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ARTICLE

Mortality Estimates for Red Snapper Based on Ultrasonic Telemetry in the Northern Gulf of Mexico

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Abstract
We used the Vemco Positioning System (VPS) to estimate mortalities from the fine-scale movements (~1-m accuracy) of Red Snapper *Lutjanus campechanus* on four artificial reef sites in the northern Gulf of Mexico in 2012, 2013, and 2014. Additional receivers on surrounding reef sites validated emigrations of tagged Red Snapper from the VPS-monitored sites. We tagged and released 86 Red Snapper and tracked 59 fish for extended periods (17 to 1,096 d). Telemetry tracking patterns identified fish status as active, emigrated, caught (*F*), or dead (*M*) at monthly intervals. At the end of the study, 17 fish had emigrated, 24 were caught by fishers, and 18 were active on VPS-monitored reef sites. For all years combined, annual fishing mortality was $F = 0.44$ (0.27–0.65, 95% confidence limit). In 2012, $F = 0.72$ (0.35–1.31) and was higher than other years, but the number of fish available for recapture at the start of the sportfishing season was low ($n = 15$). In 2013, $F = 0.18$ (0.07–0.42; $n = 30$), and in 2014, $F = 0.42$ (0.22–0.76; $n = 28$). One natural mortality (*M*) was detected in 2012, and $M = 0.12$ (0.02–0.69); no subsequent natural mortalities were detected in 2013 and 2014 ($M = 0$). Total instantaneous mortality (*Z*) for all years was $Z = 0.48$ (0.30–0.70). We attributed the low *M* to high fishing mortality but caution that sample sizes were small, which is typical of telemetry studies. The fates of 58 (98%) transmitter-tagged Red Snapper were successfully identified based on the VPS technology. Increases in *F* from 0.18 (2013) to 0.42 (2014) occurred when the length of the fishing season was decreased (42 to 9 d) and indicated that fishers increased effort during the shortened fishing season, and the management goal of reducing catch may not have been achieved.

Red Snapper *Lutjanus campechanus* is one of the most important sport and commercial species in the northern Gulf of Mexico, and the stock is considered overfished (SEDAR 2013; Cass-Calay et al. 2015). The Gulf of Mexico Fishery Management Council and National Oceanic and Atmospheric Administration (NOAA) Fisheries are responsible for managing and setting harvest limits to ensure sustainable fisheries. Critical to these management plans are accurate measures of mortality, and perhaps more important is the separation of total mortality (*Z*) into its component parts of fishing mortality (*F*) and natural mortality (*M*). Prior to telemetry-based methods, partitioning total mortality into *F* and *M* required several assumptions, and previous *M*-estimates were indirectly calculated. With the advent of telemetry-based methods, direct empirically derived estimates became obtainable (Hightower et al. 2001; Topping and Szedlmayer 2013).

In mark–recapture studies, *F* was commonly based on the number of tagged fish that were caught and reported by fishers (Pine et al. 2013). However, there were usually difficulties with nonreporting and tag shedding. Fishing mortality was then subtracted from total mortality (e.g., estimated from age frequency distributions) to estimate *M*. Estimates of Red Snapper *M* were also derived theoretically from a combination of life history characters and environmental measures, and varied from $M = 0.10$ to 0.36 (Topping and Szedlmayer 2013). Present management plans for Red Snapper use $M = 0.10$ (SEDAR 2013).

Telemetry systems have allowed for direct estimates of *M* in both freshwater and marine fish species (Hightower et al. 2001; Heupel and Simpfendorfer 2002; Pollock et al. 2004; Starr et al. 2005; Melnychuk et al. 2007; Karam et al. 2008; Topping and Szedlmayer 2013). Topping and Szedlmayer (2013) used an array

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of overlapping receivers and tag detection frequencies to directly estimate *M* (stationary transmitters) and *F* (independent of fisher returns) for Red Snapper. Estimated mortalities were $M = 0.11$ (range = 0.06–0.20) and $F = 0.27$ (range = 0.11–0.54), and showed an increase in *M* and a decrease in *F* that followed reductions in total allowable catch (TAC; Topping and Szedlmayer 2013).

In the present study, we estimated natural, fishing, and total Red Snapper mortality independent of fishers using a new fish positioning system (Vemco Positioning System [VPS]; Vemco, Nova Scotia). The VPS technology offers major advantages over traditional overlapping receiver arrays where fish positions were typically plus or minus hundreds of meters, compared with this new VPS approach with a fish position accuracy around 1 m (Piraino and Szedlmayer 2014). This new VPS technology also provides unprecedented frequencies of detections, about every 5 min, continuously for long periods (only limited by 6- to 10-year battery life of transmitters).

METHODS

*Study sites.—*The study area was in the Hugh Swingle General Permit Area located approximately 20–50 km south of Dauphin Island, Alabama, in the northeast Gulf of Mexico. The study sites ($n = 26$) consisted of steel-cage artificial reefs (2.5 × 1.3 × 2.4 m) deployed from 2006 to 2010 at unpublished locations (Figure 1). We selected unpublished or "private" reef locations to provide a more accurate estimate of mortality because there are far more private reef sites (87.3%) than public reef sites (12.6%; S. T. Szedlmayer and P. A. Mudrak, Auburn University, unpublished). Distances between steel cages ranged from 1.4 to 1.6 km, and water depth ranged from 20 to 35 m (Figure 1). Four VPS-monitored sites were among these reefs for estimating fine-scale movements, while 22 surrounding sites were for estimating larger-scale presence and absence data (Figure 1).

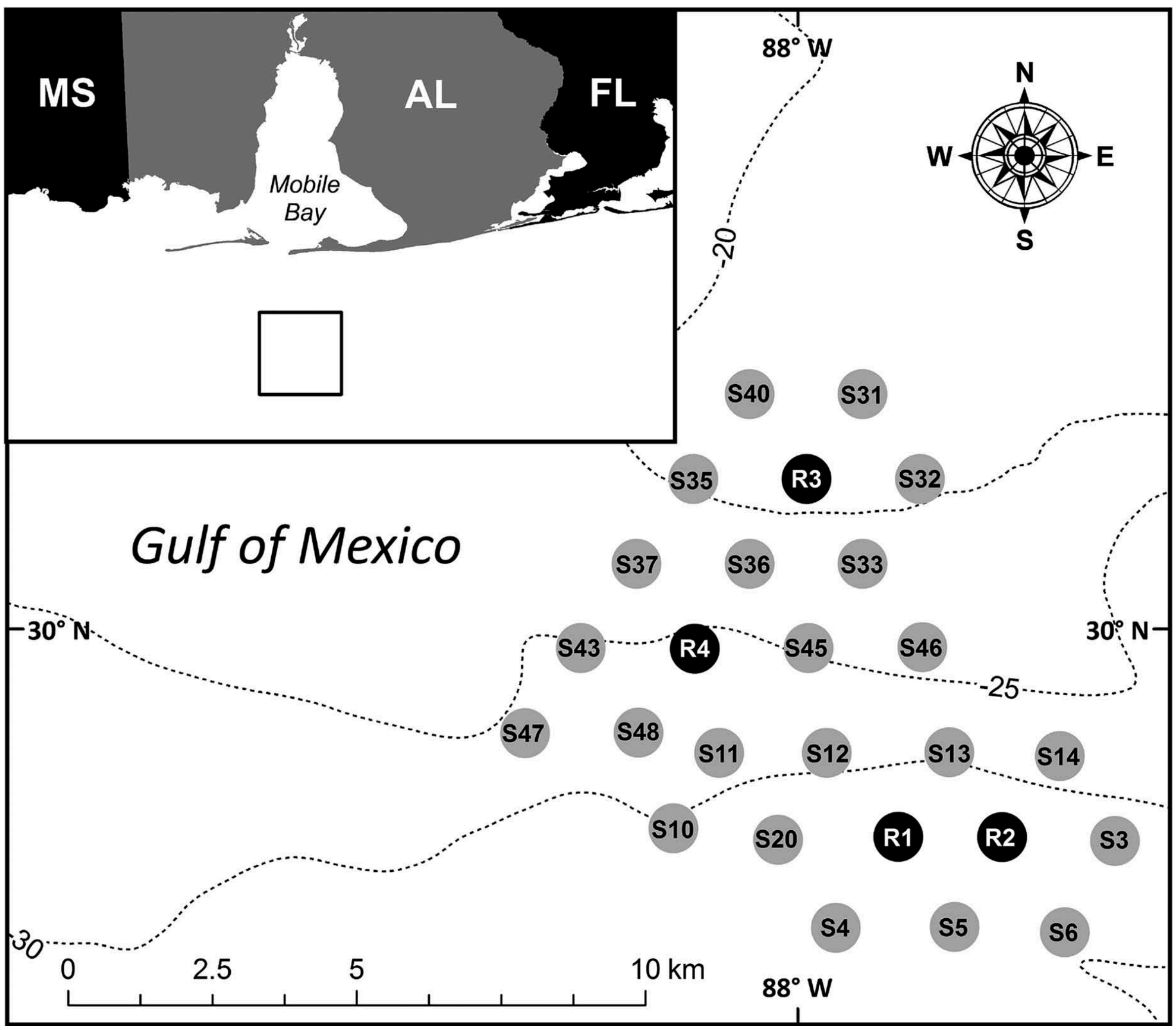

FIGURE 1. Locations of steel-cage artificial reef study sites for tracking the movements of Red Snapper in the northern Gulf of Mexico. Black circles ($n = 4$) were fish release sites (R1, R2, R3, and R4) with VPS receiver arrays. Gray circles ($n = 22$) were surrounding sites with single receivers (S3–S48, numbering not continuous) that validate emigration and mortality events. Dotted lines are depth contours (5 m).

Fish tagging and release.—Fish tagging procedures followed previous Red Snapper tagging methods described by Topping and Szedlmayer (2011a, 2011b, 2013) and Piraino and Szedlmayer (2014). All tagged Red Snapper in the present tagging study were susceptible to both commercial and sport fisheries because all released fish were greater than the 2012–2014 commercial (>330 mm TL) and sport (>406 mm TL) federal minimum size limits. Fish were caught by hook and line (8/0 circle hook baited with Gulf Menhaden *Brevoortia patronus*) and immediately anesthetized with MS-222 (150 mg tricaine methanesulfonate/L seawater for 2–3 min) in a 70-L seawater tank. Each fish was weighed (kg), measured (mm SL, FL, TL), and tagged internally with a unique acoustic transmitter (Vemco V16-6x-R64k, transmission delays = 20–69 s). The transmitter was surgically implanted into the peritoneal cavity through a small vertical incision (20 mm) above the ventral midline. The incision site was sealed with absorbable, sterile, plain gut surgical sutures (Ethicon 2-0, metric 3). Each fish was externally tagged for visual identification by scuba divers and fishers, with a unique anchor tag (Floy tag; Floy Tag, Seattle). Tagged Red Snapper were observed in a 185-L seawater recovery tank on the research vessel until they showed active opercula pumping and fin movements (~2 min).

All Red Snapper were returned to depth in a predator protection cage within 10 m of the artificial reef site of capture. The specific type of release cage was different among study years. For the first release method, we used a closed circular cage (height = 40.6 cm, diameter = 60 cm) made of vinyl-coated 12.5-gauge wire mesh (Piraino and Szedlmayer 2014). Transmitter-tagged fish were held in the cage at depth for a minimum of 1 h before scuba divers visually inspected fish condition. Only tagged fish in "acceptable" condition were released by manually opening a cage door. Tagged fish were considered acceptable for release if they were observed oriented in an upright position, swimming, and responding to diver presence (e.g., swimming against the cage trying to escape from divers), while fish were considered unacceptable for release if they were observed lying on their side and not responding to divers. This scuba diver release method was discontinued after divers had increasing encounters with larger (≥2 m) Sandbar Shark *Carcharhinus plumbeus* and Bull Shark *C. leucas*.

We modified our release method beginning in November 2012. Red Snapper were released through the use of a remotely opening rectangular cage (46 × 61 × 61 cm) made with vinyl-coated 16-gauge wire mesh (Williams et al. 2015). Tagged fish were placed into the cage at the surface, and the door was closed. The cage remained closed during descent but automatically opened when the cage reached the seafloor. The cage protected tagged fish from predators in the water column and at depth until fish exited the cage on their own initiative. The release cage was retrieved after a minimum of 15 min. If a tagged fish did not exit the cage and was brought back to the surface, it was considered to be in poor condition and was not released.

Long-term position monitoring.—We measured fine-scale movements of tagged Red Snapper from January 2012 to December 2014 following a 6-d recovery period using the VPS. For each VPS-monitored site, five Vemco VR2W receivers were positioned as described by Piraino and Szedlmayer (2014): a central receiver was positioned 20 m north of the artificial reef, and four additional receivers were placed 300 m to the north, south, east, and west of the central receiver (Figure 2). The receivers were attached to an anchor line ~4.5 m above the seafloor. A synchronization transmitter was attached 1 m above each receiver to calibrate receiver timing (sync tags; Vemco V16-6x, 69 kHz, transmission delays = 540–720 s), and a float was attached 1 m above each sync tag. The arrangement of receivers at 300 m from the center reef site allowed for transmitter-tagged fish to be simultaneously detected by at least three receivers at all times within the VPS array because the maximum distance from any receiver was 424 m (i.e., transmitter signals were detected 100% of the time at 400 m; Piraino and Szedlmayer 2014). Highly accurate (~1 m) fish positions were calculated based on a time differential of signal arrival at three or more receivers (Vemco data postprocessing). Stationary control transmitters with known locations were attached to anchors within the receiver arrays to determine the accuracy of VPS-calculated positions.

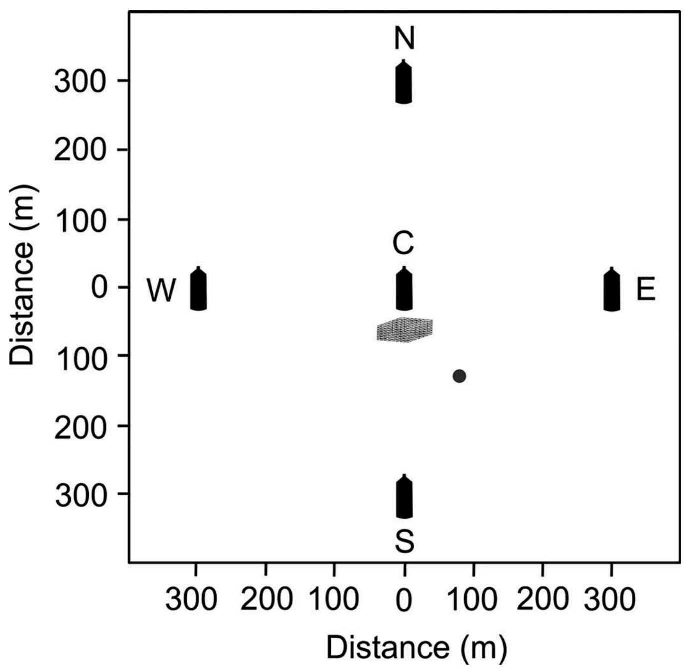

FIGURE 2. Receiver array (VPS) used to examine the fine-scale movements and mortality of Red Snapper around artificial reefs in the northern Gulf of Mexico. The center (C) receiver was positioned 20 m north of the steel-cage artificial reef. Additional receivers were placed 300 m north (N), east (E), south (S), and west (W) of the center receiver. A control transmitter was positioned within each array (direction and distance varied by site) for accuracy estimations. Black receiver icons = VEMCO VR2W receivers and synchronization transmitters; gray square = steel-cage artificial reef; gray circle = control transmitter.

The status of a tagged fish was based on VPS positions and time intervals among positions following a 6-d tagging recovery period. Movements of fish from the VPS-monitored arrays within the first 6 d (n = 27) were considered tagging stress behaviors (Topping and Szedlmayer 2011b, 2013) and were removed from further analyses. After 6 d, each fish was either classified as “active” (detections showing frequent movements around the reef) or having undergone an event. Events included “emigration” (sequential detections away from the reef), “fishing mortality” (abrupt disappearance of detections around the reef), and “natural mortality” (stationary detections or irregular large-scale movement patterns). We used surrounding site receivers (n = 22) for additional validation of emigrations detected by the VPS analysis. Fish that emigrated were frequently detected on nearby surrounding sites, while VPS identification of fishing mortality and natural mortality would lack detections on surrounding sites. Fishing mortalities were also confirmed by fisher returns. To increase the probability of fisher returns, a high reward (US$150) was offered and posted at local marinas and marine supply and bait shops, and an easily accessible Web site was created to reach larger audiences. It was assumed that fish within the VPS-monitored arrays experienced similar fates (i.e., mortality rates) to Red Snapper outside of the VPS arrays (Topping and Szedlmayer 2013).

Validating detection data.—Telemetry receivers can generate false detections that are not valid transmitter-tagged fish (Pincock 2012). False detections can result from incomplete transmission due to interference (i.e., noise) or the collision of signals from two or more transmitters that simultaneously reach a receiver (Pincock 2012). False detections that produced unknown tags were removed from analysis. Transmitter detections of known tags were further screened before acceptance as a valid tagged fish presence. Transmitter detections were accepted as valid fish presence if there was at least one short interval between detections and more short intervals than long intervals. In the present study, the short interval time was set at 23 min (30 times the average transmitter delay: 20–69 s, mean = 45 s), and the long interval was set at 9 h (720 times the mean = 45-s transmitter delay; Pincock 2012).

Estimates of survival and mortality.—A known fate model was applied in the MARK program to estimate conditional survivals, total survivals, SE, and 95% confidence limits (CLs; Topping and Szedlmayer 2013). Annual estimates were based on monthly time intervals (January to December) for each year (2012, 2013, and 2014). The MARK program calculated survival estimates based on the maximum likelihood binomial (MLE; Edwards 1992), expressed as

$$\mathcal{L}(\theta|n_i, y_i) = \prod_{i=1}^{t} S_i^{yi}(1 - S_i)^{(n_i - y_i)}$$

This equation describes the survival model for the monthly time interval (θ), the number of individuals active during each interval (n_i), the number surviving each interval (y_i), and the MLE of survival during each interval (S_i). In this model, survival was estimated from conditional probabilities of surviving specified events (i.e., emigration or mortality). For example, the probability of surviving a mortality event (i) was determined by calculating the number of individuals at risk of dying (n_i) and the number of individuals that survived (y_i) for that time interval (t). Fish that emigrated or suffered a mortality not under consideration were removed (i.e., the data were right censored). For example, when M was estimated, all emigrations and fishing (F) mortalities were removed.

Instantaneous annual (12 month) mortality rates were based on total survival after 36 months (study period) adjusted to 12 months, i.e., annual S = total $S^{(12/36)}$ for each mortality type. For example, annual $F = -\log_e S^{(12/36)}$ from fishing mortality, annual $M = -\log_e S^{(12/36)}$ from natural mortality, and annual $Z = -\log_e S^{(12/36)}$ from all mortality (Starr et al. 2005). Confidence limits for instantaneous mortality rates were calculated from the 95% CLs estimated from the MLE of the survival functions at 1 year (12 months; Klein and Moeschberger 2003; Topping and Szedlmayer 2013). The reported sample sizes for the mortality estimates were the number of fish available for recapture on the opening day of the sportfishing season for each year.

RESULTS

The fine-scale movements of Red Snapper were continuously recorded at four different VPS-monitored sites (Figure 1) for 36 months (January 2012 to December 2014). All transmitter-tagged Red Snapper were greater than the Gulf of Mexico federal recreational length minimum, 406 mm TL, with a mean size = 592 mm TL and a range of 454 to 877 mm TL. We tagged and released 86 Red Snapper, and after allowing for an initial 6-d tagging recovery period, 59 fish survived and were tracked for extended periods (17 to 1,096 d), with most (98%) fish tracked for more than 30 d.

Fish status was determined (active, emigrated, mortality) by the VPS technology for all fish (n = 59) that remained after the 6-d tag recovery period. At the end of this study, 18 fish were still being tracked (active) on the VPS-monitored reef sites (Figure 3). Emigrations (n = 17) from VPS-monitored sites occurred from 17 to 978 d after release, and all occurred outside of the federal sportfishing season during the winter, spring, and fall months. Total fish susceptible to emigrations were similar among years (n = 37 in 2012, n = 36 in 2013, and n = 32 in 2014). Three fish emigrated in 2012, nine fish in 2013, and five fish in 2014. Four Red Snapper were residents at their VPS-monitored release sites for long periods (240–978 d), then emigrated and remained away for 90–344 d, and then returned to their release site. These fish were classified as active when on their release site and as emigrations (right-censored) when they were away from their release site.

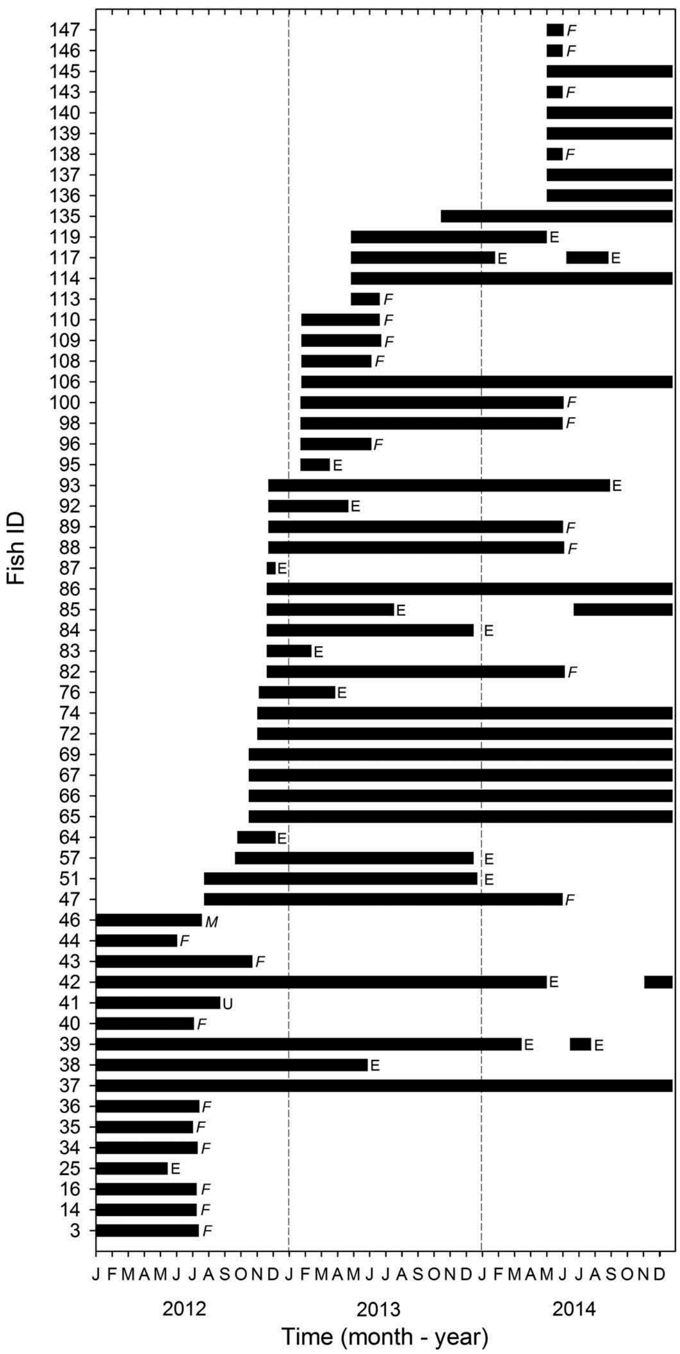

FIGURE 3. Tracking time for transmitter-tagged Red Snapper (n = 59) on VPS-monitored release sites in the northeast Gulf of Mexico. All fish present after the last month of tracking (December 2014) were active, and vertical lines separate different study years. Black bars = active on VPS site; letters denote fate for fish on VPS site: E = emigration, F = fishing mortality, M = natural mortality, and U = unknown.

Fishing mortality occurred in 24 transmitter-tagged Red Snapper. All F-mortalities were identified by VPS position patterns, but many (n = 15) were also verified by fisher reported recaptures. Total survival from all fishing mortality over the 36-month study period was S_F = 0.26 (0.14–0.44, 95% CL); adjusted to annual survival $S_F{}^{(12/36)} = 0.26^{(12/36)}$ = 0.64, and thus annual $F = -\log_e 0.64$ = 0.44 (0.27–0.65; Table 1).

Fishing mortality rates varied across years on the VPS-monitored sites. In 2012, S_F = 0.48 (0.27–0.70) with F = 0.72 (0.35–1.31) and was higher than other years, with nine fisher mortalities among the 15 tagged Red Snapper available for recapture on opening day (June 1). Fishers reported five recaptures, while four additional recaptures were identified from the VPS analysis (56% fisher reporting rate). In 2013, 30 fish were available for recapture on opening day (June 1), and we observed a lower fishing mortality with S_F = 0.83 (0.66–0.93) and F = 0.18 (0.07–0.42; Table 1). Fishers reported three recaptures, while two additional recaptures were identified from the VPS analysis (60% fisher reporting rate). In 2014, a similar number of Red Snapper (n = 28) were available for recapture on opening day (June 1) and fishing mortality increased, with S_F = 0.66 (0.47–0.80) and F = 0.42 (0.22–0.76; Figure 4; Table 1). Fishers reported seven recaptures, while three additional recaptures were identified from the VPS analysis (70% fisher reporting rate).

One natural mortality was observed in 2012, with S_M = 0.89 (0.50–0.98) and M = 0.12 (0.02–0.69). The VPS analysis showed that fish 46 disappeared close to the center of the tagging site (R3) on July 20, 2012. However, the transmitter was subsequently detected more than 800 times on multiple VPS-monitored sites and surrounding reef sites (R1, R3, S12, and S13). Some of the detections were validated after we applied the false-detection screening criteria. This detection pattern was unique and did not match any other observed Red Snapper fine-scale or large-scale movement patterns (based on >5 million fish positions) in the present study. The high number of erratic detections over wide areas was most likely caused by the movements of a larger predator that had preyed upon the tagged Red Snapper. However, the long duration of erratic detections (>2 years) is difficult to explain, as a consumed transmitter within the gut cavity of a larger predator would likely be expelled after a short period. We speculate that the transmitter somehow became trapped within the predator, perhaps in the spiral valve of a shark predator. No other natural mortalities were observed. For all years (2012–2014), M = 0.04 (0.01–0.23), F = 0.44 (0.27–0.65), and total Z ($F + M$) = 0.48 (0.30–0.70; Table 1).

The fate of one fish in this study was undetermined after extensive tracking (~1 year). The fate of fish 41 was unknown because receivers were removed from VPS-monitored reef sites due to an impending tropical storm. When the receivers were reinstalled after a 16-d absence (August 24 to September 10, 2012), this fish was no longer present. This fish was considered active until August 24, 2012, and then was right censored from subsequent survival analyses.

To test the effectiveness of the false detection screening, the criteria was first applied to all transmitter-tagged fish that showed a VPS-identified fishing mortality and whose

TABLE 1. Red Snapper instantaneous annual mortality rates (Z = total mortality, F = fishing mortality, M = natural mortality) estimated from VPS telemetry by the known fate model in the MARK program. Mortality was estimated for each year (2012, 2013, and 2014), and for all years (3 years). Values in parentheses are 95% CLs. The numbers of fish (n) were the numbers of tagged fish available for recapture at the opening of the federal sportfishing season, and days were the season durations for each year.

Year(s)	n	Z	F	M	Days
2012	15	0.84 (0.42–1.47)	0.72 (0.35–1.31)	0.12 (0.02–0.69)	46
2013	30	0.18 (0.07–0.42)	0.18 (0.07–0.42)	0	42
2014	28	0.42 (0.22–0.76)	0.42 (0.22–0.76)	0	9
All years	59	0.48 (0.30–0.70)	0.44 (0.27–0.65)	0.04 (0.01–0.23)	97

transmitters were returned by fishers. The number of false detections from the 11 transmitters that were returned and turned off varied (0 to 63; Table 2). The highest number of false detections was from a fish caught during the 2014 fishing season (false detections for 5 months after recapture). We applied the false detection screening criteria to the 11 returned transmitters for any detections after capture date, and all subsequent detections were identified as false detections. The false detection criteria was then applied to all postcapture detections of mortalities without returned transmitters (fisher-reported but not returned and VPS-identified mortalities), and all were correctly identified as false detections (Table 2).

DISCUSSION

The VPS telemetry arrays enabled continuous highly accurate (1 m accuracy; Piraino and Szedlmayer 2014) tracking of Red Snapper on artificial reef sites for 3 years. We were able to estimate mortalities independent of fisher returns because the fate of tagged Red Snapper was known within the VPS-monitored arrays (Hightower et al. 2001; Heupel and Simpfendorfer 2002; Bacheler et al. 2009; Topping and Szedlmayer 2013). The present annual estimate of F = 0.44 was higher than the suggested maximum fishing mortality rate (F_{MAX} = 0.094) used in the 2013 stock assessment models (SEDAR 2013). In addition, the present study estimate of F was higher than a previous telemetry-derived estimate of F = 0.27 (Topping and Szedlmayer 2013) and the stock assessment estimate for hook and line in the eastern Gulf of Mexico of F = 0.15 for 2007–2011 (SEDAR 2013). The present estimate of F does fall within the range of F = 0.29–0.47 from the 1999 stock assessment (Schirripa and Legault 1999).

Compared with previous studies, the higher F-estimates from the present study occurred during the shortest federal sportfishing season to date. The sportfishing seasons decreased from 46 d in 2012, to 42 d in 2013, to 9 d in 2014 due to fishers exceeding catch quotas during previous years (NMFS 2014). In the present study, most fishing mortalities (96%) occurred during these shortened sportfishing seasons. In 2012, we observed the highest fishing mortality (F = 0.72), but there was little change in sportfishing season between 2012 (46 d) and 2013 (42 d). We suggest that 2013 and 2014 likely provided more accurate mortality estimates due to larger sample sizes. Topping and Szedlmayer (2013) reported that F-rates decreased as sportfishing season and bag limits decreased. For example, in 2006, F = 0.62 (n = 26) with a 194-d season and four-fish bag limit; in 2007, F = 0.22 (n = 51) with a 194-d season and two-fish bag limit; and in 2008, F = 0.14 (n = 41) with a 65-d season and two-fish bag limit (Topping and Szedlmayer 2013). In the present study, bag limits remained the same while, surprisingly, F increased from 0.18 (2013) to 0.42 (2014) when the sportfishing season was reduced by 78%. In addition, F-estimates in the present study from 2013 and 2014 with shorter sportfishing seasons (42 and 9 d, respectively) were similar or higher than previous F-estimates in 2007 and 2008 with longer sportfishing seasons (194 and 56 d, respectively; Topping and Szedlmayer 2013). In the present study, the increase in F despite severe reductions in fishing seasons suggested that fishers concentrated their effort and total catch may not have been reduced. Thus, the present study supports stock assessments and management efforts that have reduced Red Snapper fishing seasons, even with the increase in TAC to 14.3 million lbs (SEDAR 2013; NMFS 2014, 2015). However, F may vary by region and reef type (i.e., artificial, natural, private, public), and this variation should be considered in future studies and management efforts.

In several previous studies, increased fishing mortality has been associated with fish species that congregate at "known" locations (e.g., family Gadidae, Salmonidae; Roughgarden and Smith 1996; Hutchings 2000; Worm et al. 2009). Similarly, the association of Red Snapper with known locations of artificial reefs may have contributed to increased fishing mortality. At the same time, long-term (>1 year) telemetry studies in the study area have shown high site fidelity for Red Snapper (>72%/year; Szedlmayer 1997; Szedlmayer and Schroepfer 2005; Topping and Szedlmayer 2011a, 2011b; Piraino and Szedlmayer 2014). We suggest that such high site fidelity may have partially resulted from high fishing mortality (F = 0.27, Topping and Szedlmayer 2013; F = 0.44, in the present study). We surmise that as fish are removed by fishers, competition is reduced and the remaining fish are more likely to stay. Thus, the association of Red Snapper with artificial reefs may lead to overfishing because once a reef is located with abundant Red Snapper, fishers can continue harvest until most resident fish are captured.

Fishing mortality most likely varies on reefs with unpublished (private) versus published (public) locations. Higher

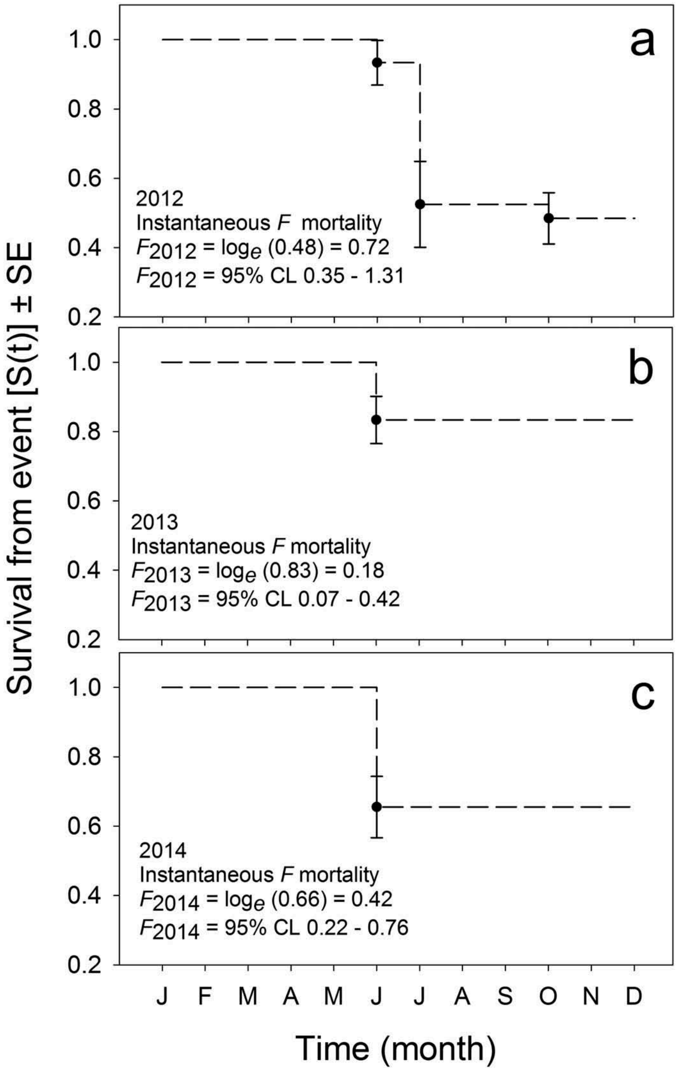

FIGURE 4. Survival (S) of Red Snapper from fishing mortality for years **(a)** 2012, **(b)** 2013, and **(c)** 2014. Dashed line shows proportion of fish surviving fishing mortality after each monthly interval. Instantaneous fishing mortality rates (F) were calculated from S at 12 months. Points and error bars (SE) were conditional estimates of S for time intervals with an event.

fishing pressure would typically be expected on reef sites with publically known locations than on reef sites with unpublished coordinates (Jaxion-Harm and Szedlmayer 2015). Jaxion-Harm and Szedlmayer (2015) measured Red Snapper density on smaller unpublished reef sites (e.g., steel cages and pyramids) and published reef sites of all sizes (e.g., pyramids, army tanks, barges), and showed that legal-sized Red Snapper were abundant on all reef types, but the greatest percentage of larger Red Snapper (>650 mm TL) were observed on unpublished reef sites. In the present study, the selected unpublished reef sites likely reflect a reduced fishing effort compared with published reef sites simply because they are more difficult to locate; thus, present estimates would likely be conservative and less than overall fishing mortality in the region.

One natural mortality was observed during this study in 2012 (with M = 0.04 for all years 2012–2014). Topping and Szedlmayer (2013) estimated M = 0.11 from 2006 to 2008 but varied by year: M = 0 (2006), M = 0.19 (2007), and M = 0.21 (2008). We suggest that the low M-estimate in the present study was most likely related to the combined effects of high fishing mortality and that we tagged relatively young fish (4 to 10 years) compared with the maximum life expectancy (>40 years; Szedlmayer and Shipp 1994; Wilson and Nieland 2001). The long-term (3 year) estimate of M = 0.04 (0.01–0.23) in the present study supports the use of low M = 0.1, which has been applied in the most recent Red Snapper stock assessment (SEDAR 2013).

Estimated fisher recapture reporting rates have historically been indirectly calculated based on a combination of secretly planted tags, fisher or port surveys, catch information, or the use of multiple tags (Pollock et al. 2001; Pine et al. 2003). In multiple tag studies, high-reward tags were assumed to be 100% reported, and the relative difference between the standard tag reporting and the high-reward reporting was considered the “actual” reporting rate (Pollock et al. 2001; Bacheler et al. 2009; Hightower and Pollock 2013). In the present study, the 63% (15 out of 24) reporting rate of high-reward tags indicates that assuming a 100% reporting rate for high-reward tags may cause underestimates in F (Pollock et al. 2001; Pine et al. 2003). The fisher reporting rate in the present study (63%) falls within the upper range of fisher reporting rates that were directly estimated by previous telemetry studies (17%, Hightower et al. 2001; 89%, Topping and Szedlmayer 2013). A great advantage of telemetry studies is that they can provide fisher-independent F- and M-estimates, but fisher-reported recaptures are still important in validating the telemetry-based estimates (Hightower and Pollock 2013; Topping and Szedlmayer 2013). In addition, fisher returns can provide a unique opportunity to understand fisher behavior (Pine et al. 2003) and generate species-specific tag reporting rates. The 63% reporting rate in the present study was low compared with the 89% reporting rate from a previous study (Topping and Szedlmayer 2013) and may be attributed to many factors, including tag shedding, unintentional noncompliance, or intentional nonreporting due to disagreement over present management restrictions.

Similar to Pincock (2012), there were false detections recorded on receivers that were removed from analyses based on a screening criteria developed in the present study. Pincock (2012) estimated that 10 to 15 transmitters with an average transmission delay of 60 s in a fixed area would generate a false detection every 5 to 7 h. In the present VPS study, false detections on single receivers were not important because in postprocessing analyses, we needed at least three simultaneous receiver detections to triangulate the position of a transmitter-tagged fish. However, false detections can be problematic on single receivers outside the VPS-monitored array. Such false detections may interfere with the correct identification of mortality and emigration events, for example,

TABLE 2. False transmitter detections on Vemco VR2W receivers after transmitter removal due to fishing mortality. Fish number = unique fish number that is comparable to Piraino and Szedlmayer (2014); transmitter status: active = transmitter was in the field or not returned by fisher, off = transmitter was returned by a fisher and turned off; mortality event: *F* = mortality reported by fishers, VPS = mortality identified by VPS data; event date = date of mortality; false detection = the number of false detections postmortality; VPS site = the reef site of capture; false site(s) = sites where the false detections were observed.

Fish number	Transmitter status	Mortality event	Event date	False detection	VPS site	False site(s)
F44	Active	VPS	Jun 3, 2012	13	R2	R1
F35	Off	F	Jul 3, 2012	6	R3	R1, R3
F40	Off	F	Jul 5, 2012	4	R3	R1
F14	Off	F	Jul 10, 2012	0	R1	
F16	Off	F	Jul 10, 2012	0	R1	
F34	Off	F	Jul 12, 2012	6	R3	R1, R3
F3	Active	VPS	Jul 14, 2012	0	R1	
F36	Active	VPS	Jul 15, 2012	12	R3	R1, R3
F43	Active	VPS	Oct 24, 2012	3	R2	R1, R3
F96	Off	F	Jun 7, 2013	3	R2	R2
F108	Active	VPS	Jun 7, 2013	28	R2	R1, R2
F113	Off	F	Jun 23, 2013	27	R3	R2, R3
F110	Active	VPS	Jun 23, 2013	15	R2	R2, S14
F109	Off	F	Jun 26, 2013	7	R2	R2, R3
F47	Off	F	Jun 5, 2014	0	R3	
F146	Active	F	Jun 5, 2014	1	R2	R3
F138	Active	F	Jun 5, 2014	4	R3	R3
F143	Active	VPS	Jun 5, 2014	0	R2	
F89	Active	F	Jun 6, 2014	0	R1	
F147	Active	F	Jun 7, 2014	0	R1	
F100	Active	VPS	Jun 7, 2014	6	R1	S11
F88	Off	F	Jun 8, 2014	63	R1	R2, R3
F82	Off	F	Jun 9, 2014	0	R3	

a tagged fish that was identified as a fishing mortality from VPS analyses but subsequently shows up on an outside receiver at a later date. Clearly, as we have accomplished in the present study, it is important to correctly identify these postevent false detections and remove them from analyses.

In the present study, we successfully used VPS telemetry to identify the fates of 98% of transmitter-tagged Red Snapper on four artificial reefs independent of fisher returns. The present estimate of low *M* can be attributed to the young ages of the fish tagged compared with their long life expectancy, and also the high fishing mortality rate as fishers have become extremely efficient at catching Red Snapper in our study area. Direct estimates of mortality showed that fishing mortality was high in all study years. Increases in *F* from 0.18 to 0.42 (2013 to 2014) when the sportfishing season was decreased from 42 to 9 d was unexpected and indicated that fishers increased effort such that total catch may not have been reduced despite the shortened fishing seasons. The high site fidelity of Red Snapper with particular artificial reefs in known areas likely contributed to increased fishing mortality. Overall, the present telemetry-based Red Snapper mortality estimates on artificial reefs in the northeast Gulf of Mexico support the present management restrictions of short fishing seasons; however, fisher success and effort likely varies by region and reef type, and such aspects of fishing mortality need further examination.

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REFERENCES

Bacheler, N. M., J. A. Buckel, J. E. Hightower, L. M. Paramore, and K. H. Pollock. 2009. A combined telemetry-tag return approach to estimate fishing and natural mortality rates of an estuarine fish. Canadian Journal of Fisheries and Aquatic Sciences 66:1230–1244.

Cass-Calay, S. L., C. E. Porch, D. R. Goethel, M. W. Smith, V. Matter, and K. J. McCarthy. 2015. Stock assessment of Red Snapper in the Gulf of Mexico 1872–2013–with provisional 2014 landings. NOAA Fisheries, Southeast Fisheries Science Center, SEDAR Red Snapper 2014 update assessment, Miami.

Edwards, A. W. 1992. Likelihood, expanded edition. Johns Hopkins University Press, Baltimore, Maryland.

Heupel, M., and C. Simpfendorfer. 2002. Estimation of mortality of juvenile Blacktip Sharks, *Carcharhinus limbatus*, within a nursery area using telemetry data. Canadian Journal of Fisheries and Aquatic Sciences 59:624–632.

Hightower, J. E., J. R. Jackson, and K. H. Pollock. 2001. Use of telemetry methods to estimate natural and fishing mortality of Striped Bass in Lake Gaston, North Carolina. Transactions of the American Fisheries Society 130:557–567.

Hightower, J. E., and K. H. Pollock. 2013. Tagging methods for estimating population size and mortality rates of inland Striped Bass populations. Pages 249–263 *in* J. S. Bulak, C. C. Coutant, and J. A. Rice, editors. Biology and management of inland Striped Bass and hybrid Striped Bass. American Fisheries Society, Symposium 80, Bethesda, Maryland.

Hutchings, J. A. 2000. Collapse and recovery of marine fishes. Nature 406:882–885.

Jaxion-Harm, J., and S. T. Szedlmayer. 2015. Depth and artificial reef type effects on size and distribution of Red Snapper in the northern Gulf of Mexico. North American Journal of Fisheries Management 35:86–96.

Karam, A., B. Kesner, and P. Marsh. 2008. Acoustic telemetry to assess post-stocking dispersal and mortality of Razorback Sucker *Xyrauchen texanus*. Journal of Fish Biology 73:719–727.

Klein, J., and M. Moeschberger. 2003. Survival analysis: statistical methods for censored and truncated data. Springer-Verlag, New York.

Melnychuk, M. C., D. W. Welch, C. J. Walters, and V. Christensen. 2007. Riverine and early ocean migration and mortality patterns of juvenile steelhead trout (*Oncorhynchus mykiss*) from the Cheakamus River, British Columbia. Hydrobiologia 582:55–65.

NMFS (National Marine Fisheries Service). 2014. NMFS–Emergency action to set Red Snapper accountability measures for the recreational sector of the reef fish fishery, including environmental assessment, and regulatory impact review. NMFS, St. Petersburg, Florida.

NMFS (National Marine Fisheries Service). 2015. NOAA Fisheries announces commercial and recreational quota increases for Red Snapper and the recreational seasons in the Gulf of Mexico. NMFS, Southeast Regional Office, Southeast Fishery Bulletin FB15-032, St. Petersburg, Florida.

Pincock, D. G. 2012. False detections: what they are and how to remove them from detection data. Vemco, Halifax, Nova Scotia.

Pine, W. E., J. E. Hightower, L. G. Coggins, M. V. Lauretta, and K. H. Pollock. 2013. Design and analysis of tagging studies. Pages 521–572 *in* A. V. Zale, D. L. Parrish, T. M. Sutton, editors. Fisheries techniques, 3rd edition. American Fisheries Society, Bethesda, Maryland.

Pine, W. E., K. H. Pollock, J. E. Hightower, T. J. Kwak, and J. A. Rice. 2003. A review of tagging methods for estimating fish population size and components of mortality. Fisheries 28(10):10–23.

Piraino, M. N., and S. T. Szedlmayer. 2014. Fine-scale movements and home ranges of Red Snapper around artificial reefs in the northern Gulf of Mexico. Transactions of the American Fisheries Society 143:988–998.

Pollock, K. H., J. M. Hoenig, W. S. Hearn, and B. Calingaert. 2001. Tag reporting rate estimation: 1. An evaluation of the high-reward tagging method. North American Journal of Fisheries Management 21:521–532.

Pollock, K. H., H. Jiang, and J. E. Hightower. 2004. Combining telemetry and fisheries tagging models to estimate fishing and natural mortality rates. Transactions of the American Fisheries Society 133:639–648.

Roughgarden, J., and F. Smith. 1996. Why fisheries collapse and what to do about it. Proceedings of the National Academy of Sciences of the USA 93:5078–5083.

Schirripa, M., and C. Legault. 1999. Status of the Red Snapper in U.S. waters of the Gulf of Mexico: updated through 1996. National Marine Fisheries Service, Southeast Fisheries Science Center, Sustainable Fisheries Division, Miami.

SEDAR (Southeast Data Assessment and Review). 2013. SEDAR 31: Gulf of Mexico Red Snapper stock assessment report, June 2013. SEDAR, North Charleston, South Carolina.

Starr, R. M., V. O'Connell, S. Ralston, and L. Breaker. 2005. Use of acoustic tags to estimate natural mortality, spillover, and movements of Lingcod (*Ophiodon elongatus*) in a marine reserve. Marine Technology Society Journal 39:19–30.

Szedlmayer, S. T. 1997. Ultrasonic telemetry of Red Snapper, *Lutjanus campechanus*, at artificial reef sites in the northeast Gulf of Mexico. Copeia 1997:846–850.

Szedlmayer, S. T., and R. L. Schroepfer. 2005. Long-term residence of Red Snapper on artificial reefs in the northeastern Gulf of Mexico. Transactions of the American Fisheries Society 134:315–325.

Szedlmayer, S. T., and R. L. Shipp. 1994. Movement and growth of Red Snapper, *Lutjanus campechanus*, from an artificial reef area in the northeastern Gulf of Mexico. Bulletin of Marine Science 55:887–896.

Topping, D. T., and S. T. Szedlmayer. 2011a. Home range and movement patterns of Red Snapper *Lutjanus campechanus* on artificial reefs. Fisheries Research 112:77–84.

Topping, D. T., and S. T. Szedlmayer. 2011b. Site fidelity, residence time and movements of Red Snapper *Lutjanus campechanus* estimated with long-term acoustic monitoring. Marine Ecology Progress Series 437:183–200.

Topping, D. T., and S. T. Szedlmayer. 2013. Use of ultrasonic telemetry to estimate natural and fishing mortality of Red Snapper. Transactions of the American Fisheries Society 142:1090–1100.

Williams, L. J., J. L. Herbig, and S. T. Szedlmayer. 2015. A cage release method to improve fish tagging studies. Fisheries Research 172:125–129.

Wilson, C. A., and D. Nieland. 2001. Age and growth of Red Snapper, *Lutjanus campechanus*, from the northern Gulf of Mexico off Louisiana. U.S. National Marine Fisheries Service Fishery Bulletin 99:653–664.

Worm, B., R. Hilborn, J. K. Baum, T. A. Branch, J. S. Collie, C. Costello, M. J. Fogarty, E. A. Fulton, J. A. Hutchings, J. Simon, O. P. Jensen, H. K. Lotze, P. M. Mace, T. R. McClanahan, C. Minto, S. R. Palumbi, A. M. Parma, D. Ricard, A. A. Rosenberg, R. Watson, D. Zeller. 2009. Rebuilding global fisheries. Science 325:578–585.