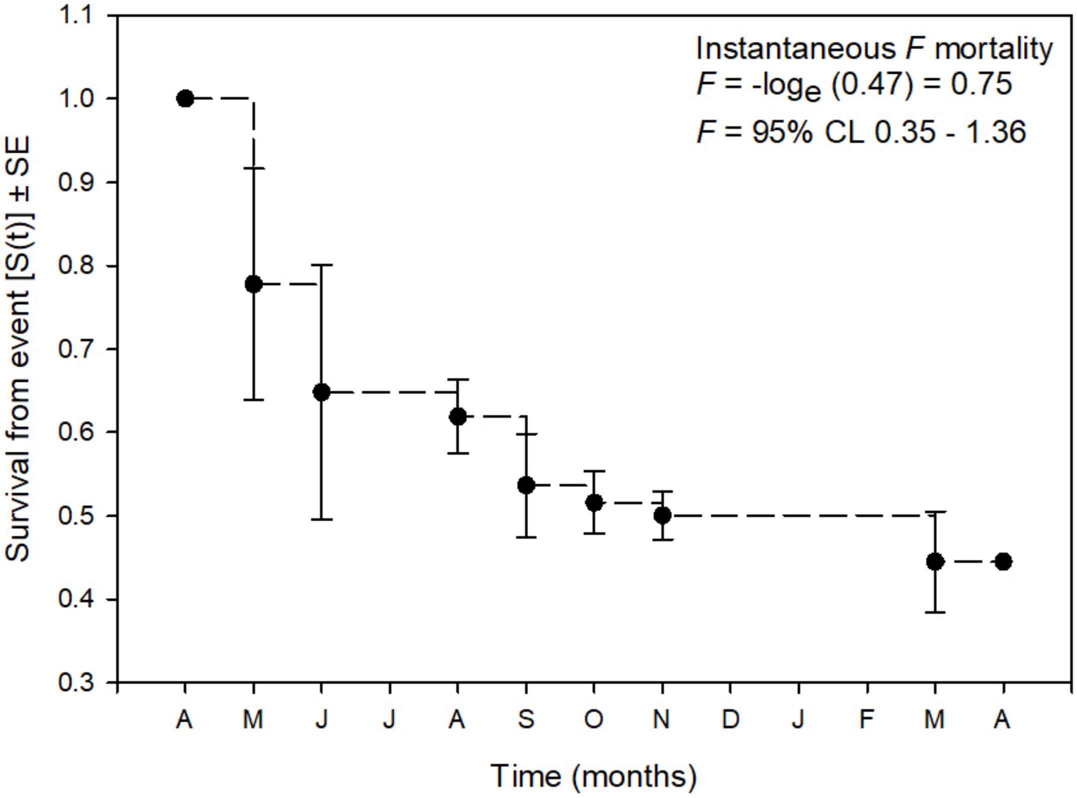


Fig. 12 Red snapper (*Lutjanus campechanus*) survival from fishing mortality on oil and gas platforms in the Gulf of Mexico. Dashed line represents the proportion of fish that survive fishing mortality at the end of each monthly interval. Instantaneous fishing mortality *F* was based on *S* at 12 months. Points and error bars (SE) were estimated for *S* for each month with a fishing mortality

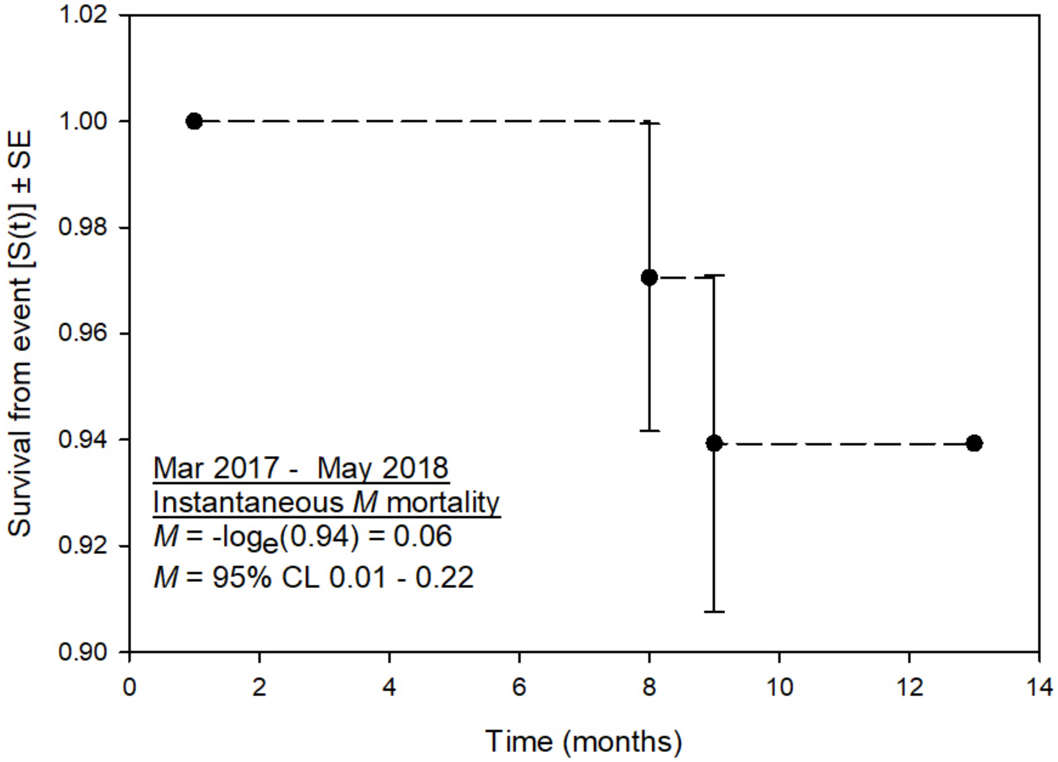


Fig. 13 Instantaneous natural mortality rate (*M*) for red snapper (*Lutjanus campechanus*) on oil and gas platforms in the Gulf of Mexico. Dashed line represents the proportion of fish that survive natural mortality at the end of each monthly interval. Instantaneous natural mortality rates were based on *S* at 12 months. Points and error bars (SE) are estimates of *S* for each month with an event