



Abstract—Gray triggerfish (*Balistes capriscus*) is a common resident of reef habitats in the northern Gulf of Mexico. It is targeted by fishermen and recently considered not overfished. However, stock status is highly dependent on indirect mortality estimates from sport and commercial fishery landings that may have errors. To enhance management efforts, we used acoustic telemetry to directly estimate fishing mortality (F), natural mortality (M), and total mortality (Z) for gray triggerfish on artificial reefs in the northern Gulf of Mexico. Over the study period, 30 fish emigrated, 4 fish were caught by fishermen, 4 fish died of natural causes, 8 fish were active when their transmitter battery expired, and 3 fish were still active at the end of the study. Annual F was 0.23 (95% confidence interval [CI]: 0.07–0.50) and was lower than in past stock assessments. This rate indicates that earlier management efforts were successful. However, our F estimate is possibly greater than a recent management goal of 0.17 based on a 30% spawning potential ratio. Therefore, gray triggerfish stocks may still be experiencing overfishing. Annual M was 0.25 (95% CI: 0.07–0.57) and supports the management applied M of 0.28. Annual Z was 0.48 (95% CI: 0.18–0.85), which was not considered sustainable under the most recent stock assessment and supports the management decision to increase fishery restrictions.

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Mortality estimates for gray triggerfish (*Balistes capriscus*) in the northern Gulf of Mexico based on acoustic telemetry

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Gray triggerfish (*Balistes capriscus*) is exploited by sport and commercial fisheries throughout the northern Gulf of Mexico and southeastern United States (SEDAR, 2015). Historically, this species was neither heavily targeted nor considered an important food resource. However, its value has increased in recent years as fishing restrictions on red snapper (*Lutjanus campechanus*) and other important species of reef fish have increased (SEDAR, 2013). This rising interest has also led to increased concern about the status of the stock of gray triggerfish in the Gulf of Mexico.

In 2011, the Gulf of Mexico stock of gray triggerfish was considered overfished and experiencing overfishing (SEDAR, 2011). As a result, the Gulf of Mexico Fishery Management Council reduced the annual catch limit, set a spawning season closure from 1 June through 31 July, a sport bag limit of 2 gray triggerfish per fishermen per day, and a commercial trip limit of 12 gray triggerfish per trip (GMFMC, 2012). A more recent stock assessment in 2015 indicated that the gray triggerfish stock was no longer experiencing overfishing, but the stock was still overfished (SEDAR, 2015). In 2017, a new rebuilding plan for gray triggerfish was developed, and through this plan a less restrictive definition of *overfished*

was adopted and characterized the stock as no longer overfished but still rebuilding (GMFMC, 2017a). The new rebuilding plan further reduced the recreational bag limit to 1 gray triggerfish per fishermen per day, increased the recreational minimum size limit for gray triggerfish to 381 mm fork length (FL) (15 in FL), increased the commercial trip limit for gray triggerfish to 16 fish per trip, and added in an additional seasonal closure from 1 January through 28 February (GMFMC, 2017b). Therefore, questions concerning the stock status of the gray triggerfish remain, reinforcing the need for a new benchmark stock assessment.

Especially important for gray triggerfish stock assessments are estimates of mortality. Prior to the implementation of the fishery management plan for reef fish resources of the Gulf of Mexico in 1984 (GMFMC, 1981), the total mortality (Z) for this stock of gray triggerfish was estimated to range from 0.40 to 0.67 during 1979–1982 (Johnson and Saloman, 1984). More recent estimates based on catch-curve analyses indicate that the mean Z for the period of 1986–2011 was 0.95 (Burton et al., 2015), which exceeds the estimated maximum sustainable Z of 0.45 (with fishing mortality [F] of 0.17, based on a 30% spawning potential ratio, and

natural mortality [M] of 0.28; i.e., $Z=F+M$) determined from the 2015 stock assessment (SEDAR, 2015). From this 2015 assessment, the estimated F for 2013 was 0.12, but previous estimates indicate that F exceeded sustainable levels and ranged from 0.35 to 0.67 in that year (SEDAR, 2011; Burton et al., 2015). Estimates of M have been relatively constant over time, ranging from 0.27 to 0.28 (SEDAR, 2011; Burton et al., 2015; SEDAR, 2015; GMFMC, 2017b).

Estimates of F , M , and Z for gray triggerfish are critical for management but are highly dependent on fishery-dependent data from the Marine Recreational Information Program, which is known to have difficulties (NASEM, 2017). Also, it is relatively easy for management to estimate Z from age–frequency analyses, but it is more difficult to separate Z into F and M for an exploited stock (Ricker, 1975). Some authors have proposed methods to estimate M with equations that attempt to relate M to life history characteristics, such as maximum length, maximum age, or growth rates (Hewitt and Hoenig, 2005; Charnov et al., 2013). Mortality can also be estimated through mark-recapture studies on the basis of the number of tagged fish that were caught and reported by fishermen (Pine et al., 2012). However, there are inherent caveats with conventional mark-recapture studies; for example, fishermen not reporting catch of tagged fish, fish shedding tags, and fish emigrating from study areas (Schwartz, 2000; Pollock et al., 2001; Denson et al., 2002; Pine et al., 2003, 2012).

Telemetry methods have been used in terrestrial animals for some time (Trent and Rongstad, 1974; Pollock et al., 1995) and more recently have been applied to aquatic organisms (Hightower et al., 2001; Heupel and Simpfendorfer, 2002; Pollock et al., 2004; Starr et al., 2005; Knip et al., 2012). In the northern Gulf of Mexico, telemetry methods have been successfully used to estimate F and M of red snapper residing on natural and artificial reefs, independent of tag returns by fishermen (Topping and Szedlmayer, 2013; Williams-Grove and Szedlmayer, 2016a; Mudrak and Szedlmayer, 2020). Telemetry can also be used to estimate non-reporting by fishermen and tagging mortality (Hightower et al., 2001; Williams-Grove and Szedlmayer, 2016a; Mudrak and Szedlmayer, 2020). In previous studies, telemetry methods have been applied to gray triggerfish to estimate movement patterns (Herbig and Szedlmayer, 2016; McKinzie, 2018; Bacheler et al., 2019a, 2019b), and responses to baited fish traps (Bacheler et al., 2018), but have not been reported for mortality estimations. In our study, we applied telemetry methods to estimate mortality of gray triggerfish from artificial reef habitats in the northern Gulf of Mexico from 2013 through 2017. We estimated M , F , and Z with a known-fate model (Kaplan and Meier, 1958; Pollock et al., 1989) on the basis of fine-scale positions obtained from Vemco Positioning Systems¹ (VPS; Innovasea Systems, Boston, MA) composed of acoustic receivers and transmitters, and these

estimates can potentially enhance management efforts for this species.

Materials and methods

Study area and array design

Covering 64 km², the study area was located 23–35 km south of Dauphin Island, Alabama, in the northern Gulf of Mexico. The study area contained 26 steel-cage artificial reefs (2.5 × 1.3 × 2.4 m), each positioned 1.4–1.6 km apart at depths of 18–35 m (Fig. 1). The artificial reefs were deployed at unpublished locations from 2006 through 2010 within a designated reef building zone (Hugh Swingle General Permit Area; Syc and Szedlmayer, 2012). A VPS array of acoustic receivers (VR2W, Innovasea Systems; 69 Hz) and synchronization transmitters (V16-6x, Innovasea Systems; 69 kHz, transmission delay of 540–720 s) was deployed at each of 5 reef sites to monitor patterns of fine-scale movements (in meters) and to estimate mortality of gray triggerfish tagged with acoustic transmitters (V13-1L or V13P-1L, Innovasea Systems; 69 kHz, transmission delay of 40–80 s, battery life of 566–991 d). The depths at the 5 reef sites were 18, 23, 25, 26, and 35 m. In addition, a single VR2W acoustic receiver was placed at each of 21 surrounding reef sites to detect large-scale movements (in kilometers) and emigrations away from VPS sites (Fig. 1).

Each of the 5 VPS sites consisted of 5 acoustic receivers: a center receiver placed 10–20 m north of the reef site and 4 receivers placed 300 m north, south, east, and west of the center receiver (Piraino and Szedlmayer, 2014). The V16-6x synchronization transmitters were attached 1 m above each receiver to standardize the internal receiver clocks (Piraino and Szedlmayer, 2014). The design of the receiver arrays at VPS sites permitted high detection efficiency of tagged gray triggerfish (≥88%; McKinzie, 2018). Every 4–6 months, data were downloaded and all receivers were exchanged. Data from the VPS receivers were sent to Innovasea Systems for post-processing after every download. A stationary control transmitter (V13-1L) was placed at a known location within each VPS array to validate the accuracy of Innovasea-derived positions and to ensure continuous data collection throughout the study period.

Each of the 21 surrounding reef sites contained a single VR2W receiver that detected presence and absence of tagged fish. Every 6–12 months, data were downloaded and these single receivers were exchanged. The maximum radius for transmitter detection around each receiver was estimated to be 770 m (McKinzie, 2018). Therefore, tagged gray triggerfish were detected in 82% (53 km²) of the area within the array of 21 receivers used to monitor large-scale movements, leaving 18% (11 km²) of the area with little coverage. The areas of low detection occurred over paths that were 100–300 m wide between the coverage areas of single receivers at surrounding reef sites (McKinzie, 2018).

¹ Mention of trade names or commercial companies is for identification purposes only and does not imply endorsement by the National Marine Fisheries Service, NOAA.

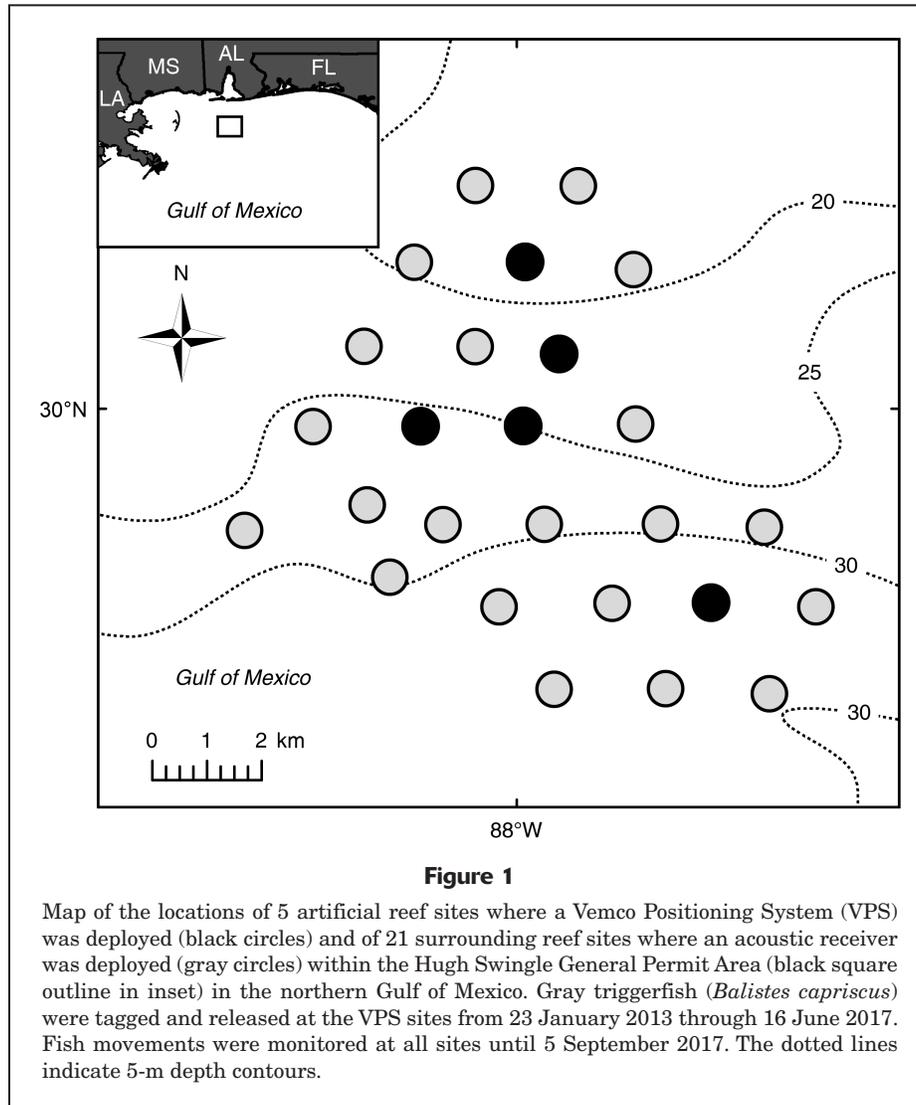


Figure 1

Map of the locations of 5 artificial reef sites where a Vemco Positioning System (VPS) was deployed (black circles) and of 21 surrounding reef sites where an acoustic receiver was deployed (gray circles) within the Hugh Swingle General Permit Area (black square outline in inset) in the northern Gulf of Mexico. Gray triggerfish (*Balistes capriscus*) were tagged and released at the VPS sites from 23 January 2013 through 16 June 2017. Fish movements were monitored at all sites until 5 September 2017. The dotted lines indicate 5-m depth contours.

Fish tagging and cage-release method

We tagged and released adult gray triggerfish (sample size [n]=56) on artificial reef sites from 23 January 2013 through 16 June 2017 and monitored movements until 5 September 2017. Prior to tagging, we measured dissolved oxygen concentration and temperature throughout the water column using a multiparameter water-quality sonde (YSI Model 6920, YSI Inc., Yellow Springs, OH). Fish were tagged and released if dissolved oxygen levels were >2.5 mg/L. If water temperatures at the surface exceeded 27°C , ice was added to the holding tanks during sedation and recovery to reduce stress from high temperatures.

Gray triggerfish were captured with hook-and-line gear baited with squid (*Loligo* spp. or *Lolliguncula* spp.) at 5 VPS sites (Fig. 1). On the research vessel, adult fish ≥ 250 mm FL (Kelly-Stormer et al., 2017) were anesthetized in 70-L containers with 150 mg tricaine methanesulfonate (MS-222)/L seawater (Munday and Wilson, 1997; Cho and Heath, 2000) for 80 s to level 4 of sedation

(loss of equilibrium, fin movement stopped; Summerfelt and Smith, 1990). After anesthesia, fish were weighed (to the nearest 0.1 kg) and measured to the nearest millimeter in total length, FL, and standard length. An acoustic transmitter (V13-1L or V13P-1L) was surgically implanted within the peritoneal cavity through a vertical incision of 1–2 cm on the ventral left side. The incision was then closed with 2–3 discontinuous, dissolvable sutures (chromic gut surgical sutures, Ethicon Inc., Raritan, NJ). Povidone-iodine (Betadine, Avrio Health L.P., Stamford, CT) was applied over the incision to reduce the risk of infection. Fish were also tagged with an external anchor tag (FM-95W, Floy Tag & Manuf. Inc., Seattle, WA) inserted 1–2 cm posterior to the incision, with a unique identification number, contact information, and reward notice for later identification by fishermen or scuba divers (Herbig and Szedlmayer, 2016).

After tagging, fish were transferred to a 185-L recovery tank with aerated seawater. During the recovery period, fish were monitored for increased opercular pumping, control

of body orientation, and resumption of normal swimming motion. Recovered fish were then placed into a weighted rectangular cage (46 × 61 × 61 cm) made of plastic-coated 13-gauge wire and quickly lowered to the seafloor (depths: 19–31 m) within 10 m of the capture site. Once the cage reached the seafloor, a door automatically opened, allowing the tagged fish to leave on its own initiative (Williams et al., 2015). Any tagged fish that did not leave the cage after 20 min on the seafloor were not released.

Validation of detection data

Acoustic receivers can generate false detections that are not from valid transmitters in tagged fish (Pincock²). False detections can result from incomplete transmission due to interference (noise) or collision of signals when 2 or more transmitters simultaneously reach a receiver (Pincock²). To reduce the potential for data loss due to signal collisions, no more than 10 transmitters (tagged fish plus a control transmitter) were deployed at any individual VPS site at any one time (Topping and Szedlmayer, 2011; Piraino and Szedlmayer, 2014; McKinzie, 2018). False detections that resulted in the production of unknown tag IDs were removed from all subsequent analyses. Transmitter detections of known tags were screened before they were accepted as valid. Transmitter detections were accepted as valid if there were a minimum of 2 detections for a single transmitter ID and if there was at least one short interval between detections and more short intervals than long intervals. The short interval time was set at 30 min (30 times the nominal ping interval of 60 s). The long interval was set at 12 h (720 times the nominal ping interval of 60 s; Pincock²). All false detections of valid transmitters were removed from analysis.

Survival and mortality estimates

Fish positions (latitude and longitude) were calculated by Innovasea Systems from the time differential of signal arrival at 3–5 receivers. Status of each fish tagged with a transmitter was based on positions and the time interval between detections after a 3-d post-tagging recovery period. Any fish that remained stationary after exiting their release cage or that permanently emigrated away from the VPS site within the 3-d recovery period were considered lost and were removed from analyses. After 3 d, tagged gray triggerfish were categorized as active (continuously swimming around a VPS site), emigrated (progressively moving farther away from a VPS site until it was lost or had moved to a surrounding reef site), dead as a result of natural causes (*M*, tag became stationary or data indicates erratic large-scale movements, e.g., shark movement patterns; Altobelli and Szedlmayer, 2020), or dead or removed from stock as a result of fishing (*F*, suddenly disappeared from a VPS site).

Fish that emigrated were frequently detected with receivers at surrounding reef sites, and fish that experienced a mortality event were not detected at surrounding sites. Fishing mortalities were also confirmed by tags returned by fishermen. To increase the probability that fishermen would return tags, a high monetary reward was offered (\$150). Posters describing the study and reward offer were posted at marinas, bait shops, and other public sites and on the Auburn University fish tagging [website](#). It was assumed that tagged gray triggerfish active within the VPS sites where they were tagged and released experienced similar mortality rates to untagged fish outside of these VPS sites (Williams-Grove and Szedlmayer, 2016a; Mudrak and Szedlmayer, 2020).

A known-fate model was applied in the program MARK (vers. 8.2, available from [website](#); White and Burnham, 1999) to estimate probabilities of conditional survival and total survival, as well as standard errors and 95% confidence intervals (CIs) (Schroepfer and Szedlmayer, 2006; Topping and Szedlmayer, 2013; Herbig and Szedlmayer, 2016; Williams-Grove and Szedlmayer, 2016a, 2016b; Mudrak and Szedlmayer, 2020). Annual estimates were based on weekly time intervals for each year of the study (2013–2017). The program MARK was used to calculate estimates of survival based on the maximum likelihood binomial (Edwards, 1992). The probability of surviving a mortality event was determined by calculating the number of individuals at risk of dying and the number of individuals that survived for that time interval. Fish that emigrated or suffered a mortality event not under consideration were removed (right censored). For example, when *F* was estimated, all data for fish that emigrated or died as a result of natural causes were removed (Williams-Grove and Szedlmayer, 2016a).

Instantaneous annual mortality rates were based on total survival (*S*) throughout the entire study period (241 weeks) adjusted to 52 weeks ($annual\ S = total\ S^{(52/241)}$) for each type of mortality. For example, the following equations were used for adjustments: $annual\ F = -\ln S^{(52/241)}$ for fishing mortality, $annual\ M = -\ln S^{(52/241)}$ for natural mortality, and $annual\ Z = -\ln S^{(52/241)}$ for total mortality (Starr et al., 2005). Confidence limits for instantaneous mortality rates were calculated from the 95% CIs estimated from the maximum-likelihood estimator of the survival functions at 1 year (52 weeks) (Klein and Moeschberger, 2003; Topping and Szedlmayer, 2013; Williams-Grove and Szedlmayer, 2016a; Mudrak and Szedlmayer, 2020). The reported sample sizes for the mortality estimates were the number of tagged gray triggerfish at risk during the time interval under analysis (Klein and Moeschberger, 2003).

Results

Mean fish size was 395 mm FL (standard deviation 52) and ranged from 276 to 535 mm FL. Most tagged gray triggerfish (86%) were above the legal sport and commercial size limit (356 mm FL). Five fish (9%) left their

² Pincock, D. G. 2012. False detections: what they are and how to remove them from detection data. Amirix Syst. Doc. DOC-004691, vers. 3, 11 p. [Available from [website](#), accessed February 2022.]

VPS site within 3 d post-release, and 2 additional fish (3%) did not move after exiting their release cage. Data for these 7 individuals were removed from all analyses. The remaining individuals ($n=49$, 88%) were categorized as active, caught, emigrated, or deceased, and data for them were included in all subsequent estimates of mortality.

Movement patterns of gray triggerfish that remained after the 3-d recovery period ($n=49$) were monitored for 4–622 d. Among these tracked individuals, 30 fish had a final status of emigrated, 4 fish were caught by fishermen, 4 fish died of natural causes, and 11 fish were active when either their transmitter battery failed ($n=8$) or the study period ended ($n=3$) (Fig. 2). These fish were considered

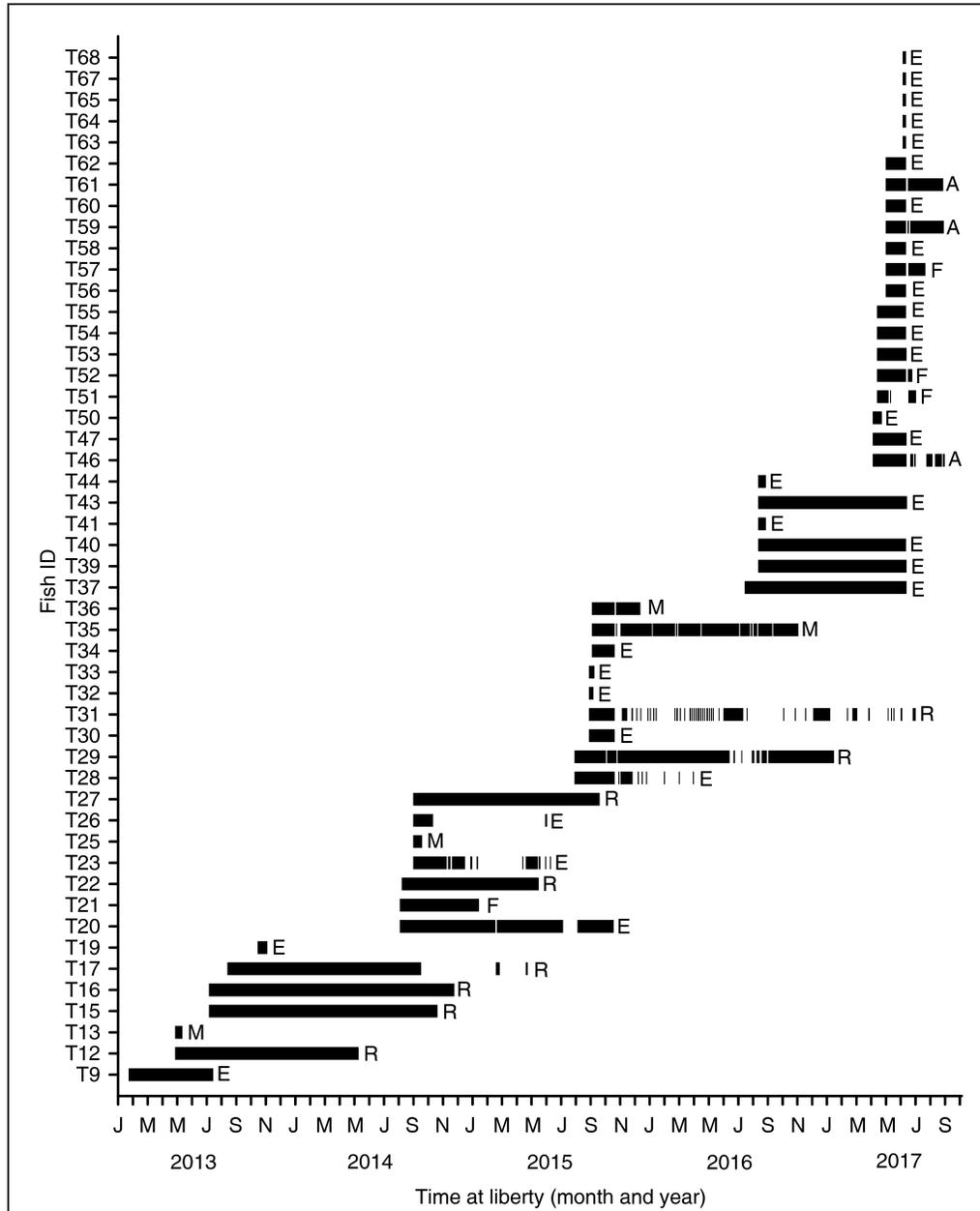


Figure 2

Duration of detections of 49 gray triggerfish (*Balistes capriscus*) (black bars) tagged with transmitters and tracked at artificial reef sites in the northern Gulf of Mexico from January 2013 through September 2017. Letters at the end of the bars denote the final fate of fish at sites where a Vemco Positioning System (VPS) was deployed: emigrated (E), fishing mortality (F), natural mortality (M), unknown (U), active as of the end of the study on 5 September 2017 (A), and resident at VPS site when transmitter battery failed (R).

active while residing at their respective VPS sites and were removed (right censored) from the data set when they emigrated away from their VPS sites.

Fishing mortality occurred for 4 tagged gray triggerfish (8%) while they resided at their VPS site (Fig. 2). All events of fishing mortality identified with telemetry were verified by reports of recapture by fishermen (a 100% reporting rate). Two additional fish (T20 and T28) were reported as captured by fishermen in 2016 after they emigrated from their VPS site. Fish T20 was detected and tracked intermittently for 443 d at the VPS site where it was tagged and released, and then it emigrated and was caught 693 d after release 2.2 km northwest of its VPS site. Fish T28 emigrated from its VPS site 12 d after release and was caught 249 d after release 0.9 km west of its VPS site. Total S from F (S_F) within the VPS sites over the 241-week study period was 0.35 (95% CI: 0.10–0.73). Total S adjusted to annual S , calculated as $S_F=0.35^{(52/241)}$, was 0.80; therefore, annual F , calculated as $F=-\ln 0.80$, was 0.23 (95% CI: 0.07–0.50) (Fig. 3). In 2015, 1 gray triggerfish was caught, among the 15 fish available for recapture at the VPS sites, and F was 0.29 (95% CI: 0.03–1.44). In 2017, 3 gray triggerfish were caught, among the 26 fish available for recapture, and F was 1.13 (95% CI: 0.29–2.87). No fishing mortalities were detected in 2013 (7 fish at liberty), 2014 (11 fish at liberty), or 2016 (9 fish at liberty) (Table 1). However, CIs overlap and indicate no significant differences in F among years.

During this study, natural mortalities were detected for 4 fish (8%), while they were active at their VPS site (Fig. 2).

One additional natural mortality was detected for fish T34 outside the VPS site 199 d after it emigrated, but this fish had been removed from analysis. Total S from M (S_M) over the entire study period was 0.32 (95% CI: 0.07–0.74). Total S adjusted to annual S , calculated as $S_M=0.32^{(52/241)}$, was 0.78; therefore, annual M , calculated as $M=-\ln 0.78$, was 0.25 (95% CI: 0.07–0.57) (Fig. 4). One natural mortality occurred in each of the following years: 2013 ($M=0.42$; 95%

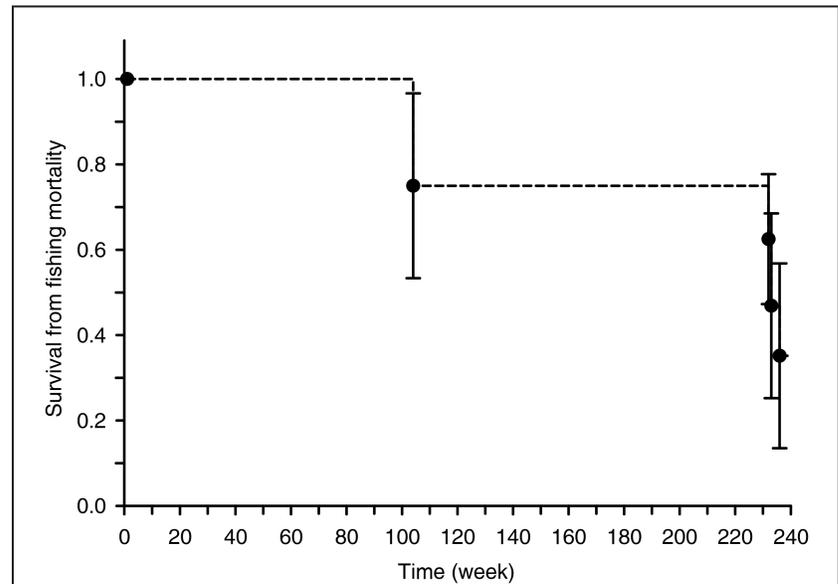


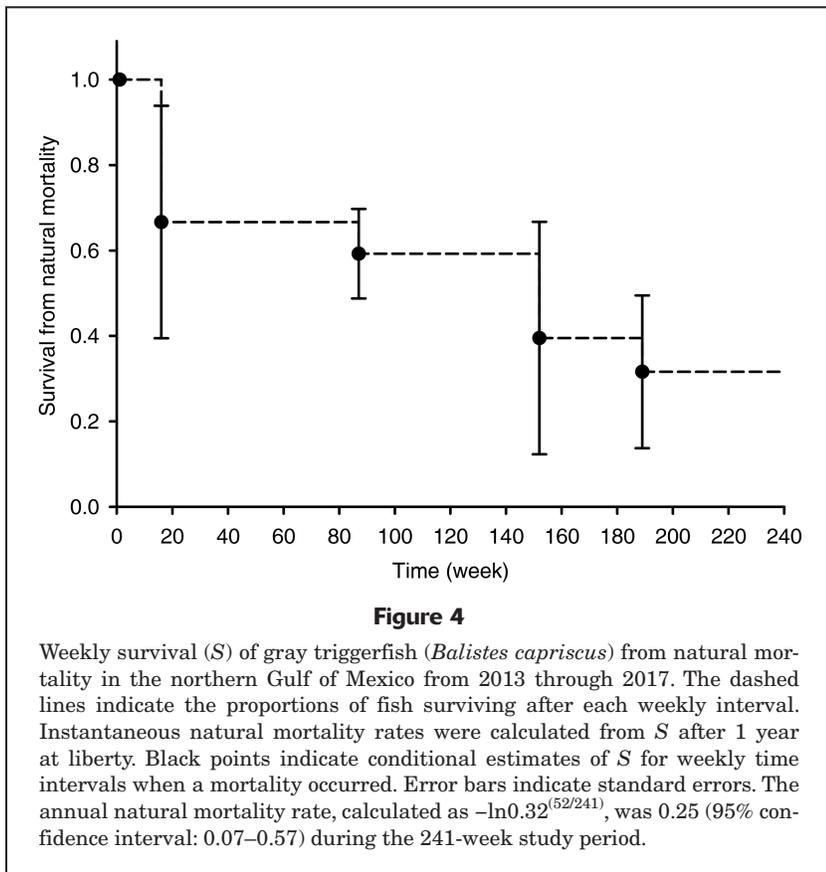
Figure 3

Weekly survival (S) of gray triggerfish (*Balistes capricus*) from fishing mortality in the northern Gulf of Mexico from 2013 through 2017. The dashed lines indicate the proportions of fish surviving fishing mortality after each weekly interval. Instantaneous fishing mortality rates were calculated from S after 1 year at liberty. Black points indicate conditional estimates of S for weekly time intervals when a mortality occurred. Error bars indicate standard errors. The annual fishing mortality rate, calculated as $-\ln 0.35^{(52/241)}$, was 0.23 (95% confidence interval: 0.07–0.50) during the 241-week study period.

Table 1

Estimates of instantaneous annual total (Z), fishing (F), and natural (M) mortality rates of gray triggerfish (*Balistes capricus*) from the use of telemetry methods with Vemco Positioning Systems at reef sites in the northern Gulf of Mexico from 2013 through 2017. Mortality rates were estimated for each year and for all 5 years combined by using the number of tagged fish available for recapture during each year (n) and the number of days in the fishing season for each year. The 95% confidence intervals for mortality rates are provided in parentheses.

Year	n	Z	F	M	Season	No. of days
2013	7	0.42 (0.05–1.95)	0.00	0.42 (0.05–1.95)	1 Jan–9 Jun; 1 Aug–15 Oct	236
2014	12	0.12 (0.02–0.69)	0.00	0.12 (0.02–0.69)	1 Jan–30 Apr	120
2015	15	0.69 (0.13–2.09)	0.29 (0.03–1.44)	0.41 (0.04–1.87)	1 Jan–6 Feb	37
2016	9	0.22 (0.03–1.17)	0.00	0.22 (0.03–1.17)	1 Jan–31 May	152
2017	26	1.13 (0.29–2.87)	1.13 (0.29–2.87)	0.00	Closed	0
Total	49	0.48 (0.18–0.85)	0.23 (0.07–0.50)	0.25 (0.07–0.57)	–	545



CI: 0.05–1.95), 2014 ($M=0.12$; 95% CI: 0.02–0.69), 2015 ($M=0.41$; 95% CI: 0.04–1.87), and 2016 ($M=0.22$; 95% CI: 0.03–1.17). Again, CIs overlap and indicate no significant difference in M among years. No natural mortalities were detected in 2017 (Table 1).

Total S from Z (S_Z) for all years of the study was 0.11 (95% CI: 0.02–0.44), S_Z adjusted to annual S , calculated as $S_Z=0.11^{(52/241)}$, was 0.62, and annual Z , calculated as $-\ln 0.62$, was 0.48 (95% CI: 0.18–0.85) (Fig. 5). Total mortality ranged from 0.12 (in 2014) to 1.13 (in 2017), but again CIs overlap and indicate no significant difference in Z among years (Table 1). No false detections were recorded by receivers at VPS sites or surrounding reef sites after mortalities occurred. The lack of false detections, along with reports from fishermen of recaptured fish, verify all mortalities determined with the VPSs (deaths resulting from both natural causes and fishing).

Discussion

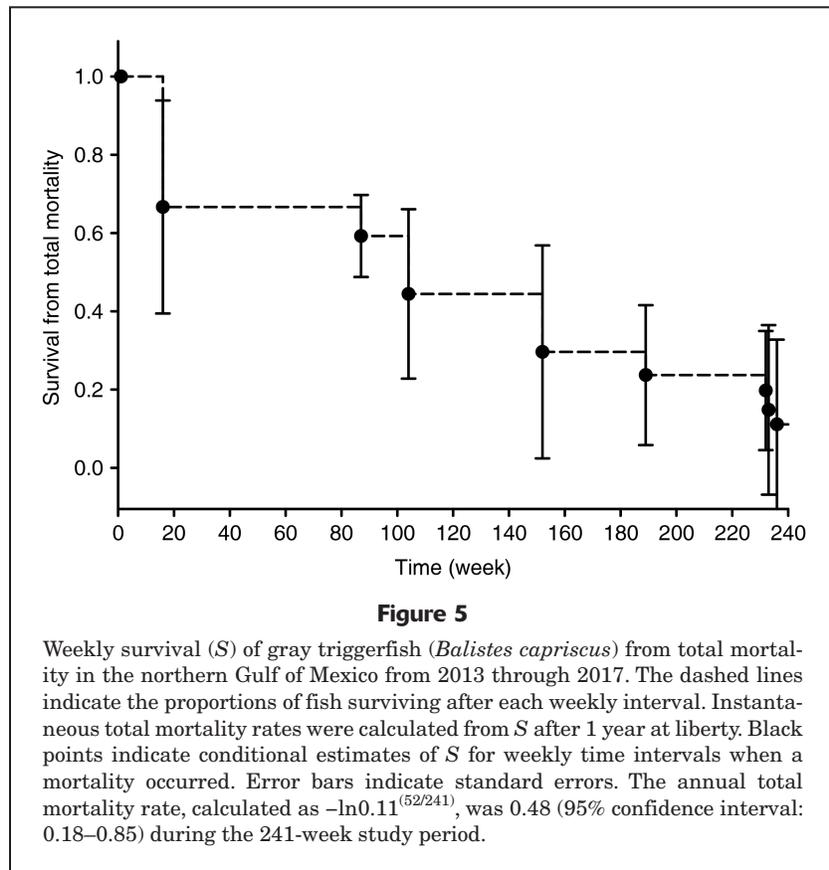
In this study, acoustic telemetry was applied to directly estimate instantaneous rates of F , M , and Z for gray triggerfish. The arrays of receivers at VPS sites allowed continuous, long-term (up to 662 d), highly accurate (to ≤ 3 m) tracking of tagged gray triggerfish that resided around artificial reefs in the northern Gulf of Mexico. Importantly,

the number of mortalities were estimated directly, independent of the number of tags returned by fishermen, because the fates of tagged individuals were known while they resided at VPS-monitored reef sites (Hightower et al., 2001; Heupel and Simpfendorfer, 2002; Bacheler et al., 2009; Topping and Szedlmayer, 2013; Williams-Grove and Szedlmayer, 2016a).

The estimated annual F from this study is 0.23 for the period of 2013–2017, a level lower than that from the previous stock assessment in 2015, indicating that management efforts of amendment 37 have been successful in reducing F (GMFMC, 2012). However, the F of 0.23 from this study is still greater than the F of 0.12 estimated for 2013 in the previous stock assessment (SEDAR, 2015). The greater F in this study indicates that the Gulf of Mexico stock of gray triggerfish may still be experiencing overfishing because the value is greater than the maximum F threshold of 0.17 from the stock assessment in 2015; the threshold was based on a spawning potential ratio of 30% (SEDAR, 2015). The rebuilding plan developed in 2017 also noted that the Gulf of Mexico stock of gray triggerfish was not rebuilding on target, possibly as a result of the sport fishery often exceeding annual catch limits, incompatibilities between the federal and state fishing seasons, and low annual recruitment (GMFMC, 2017b).

Limits on catch of gray triggerfish were unchanged over the study period of 2013–2017. However, sport fishery accountability measures led to seasons of varying lengths (from 37 to 236 d) during 2013–2016, with a complete closure in 2017 because of landings in 2016 exceeding the catch limit by 245% (GMFMC, 2017b). In this study, we did not detect a significant difference in annual F , as indicated by overlapping CIs. It is possible that no trends were observed because fishermen were unaware of season length and closure dates prior to the start of the annual fishing season because they were announced mid-season once annual catch limits were estimated to have been reached. Yet, as has been the case with most telemetry tagging studies, sample sizes were small in this study. Therefore, annual comparisons of F should be treated with caution because of the limited number of tagged fish that were available for recapture each year.

Fishery regulations for target and non-target species may have unexpected consequences (Gislason, 2003; Walters et al., 2005). In this study, although no significant differences were detected for F among years, the trend in F indicates that the highest annual rate was 1.13 in 2017. Surprisingly, this level of F occurred when the federal sport fishery for gray triggerfish was completely closed because fishermen exceeded the quota for 2016 (GMFMC, 2017b).



All fishing mortalities of gray triggerfish in 2017 occurred in July during the extended sport fishery season for red snapper (NMFS³). Therefore, we suggest that the sport fishery for red snapper affected a non-target species, gray triggerfish, because of their shared dependence on natural and artificial reef habitats (Simmons and Szedlmayer, 2011, 2018; Jaxion-Harm et al., 2018). Previous telemetry studies have confirmed that both species are reef dependent, maintain long-term residences, and have high site fidelity to individual reef structures (Szedlmayer and Schroepfer, 2005; Topping and Szedlmayer, 2011; Piraino and Szedlmayer, 2014; Herbig and Szedlmayer, 2016; Williams-Grove and Szedlmayer, 2016b, 2017; McKinzie, 2018). Increased F has also been linked to fish species that congregate at predictable or known locations (Roughgarden and Smith, 1996; Hutchings, 2000; Worm et al., 2009; Williams-Grove and Szedlmayer, 2016a).

At the time of our study, the Gulf of Mexico stock of gray triggerfish was overfished and not rebuilding on target. In addition, the population size and spawning stock biomass were near historic lows (GMFMC, 2017b). However, because of recent changes to the minimum stock size

threshold, the stock is no longer considered overfished, but it is still not rebuilding on target (GMFMC, 2017a). Any additional fishing pressure on gray triggerfish, particularly during critical periods, such as spawning when the fishery is closed, could further slow stock recovery (van Overzee and Rijnsdorp, 2015).

Historically, rates for reporting of tagged fish by fishermen were indirectly measured with secretly implanted tags, port or processor surveys, landings data, and multiple-tag studies (Pollock et al., 2001; Pine et al., 2003). In multiple-tag studies, reporting of recovery of high-reward tags is assumed to be 100%, and the difference between the reporting for recovery of standard tags and that for high-reward tags is used to adjust the reporting rate (Pollock et al., 2001; Bacheler et al., 2009; Hightower and Pollock, 2013). In this study, we used a high reward (\$150) for all tags, and reporting rates were 100%, based on the number of fishing mortalities determined by using telemetry. However, these results should be interpreted with caution because of small sample sizes, and always assuming 100% return rates for high-reward tags may cause underestimates of F (Pollock et al., 2001; Pine et al., 2003). For example, in previous telemetry studies in which tag reporting rates were directly estimated, reporting rates were <100%: 17% (Hightower et al., 2001), 89% (Topping and Szedlmayer, 2013), 63% (Williams-Grove and Szedlmayer, 2016a), and 77.1% (Mudrak and Szedlmayer, 2020).

³ NMFS (National Marine Fisheries Service). 2017. NOAA announces the 2017 Gulf of Mexico red snapper recreational seasons. FB17-023 Gulf of Mexico Fishery Bulletin. [Available from [website](#), accessed February 2022.]

Reporting rates less than 100% were attributed to tag shedding, unintentional noncompliance, or intentional non-reporting due to disagreements over management restrictions (Schwartz, 2000; Pollock et al., 2001; Denson et al., 2002; Gaertner and Pierre-Hallier, 2015; Williams-Grove and Szedlmayer, 2016a).

Another advantage of telemetry is that it can be used to provide fishery-independent estimates of F and M , but reports of recaptured fish by fishermen are still important for validating the telemetry-based estimates (Hightower and Pollock, 2013; Topping and Szedlmayer, 2013; Williams-Grove and Szedlmayer, 2016a; Mudrak and Szedlmayer, 2020). In addition, data on tag returns by fishermen provide a rare opportunity to understand fishermen behavior (Pine et al., 2003) and can be used to generate species-specific reporting rates of tagged fish (Mudrak and Szedlmayer, 2020).

In this study, one natural mortality event was observed during each year of the study, except in 2017. The overall annual estimate of M was 0.25 (95% CI: 0.07–0.57) for all years of the study (2013–2017) and was similar to the M of 0.28 that was used in the stock assessment model for 2015 (Burton et al., 2015; SEDAR, 2015). Both the 2015 stock assessment and the telemetry approach used in this study are validated by the similarity of the values of M estimated with the 2 totally different methods.

Interestingly, one gray triggerfish (T35) was identified as a fish that experienced natural mortality rather than as an emigrated fish on the basis of patterns of detections with receivers at surrounding reef sites after the fish left the VPS site. Detections of fish T35, after almost continuous tracking for 426 d at the VPS site where it was tagged and released (Fig. 2), were recorded at 15 different surrounding reef sites and indicate that 38 directed movements occurred over a 5-d period, with a total distance moved of 91 km. This pattern of substantially increased horizontal movement matches movement patterns of a tagged sandbar shark (*Carcharhinus plumbeus*) and a tagged bull shark (*C. leucas*) detected with telemetry in the same study area (Altobelli and Szedlmayer, 2020). Therefore, these detections of fish T35 indicate the movements of a predator rather than of a gray triggerfish.

Conclusions

In this study, we successfully identified the fates of 100% of tagged gray triggerfish residing on artificial reefs in the northern Gulf of Mexico after a 3-d recovery period, independent of tag returns by fishermen, and used telemetry from VPS sites for direct estimation of F , M , and Z . Valid detections from receivers at surrounding reef sites were used to successfully verify that fish emigrated. Mortalities identified with telemetry were confirmed by using information on tag returns by fishermen, on the lack of detections with single receivers after fish were caught, or on detection patterns that indicate predator movements. The estimate of M from this study supports values applied in management efforts, and the F from this study indicates

that previous management efforts have been successful in reducing F but that the stock may still be experiencing overfishing. This study also highlights the importance of bycatch mortality of gray triggerfish (i.e., as fishermen pursue other species, such as red snapper, gray triggerfish are caught despite a closed season for this species).

One difficulty in this study was comparing mortality estimates for a relatively small area off the coast of Alabama to estimates for the entire Gulf of Mexico. Therefore, the telemetry estimates from this study may be limited. Still, estimates of mortality based on telemetry methods are likely more accurate than estimates based on landings data from phone or mail surveys (i.e., based on fishery-dependent data from the Marine Recreational Information Program; SEDAR, 2015). Therefore, the expansion of the use of acoustic telemetry for estimation of mortality rates could improve the management of gray triggerfish.

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