MOVEMENT PATTERNS AND DISCARD MORTALITY OF COBIA IN THE GULF OF MEXICO

FINAL REPORT

Submitted To:

Gulf of Mexico Fishery Management Council

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ABSTRACT

Cobia (*Rachycentron canadum*) is a highly prized coastal migratory pelagic species supporting a popular recreational fishery throughout the Gulf of Mexico (GOM). The most recent stock assessment (SEDAR 28 Update) suggested the stock was experiencing overfishing and at risk of becoming overfished in the near future. As in previous assessments, severe knowledge gaps limited confidence in the update assessment results, hindering management advice. Among these were significant uncertainties regarding stock structure, seasonal movements, estimated landings and discards, and post-release mortality. For example, the southern boundary of the GOM Cobia stock is unknown, particularly with respect to Texas and Mexican waters. Furthermore, no study has directly estimated the post-release mortality rate in the GOM recreational fishery. Using pop-up satellite archival tags (PSATs), the ***primary goal*** of this project was to evaluate seasonal movements and regional connectivity and to estimate post-release mortality for Cobia captured in the recreational fishery in the western GOM. We tagged 17 Cobia (size range: 838 mm FL [33 in] to 1092 mm FL [43 in]) with PSATs off the coast of Texas between June and October 2020. Tags were programmed to release from fish between late fall and early spring to aid in the identification of overwintering areas and any potential connectivity with Mexican waters. As of March 15, 2021, 12 PSATs had reported location data, 3 did not report, and 2 were presumably still attached to free-swimming Cobia with release dates scheduled for late March and mid-April. Of the 12 reporting tags, 5 transmitted location data on schedule, 5 experienced tag attachment failure resulting in shortened deployment periods (mean = 44% of scheduled deployment period), and sensor data from the 2 remaining tags indicated mortalities. Tag reporting dates occurred from mid-August to mid-February. Net dispersal from the tagging area (minimum straight-line distance from the tagging location to reporting location) averaged 80 km and was lower for PSATs reporting before November (mean = 52 km) than those reporting from November through February (mean = 130 km). For these tags reporting from November onward, net movements were primarily (5 of 6 PSATs) southerly and offshore. Although most PSATs reported at locations within the U.S. GOM, 4 were ≤ 70 km from the U.S.-Mexico Maritime Boundary, and 1 PSAT, representing a net dispersal of 202 km, reported 3 km into Mexican waters. However, given this PSAT's delayed transmission (~ 11 hrs after release) and prevailing southerly currents at the time, this fish was likely in U.S. waters when the tag released. No fish were observed moving into the northwestern GOM (N. Texas or Louisiana). The two mortalities observed during this study included one fish harvested by an angler 5 days after release, while sensor data indicated the other fish was depredated within 1.5 hrs post-release. This mortality was considered a post-release mortality in subsequent estimates of discard mortality. When considering only tags where mortality or survival was definitively inferred, we estimated a post-release mortality rate of 7% (95% CI: 0–23%). A second more conservative estimate, which considered PSATs that did not report (DNR) as mortalities (4 mortalities assumed: 1 PRM + 3 DNR) was also calculated, yielding a post-release mortality rate of 24% (95% CI: 6-47%). As the first study to employ PSAT technology to observe seasonal movements and fates of Cobia tagged in the western GOM, our data allow new insights into Cobia stock structure and overwintering areas in the region and provide the first direct estimate of post-release mortality in the GOM recreational fishery. While inferences are somewhat limited by a small sample size that is typical for these satellite-tagging based studies,

some important general observations can be drawn. For example, while most fish moved south and/or offshore during the winter months, significant movements into Mexican waters were not observed. Nevertheless, more Cobia may have been observed further south if more tags reported during the winter months, and fish overwintering in the area south of Port Mansfield during this time of year are subject to increased rates of illegal, unreported, unregulated (IUU) fishing activity. Our estimate of post-release mortality (7%) is similar to the rate used in the SEDAR 28 Update (5%); however, if non-reporting tags represent post-release mortalities, then the true rate would be higher. Finally, this study also demonstrates that netting is a viable catch and release method even for large individuals, given all fish were netted (up to 50 in TL) and high post-release survival was observed. Additional tagging efforts (PSAT and acoustic) will help corroborate the patterns observed in this study and improve bias and precision of the estimated discard mortality rate.

PROJECT BACKGROUND AND OBJECTIVES

Cobia (*Rachycentron canadum*) is a highly prized coastal migratory pelagic species managed as separate Atlantic and Gulf migratory stocks by the South Atlantic Fishery Management Council (authority delegated to the Atlantic States Marine Fisheries Commission [ASMFC] in Amendment 31; SAFMC 2018) and the Gulf of Mexico Fishery Management Council (GMFMC 2019). Cobia support a popular recreational fishery (>90% of landings) but are also captured in commercial fisheries and as bycatch in shrimp fisheries along the U. S. Atlantic coast and throughout the Gulf of Mexico (GOM; SEDAR 2013; GMFMC 2019). Despite the species popularity as a sportfish, few stock assessments have been conducted, and only recently has Cobia been assessed through the Southeast Data, Assessment, and Review (SEDAR) process. The most recent assessment for the GOM migratory stock was completed in 2020 (SEDAR 28 Update; SEDAR 2020). Assessment results indicated overfishing was occurring, and the stock was at risk of becoming overfished in the near future with spawning stock biomass at reduced levels (2018 SPR = 0.21). Like previous assessments, confidence in the update assessment was low, and management advice was greatly hindered by severe data gaps (SEDAR 2013; SEDAR 2020). In particular, deficiencies regarding stock structure, life history, movement patterns, and post-release survival contributed toward high uncertainty in the stock assessment. For example, the southern boundary of the GOM stock, particularly with respect to Mexican and Texas waters, is unknown (SEDAR 2013, 2018). Furthermore, stakeholders fishing for GOM Cobia have sent clear messages through public testimony at recent Gulf Council meetings and an anonymous survey conducted by the Council (GMFMC 2020) expressing dire concerns about the condition of the stock. The Council has been proactive in addressing these concerns, with an increased minimum size limit recently implemented in 2020. The goal of increasing the minimum size limit was to reduce fishing mortality until new information from the SEDAR 28 Update could better inform management. However, now that overfishing is officially occurring, additional regulatory measures are under consideration to prevent the stock from becoming overfished (Draft Amendment 32). An unintended side effect of the recent minimum size limit increase and any future regulatory measures will likely be increased regulatory discards. The unknown fate of discarded Cobia is a serious knowledge gap and a major impediment to effective management. In fact, no study has directly estimated post-release mortality for cobia discarded in the GOM recreational fishery. In the most recent stock assessment for Gulf Cobia (SEDAR 28 Update), a post-release mortality rate of 5% was assumed for the recreational and commercial hook-and-line fisheries. This estimate was derived from limited commercial logbook data suggesting that a high percentage of discarded Cobia were released alive in bandit (98%) and longline (92%) fisheries and from South Carolina Department of Natural Resources observations that only 1 of 60 Cobia collected for broodstock died within one week of collection and transport (SEDAR 2013). While Cobia may be hardy, accurate and precise estimates of post-release mortality are critical because small changes in fishing mortality can result in large changes in estimated spawning stock biomass and ultimately population growth and sustainability (Musyl et al. 2015). This is especially true considering the GOM recreational fishery where, like many other recreational fisheries, Cobia discards have and continue to exceed total landings (Matter and Nuttall 2020). More importantly, these data sources do not consider delayed mortality following release, differences in fishing tackle, handling time, or handling practices (e.g., SC broodstock likely supplied with supplemental oxygen following collection and during transport) – all of which may influence post-release mortality (Bartholomew and Bohnsack 2005; Curtis et al. 2015). Given these data needs, the ***overall goal*** of this project was to provide new information on movement, stock structure, and discard mortality of Cobia captured in the GOM recreational hook-and-line fishery using advanced tagging technologies. The ***specific objectives*** of this project were to:

1) Examine seasonal movement patterns of Cobia and evaluate the degree of connectivity between sub-regions in the Gulf of Mexico;

2) Estimate the post-release mortality rate for Cobia captured in the U.S. recreational hook-and-line fishery.

METHODS

Three different pop-up satellite archival tag (PSAT) models were used to obtain new information on Cobia movements, stock structure, and discard mortality. These included the miniPAT, sPAT, and mrPAT (Wildlife Computers, Redmond, Washington). Briefly, miniPATs provide data on movement, high-resolution behavior (temperature, depth, light level at 1-10 minute resolution), and mortality. The sPAT is a survivorship tag primarily designed to provide data for mortality detection, but it can provide movement and behavior data over shorter time periods (60-day maximum tag life). The mrPAT is a slightly smaller tag that provides a location estimate marking the last known site of the fish at release. Inclinometer and minimum and maximum temperature records for the last 100 days of a mrPAT deployment can also be helpful for inferring fish survival. Both miniPAT and sPAT tags were programmed to release under certain conditions that indicate a mortality. If the tag experienced a constant depth (± 1.5 m; Sitter) or dry state for three days (deceased fish or premature detachment), it would release from the fish and transmit data. Similarly, mrPAT tags were programmed to monitor for premature detachment from the fish and begin transmitting data if the wet/dry sensor was "dry" (at the surface) for a period of two consecutive hours. The two sPATs had a maximum deployment duration (i.e., time until scheduled release) of 60 days. The deployment duration of the miniPATs and mrPATs extended to periods up to six months or were scheduled for specific dates. These tags were programed to release and begin transmitting data in the early fall, late fall, and winter to provide new information on movements and dispersal to overwintering habitats. Prior to deployment, all PSATs were rigged with a 136-kg (300 lb) monofilament tether measuring 15.2 cm (6 in) long that terminated with a titanium dart anchor. All PSATs were coated with antifouling paint following manufacturer recommendations to minimize biofouling and maintain transmission efficiency for longer deployments.

Cobia were captured using gear and methods representative of the recreational hook-and-line fishery in the western GOM. Once hooked, fish were brought alongside the vessel, netted, and placed into a V-shaped measuring board with one end submerged in a cooler with seawater to cover the gills. Fish were then measured (fork length [FL], total length [TL]; cm), and a PSAT was affixed to any Cobia measuring 838 mm FL (33 in) or larger by inserting the titanium dart anchor into the dorsal musculature of the fish below and just posterior to the leading edge of the dorsal fin. All fish (i.e., including those that did not receive a PSAT) were also conventionally tagged with a uniquely numbered dart tag with contact information and 'reward' printed in English and Spanish to allow reporting of any recaptures. Other data recorded for each capture event included fight time (time from being hooked until being netted and brought onto vessel; min), handling time (time from landing until release including any revival time in water), hooking location (shallow: mouth or jaw, hook visible; or deep: gills, esophagus, gut), and capture location (GPS coordinates).

To engage recreational stakeholders and increase the potential for additional movement data, conventional dart tags were distributed to 18 charter captains and/or private anglers. Participants in this cooperative tagging program were supplied with a tagging kit containing a tag applicator, dart tags, tagging instructions, and data cards to record information for each fish tagged. Dart tags supplied in this cooperative tagging program were identical to those used for PSAT-tagged Cobia. Acoustic transmitters from a previous project were also surgically implanted in four Cobia.

Data received from transmitting PSATs were used to observe dispersal from the tagging location, identify overwintering habitat, and estimate the post-release mortality rate for Cobia captured in the recreational fishery in the western GOM. Sensor data and observed movement characteristics were used to infer the post-release fate of individual Cobia (i.e., survived or mortality). For individuals showing characteristics consistent with survival, movement between the tagging location and the subsequent tag reporting location (pop-up location) was estimated as the minimum straight-line displacement (km) between these two points, with pop-up location recorded as the first transmission with a location accuracy of $\leq$ 1.5 km (i.e., Argos location class 3, 2, or 1). Dispersal vectors were also classified by net movement direction relative to the tagging location (e.g., north, south, onshore, offshore). Pop-up locations for Cobia classified as survivors and reporting between November and February were used to qualitatively identify overwintering habitat.

Post-release (or discard) mortality has been estimated to occur shortly after release because of acute injury (Muoneke and Childress 1994; Musyl et al. 2015). However, delayed mortality due to loss of ability to feed or infection can occur several days to weeks following release, especially if the fishing gear was not completely removed from the animal (Burns and Froeschke 2012; Curtis et al. 2015; Francois et al. 2019). Although increasing the observation period beyond several days allows the incorporation of delayed mortalities, there is a risk of confounding results with natural mortality (*M*) unassociated with the initial capture event or additional capture-related events subsequent to the capture event of interest (e.g., fish recaptured two weeks later, but it sustains significant injuries which lead to mortality). To guard against including these sources in analyses of post-release mortality, and following similar studies (e.g., Jensen and Graves 2020), only Cobia that appeared to perish during the first 10 days after tagging were considered post-release mortalities (PRM). The post-release mortality rate was estimated using two well-established methods (e.g., Schlenker et al. 2016; Orbesen et al. 2019) for PSAT-tagged fish. The first method included only mortalities definitively inferred from the tag data (e.g., Sinker or Sitter) using the expression:

$$\text{PRM rate} = \frac{\text{mortality}}{\text{survived + mortality}}.$$

The second and more conservative method yielded the highest possible mortality estimate, in which PSATs that failed to report or failed to remain attached for > 10 days (e.g., Floater) were also considered mortalities using the expression:

$$\text{PRM rate} = \frac{\text{mortality + tag attachment failure<10d + did not report}}{\text{total number of tags deployed}}.$$

The second method is based on the consideration that a PSAT may fail to report from a live or dead Cobia for multiple reasons, including mechanical failure of the release mechanism, biofouling, or destruction of the tag during an attempted or genuine predation event (Musyl et al. 2011). We included this method because eliminating non-reporting and premature releasing tags decreases the precision of the estimated post-release mortality rate and may artificially lower estimates of post-release mortality (Graves et al. 2002; Schlenker et al. 2016). Confidence intervals for these two estimates of post-release mortality were calculated using software developed by Goodyear (2002), which used tag data to bootstrap the proportion of inferred mortality, survival, and non-reporting tags over 10,000 simulations assuming no tagging-induced or natural mortality during the 10-day survival expression period.

RESULTS

From June to October 2020, 17 Cobia were tagged with PSATs (5 miniPATs, 2 sPATs, and 10 mrPATs) off the Texas coast. Tag deployments were concentrated around Port Aransas; however, tagging effort occurred between Port Mansfield and Port O’Connor. Cobia were tagged at a variety of habitats including artificial reefs (standing platforms and ships, n=9), navigation buoys (n=6), and shrimp boats (n=2). PSAT-tagged fish ranged in size from 838 mm FL (33.0 in) to 1092 mm FL (43.0 in) and averaged 949 mm FL (sd = 82 mm; **Table 1**). PSAT-tagged Cobia experienced fight times ranging from < 1 to 6 min (mean = 3 min; sd = 1 min) and handling times ranging from 2 to 6 min (mean = 4.2 min; sd = 1 min). All PSAT-tagged fish were hooked in the jaw or mouth (shallow). In addition to these fish, 47 more Cobia were dart tagged by the research team (n = 28) or anglers participating in the cooperative tagging program (n =

19). Considering all fish tagged during the project period (n = 64), Cobia ranged in size from 528 mm FL (20.8 in) to 1279 mm FL (50.4 in) and averaged 812 mm FL (sd = 173 mm). Given the requirement of larger fish for PSAT deployments, PSAT-tagged Cobia dominated the larger end of the observed size frequency distribution (**Figure 1**). Of the 64 Cobia that were tagged, seven were recaptured and reported (n=1 PSAT and n=6 dart tags), resulting in a recapture rate of 10.9% (7/64). One fish was recaptured within five hours of being tagged.

At the writing of this report, 12 PSATs had reported data to the Argos System. Of these, 5 transmitted on schedule, and 7 transmitted prematurely for various reasons including mortality (M; from angler harvest or depredation, n=2) or tag attachment failure (TAF; n=5). Three PSATs did not report (DNR) by the scheduled release date, and two PSATs were presumably still attached to free-swimming Cobia (**Table 1**). Tags experiencing TAF reported release reasons including "Floater" or "Pin Broke" and resulted in early transmissions and a correspondingly shortened deployment period (mean = 44% of scheduled deployment period). "Floater" indicated the tag and tether assembly came off the animal and floated to the surface, while "Pin Broke" indicated some external force pulled on the tether and broke the pin (tag stuck in structure, human intervention, etc.). No TAFs were observed within the first 10 days after tagging. Excluding the two fish that are presumably still at large and the two fish where mortality was inferred, PSAT deployments averaged 55% of the scheduled deployment period. All three miniPATs were recovered after washing ashore, and archived data was successfully retrieved.

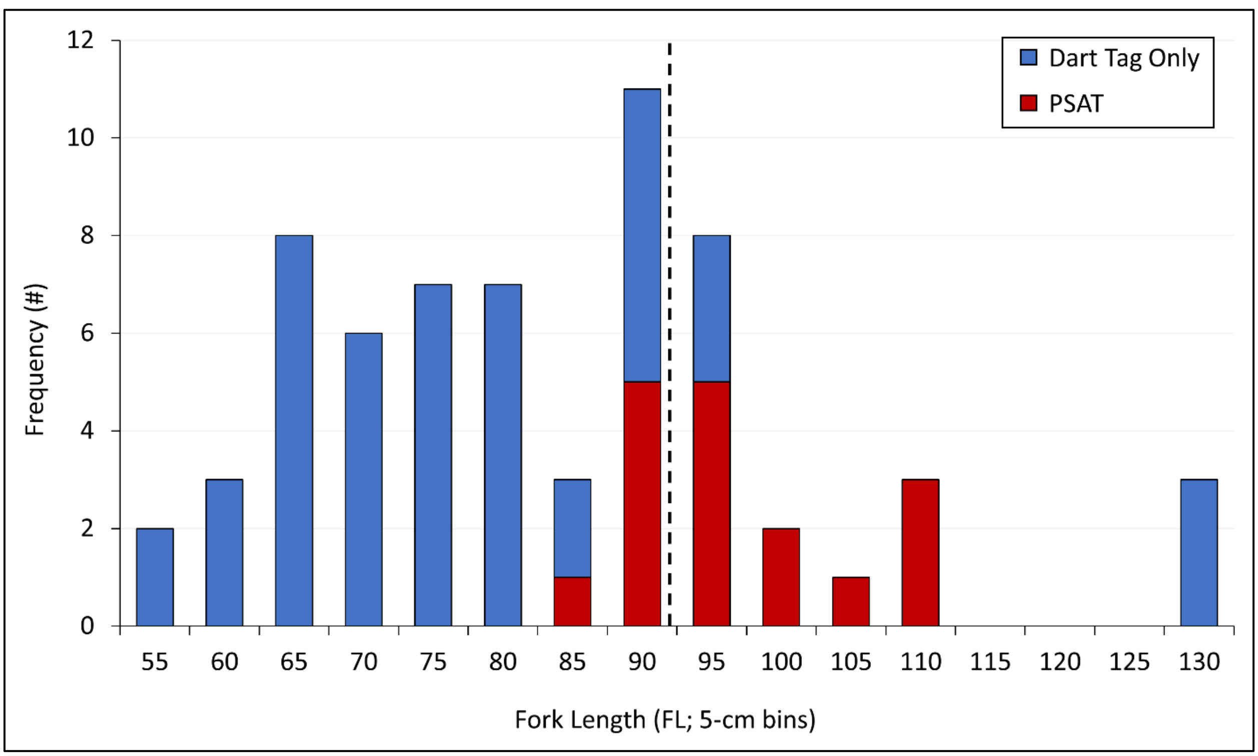

Figure 1 – Length frequency of Cobia (fork length; 5-cm bin size) captured and tagged in the western Gulf of Mexico between June and October 2020. Fish conventionally tagged with dart tags (blue) and those receiving PSATs (red) are included. The minimum legal-size limit (36 in FL; 91.4 cm FL) during 2020 is also included for reference (black vertical dashed line).

Table 1 – Summary information for PSAT deployments on Cobia tagged in the Gulf of Mexico off Texas from June to October 2020. Two Cobia presumably still carrying PSATs at the writing of this report and are denoted with a •.

Fish ID	FL (mm)	Tag Model	Tagging Date	Scheduled Release	Release Date	Scheduled Deployment (d)	Actual Deployment (d)	% of Scheduled Deployment	Release Reason	Deployment Location
1	945	sPAT	6/17/2020	8/16/2020	8/10/2020	60	54	90	TAF - Pin Broke	27.64 -97.01
2	895	mrPAT	8/6/2020	11/27/2020	9/15/2020	113	40	35	TAF - Floater	27.75 -96.99
3	916	mrPAT	10/1/2020	11/27/2020	11/27/2020	57	57	100	Scheduled	28.07 -96.77
4	1035	miniPAT	8/4/2020	12/4/2020	10/12/2020	122	66	54	TAF - Floater	27.39 -97.08
5	923	mrPAT	10/1/2020	12/4/2020	12/4/2020	64	64	100	Scheduled	27.83 -97.02
6	995	sPAT	10/14/2020	12/13/2020	12/13/2020	60	60	100	Scheduled	27.75 -96.99
7	1092	mrPAT	9/7/2020	12/18/2020	—	102	0	0	DNR	27.92 -96.65
8	925	mrPAT	10/1/2020	12/18/2020	12/18/2020	78	78	100	Scheduled	27.83 -97.02
9	838	mrPAT	9/16/2020	1/1/2021	—	107	0	0	DNR	27.79 -96.96
10	865	mrPAT	9/25/2020	1/1/2021	10/15/2020	98	20	20	TAF - Floater	27.66 -97.17
11	865	mrPAT	10/14/2020	1/15/2021	—	93	0	0	DNR	27.82 -97.01
12	1090	mrPAT	10/14/2020	2/12/2021	10/19/2020	121	5	4	M - Harvest	27.71 -97.03
13	867	mrPAT	10/14/2020	2/12/2021	2/12/2021	121	121	100	Scheduled	27.79 -96.96
14	898	miniPAT	10/1/2020	3/30/2021	•	180		0		27.79 -96.96
15	990	miniPAT	10/13/2020	4/11/2021	10/20/2020	180	1	1	M - Depredation	27.64 -97.13
16	1067	miniPAT	10/13/2020	4/11/2021	11/20/2020	180	38	21	TAF - Pin Broke	27.62 -97.13
17	925	miniPAT	10/13/2020	4/11/2021	•	180		0		27.65 -97.13

Net dispersal from the tagging area was estimated for 11 of the 12 reporting PSATs using pop-up locations with quality Argos location data (**Table 2**). Tag releases occurred from mid-August through mid-February. With some exceptions, minimum displacement between the tagging location and the pop-up location was lower for PSATs reporting before November (n = 5; mean = 52 km) and higher for those reporting from November through February (n = 6; mean = 130 km). After mid-October, net movement vectors for most (7 of 8; 87.5%) fish were south and/or offshore (deeper water; **Figure 2**). There was a moderate negative correlation between net dispersal and the mean daily ocean temperature in the tagging region (r = -0.63, df = 9, P = 0.04; **Figure 3**). Given net dispersal represented minimum straight-line distances between the tagging and pop-up location, extensive movements during the deployment period by some individuals were feasible. For example, archived PSAT data for the 66-day deployment period for Fish 4 revealed movements out to the continental shelf edge occurred during mid-September (and use of depths of up to 110 m) despite a pop-up location relatively close to the tagging location (34 km).

Table 2 – Minimum displacement (straight-line distance [km]) and net movement direction from the tagging location to the reporting location for 11 PSAT deployments on Cobia tagged in the western Gulf of Mexico between June and October 2020. Deployments are sorted by release date.

Fish ID	Tagging Date	Release Date	Actual Deployment (d)	Minimum Displacement (km)	Net Movement
1	6/17/2020	8/10/2020	54	15	North
2	8/6/2020	9/15/2020	40	35	South
4	8/4/2020	10/12/2020	66	34	North
10	9/25/2020	10/15/2020	20	158	South
12	10/14/2020	10/19/2020	5	19	South
16	10/13/2020	11/20/2020	38	84	South
3	10/1/2020	11/27/2020	57	19	North
5	10/1/2020	12/4/2020	64	49	Offshore
6	10/14/2020	12/13/2020	60	131	South
8	10/1/2020	12/18/2020	78	133	South/Offshore
13	10/14/2020	2/12/2021	121	202	South/Offshore

Other notable movements (minimum displacement) from the tagging site were observed for six Cobia. One of these individuals (Fish 5) was tagged on 10/1/20 at a site in 12.2 m (40 ft) of water and moved 49 km offshore where the tag reported on 12/4/20 in a location that was 44 m (145 ft) deep. The other five Cobia (Fish 6, 8, 10, 13, and 16) showed more extensive movements ranging from 84 to 202 km to areas south and offshore (mid-shelf; 48-52 m ambient depth) of the tagging region (**Table 2**). Although most PSATs reported at locations within the U.S. GOM, four were $\leq$ 70 km from the U.S.-Mexico Maritime Boundary (**Figure 2**). The first reported location for one of these PSATs (Fish 13; 2/12/2021) was 3 km into Mexican waters; however, the fish was likely in U.S. waters when the tag released because the first successful transmission was delayed (approximately 11 hours after release) and strong southerly currents were prevailing at the time. Detections for one of the four acoustically tagged Cobia revealed the individual was still residing in the nearshore waters off Port Aransas in early November. No Cobia were observed moving into the northwestern GOM (N. Texas or Louisiana) or any other regions of the GOM during the study period.

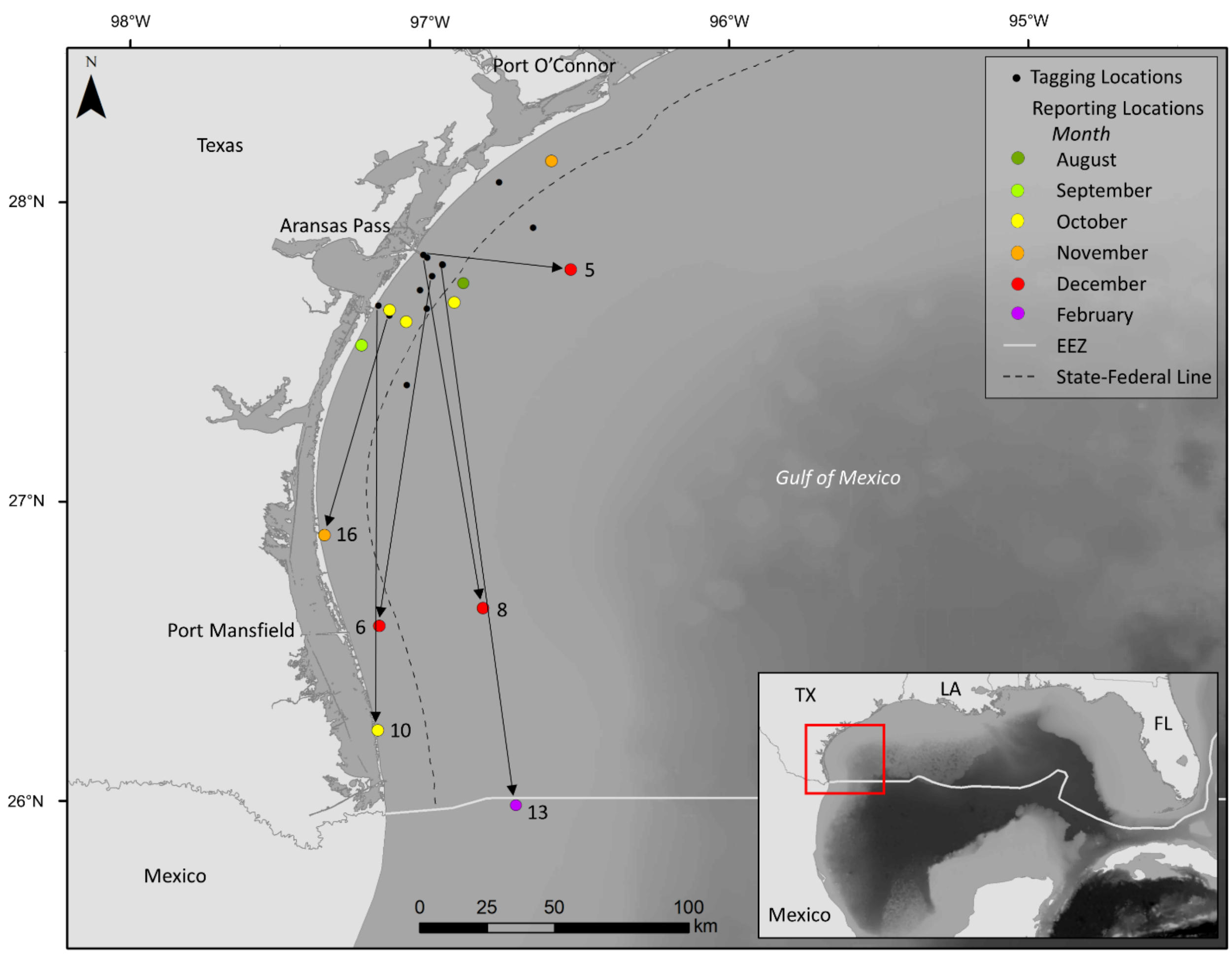

Figure 2 – Tagging locations (black circles) and reporting locations (color coded by month) for PSAT deployments on Cobia in the western Gulf of Mexico. Net movement (minimum straight-line displacement) and direction are indicated by arrows with numbers representing Fish ID (from Tables 1 & 2). The exclusive economic zone (EEZ) and State-Federal boundary are also drawn for reference. The inset map shows the study relative to the Gulf of Mexico and depicts the geographic extent of observed reporting locations.

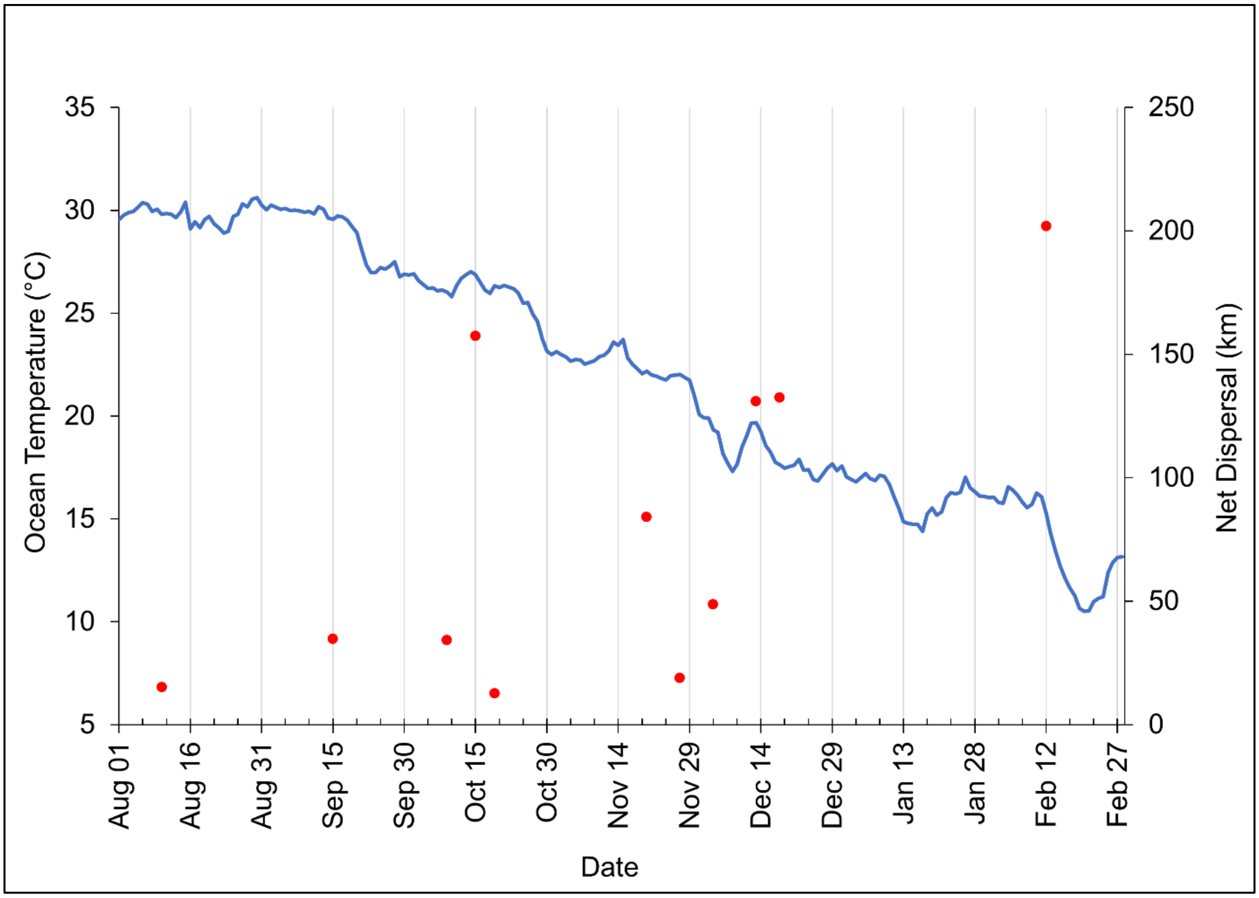

Figure 3 – Mean daily ocean temperature (°C; blue line) in the tagging area (NDBC Station 42048; 8/1/2020 – 2/28/2021) and net dispersal (km; red points) observed for PSAT-tagged Cobia reporting quality locations (Argos 3, 2, or 1).

Table 3 – Assigned fates for 17 PSAT deployments on Cobia captured in the recreational fishery in the western Gulf of Mexico during 2020. These fates were used for post-release mortality calculations. S – survivor, PRM – post-release mortality, DNR – did not report, FM (S) – observed subsequent fishing mortality but considered a survivor for analyses of post-release mortality.

Fish ID	Fate
1	S
2	S
3	S
4	S
5	S
6	S
7	DNR
8	S
9	DNR
10	S
11	DNR
12	FM (S)
13	S
14	S
15	PRM
16	S
17	S

Tag sensor data from the 12 reporting PSATs were used to infer the post-release fate of tagged Cobia (**Table 3)**. Transmitted data indicated 2 mortality events. One individual (Fish 12) was harvested 5 days after tagging (revealed by an Argos track to land and later confirmed by the angler). This fish was not considered a PRM as it had clearly recovered and was ready to feed again. The other mortality (Fish 15) revealed a depredation event occurred within 1.5 hours following release based on archived depth, temperature, and light level time series data recovered from the tag (**Figure 4**). This fish was considered a PRM given the short time window between the release and depredation event – there were no obvious factors that may have contributed to this mortality (e.g., long fight time, handling time, etc.). The remaining Cobia demonstrated horizontal movements, depth, temperature, or tilt readings consistent with survival (**Figures 5 & 6**). The two fish presumably still at large were also considered survivors (**Table 3)**. Thus, using the first method for estimating post-release mortality, 1 mortality was inferred from 14 PSAT deployments to yield a post-release mortality rate of 7% (95% CI: 0–23%). Using the second more conservative approach including tags that DNR as mortalities, 4 mortalities were assumed (1 PRM + 3 DNR) out of 17 PSAT deployments to yield a post-release mortality rate of 24% (95% CI: 6–47%).

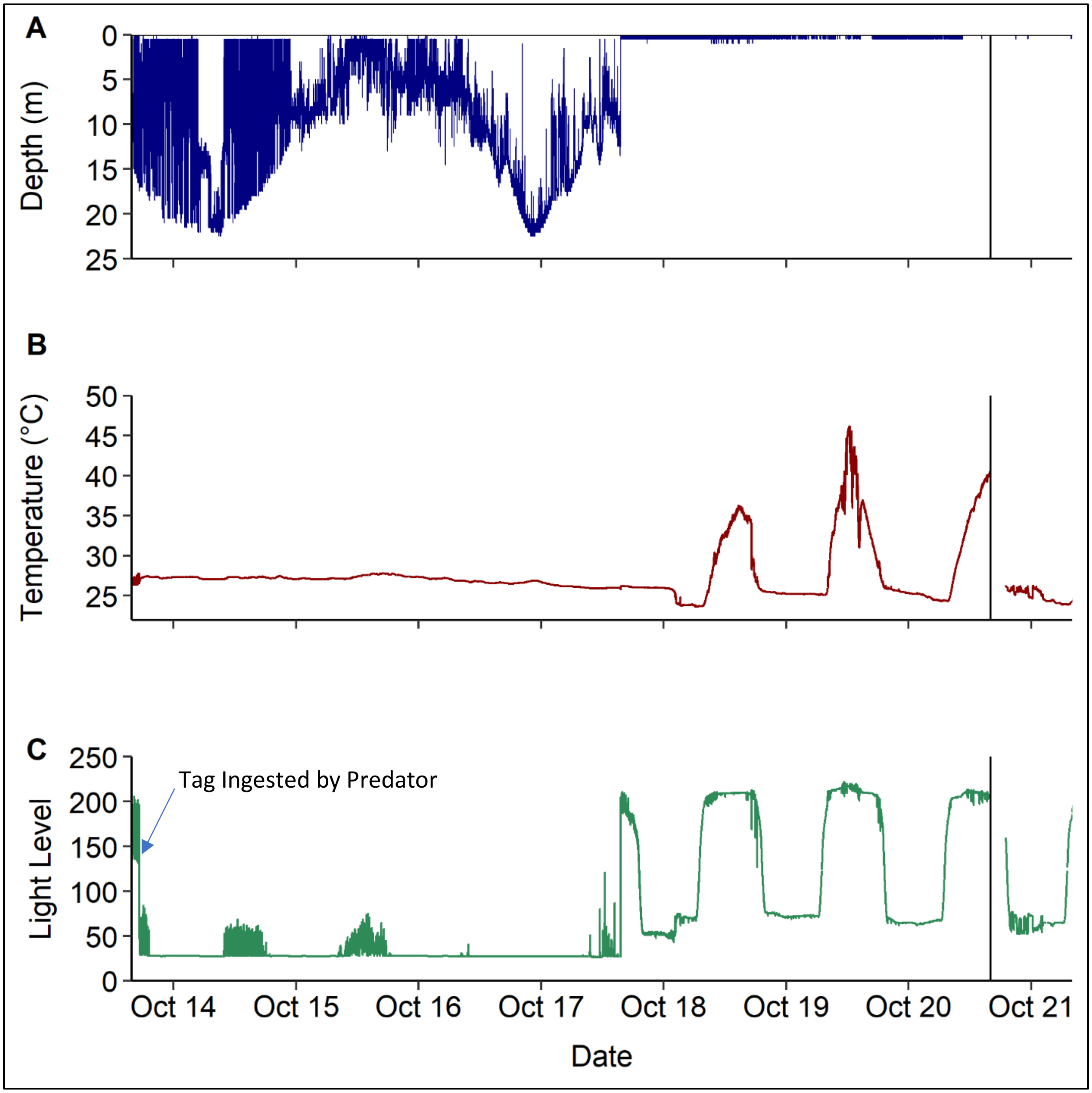

Figure 4 – Archived depth (A; m), water temperature (B; °C), and light level (C) time series for a PSAT-tagged cobia that indicate post-release mortality (Fish 15). The fish was most likely depredated within 1.5 hours following release. The light level and depth data indicate the tag was ingested by a predator and regurgitated approximately 3.5 days later when the tag floated to the surface (normal light cycle). The tag met conditional release criteria 3 days later, triggering release from the tether and subsequent satellite transmissions (black vertical line).

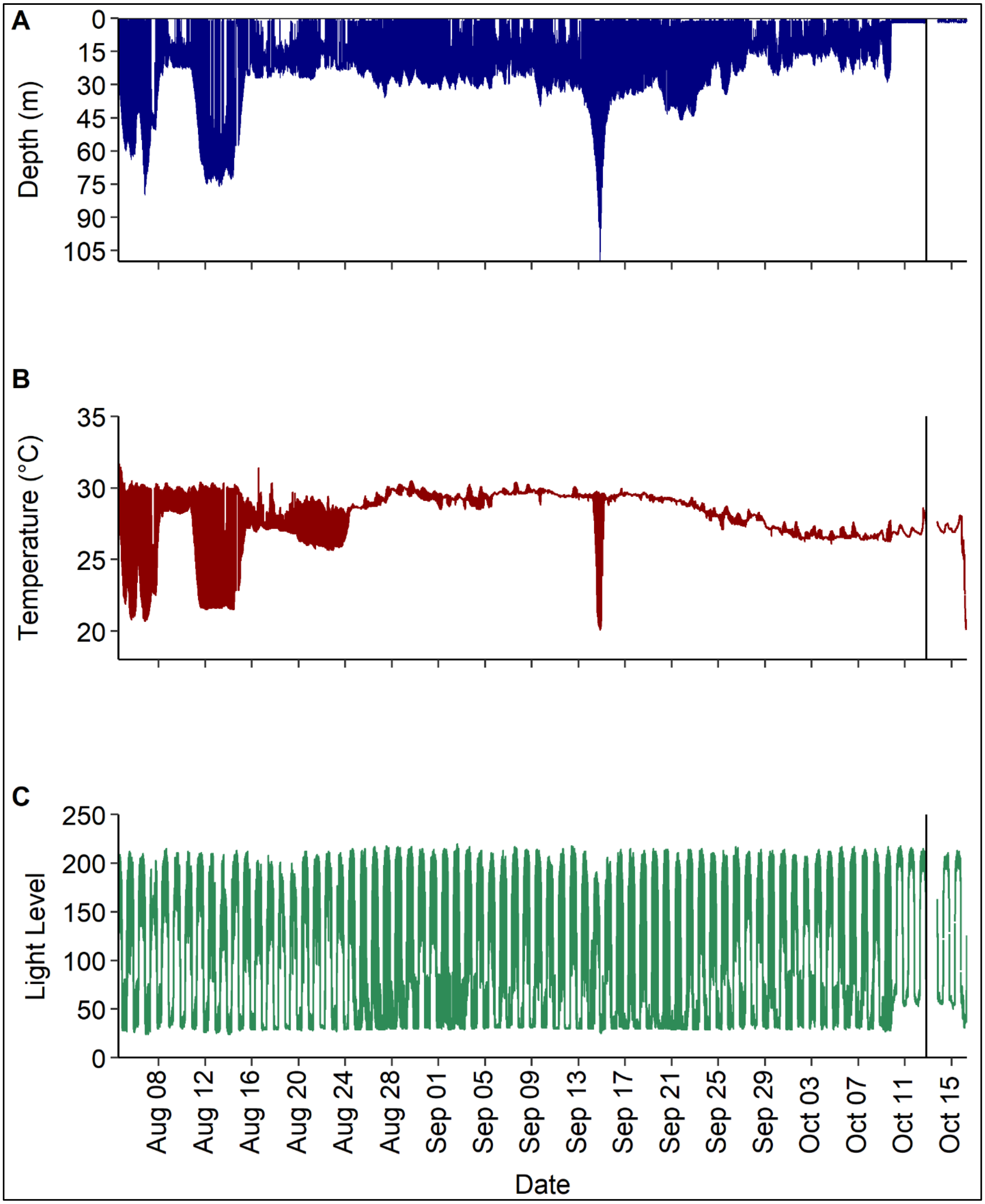

Figure 5 – Archived depth (A; m), water temperature (B; °C), and light level (C) time series for a PSAT-tagged cobia that indicate post-release survival (Fish 4). During the 66-day deployment period, the time series data showed regular changes in vertical and horizontal (based on geolocation) movements and displayed regular changes in the daily light cycle. This tag released prematurely ("Floater") and began transmitting after the three-day conditional release period (black vertical line).

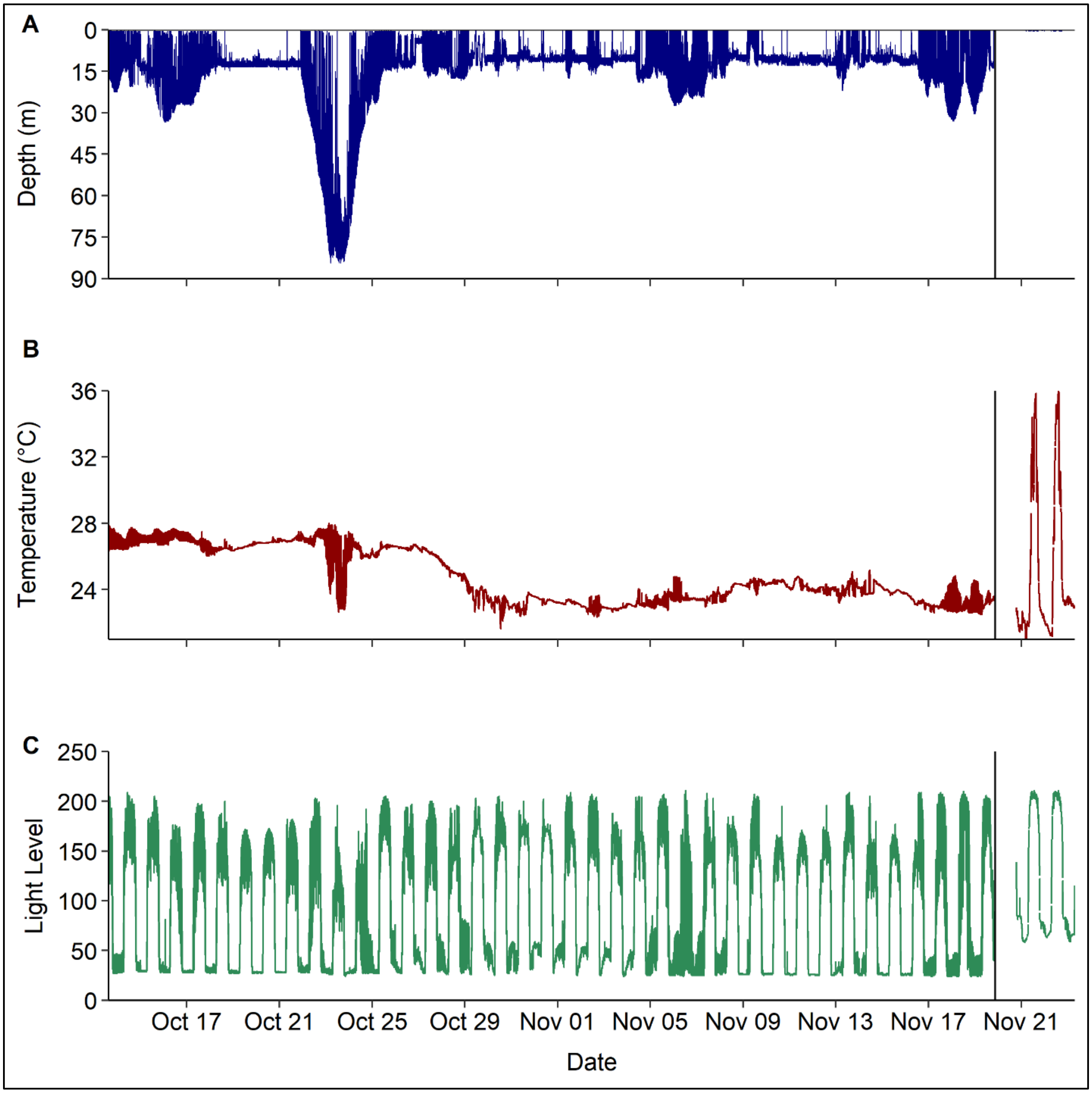

Figure 6 – Archived depth (A; m), water temperature (B; °C), and light level (C) time series for a PSAT-tagged cobia that indicate post-release survival (Fish 16). During the 38-day deployment period, the time series data showed regular changes in vertical and horizontal (based on geolocation) movements and displayed regular changes in the daily light cycle. This tag indicated the pin had been broken, resulting in a premature release and .

DISCUSSION

A primary objective of this study was to employ PSAT tagging to provide new information regarding Cobia stock structure in the western GOM by evaluating seasonal movements and regional connectivity. Despite a relatively limited sample size, several important observations can be drawn from these data. For example, while most Cobia moved south and/or offshore after mid-October, significant movements into Mexican waters were not observed. Only 1 of the 12 reporting PSATs reported from Mexican waters and given its delayed transmission and prevailing southerly currents, the fish was likely in U.S. waters when the tag released from the fish. More Cobia may have been observed further south had more tags reported during the winter months. For example, three tags that were programed to release between mid-December and min-January did not report and another tag programed to release in mid-February was removed from the study by angler harvest. Although the observed non-reporting rate (3/17; 18%) is similar to the non-reporting rate reported from a large meta-analysis of PSAT tagging studies (21%; Musyl et al. 2011), it is unfortunate that these three tags failed during a critical period in the study. Nevertheless, given that most PSATs reporting locations after mid-October indicated movements into waters off south Texas, it is probable that these fish are subject to increased fishing mortality from illegal, unreported, unregulated (IUU) fishing activity near the U.S.-Mexico Border during the winter months.

No fish were observed moving out of the tagging region (i.e., central Texas region) before mid-October suggesting a semi-resident group of fish prior to the fall when water temperatures began to decline (**Figure 3**). Dippold et al (2017) also suggested Cobia in the western Gulf may exhibit limited movement based on a long-term conventional tagging data set. A lack of observations of fish in other areas of the U.S. GOM (e.g., N. Texas, Louisiana) in this study is likely a tagging artifact as tagging did not begin until June 2020. It is possible that a large portion of the Cobia stock in the western GOM may have already migrated northward past the tagging region or simply a consequence of a low sample size. Our team has acoustic tagging efforts planned for 2021 using multi-year tags (3+ yrs) that should help to address this uncertainty.

This study provides the first direct estimate of post-release mortality for Cobia in the GOM fishery. Our estimated post-release mortality rate (7%; 95% CI: 0–23%) is only slightly higher than the rate used in the SEDAR 28 Update Assessment (5%) and is encompassed by the high post-release mortality rate (10%) used in a sensitivity model run (SEDAR 2020). Conveniently, the size of fish tagged in this study (i.e., able to carry a PSAT) will become more representative of true discards pending any increases to minimum size limits or bag limits. Only one PRM was inferred, a fish that was likely depredated shortly after release based on archived sensor data. We included this fish as a mortality because it would be extremely unlikely for this fish to not survive 1 day (0.1% chance) because of natural mortality, given the assumed natural mortality rate for GOM Cobia (0.38/yr; SEDAR 2020). Our estimates assumed no tagging-induced mortality, which is not easily separated from mortality resulting from the catch and release process (Goodyear 2002). Given the high post-release survival observed for Cobia tagged in Virginia (Jensen and Graves 2020) and high post-release survival observed here, we feel any additional probability of mortality caused by the tagging process is negligible.

Several factors could significantly sway the estimate of post-release mortality derived from these data. For example, in the second, more conservative estimate of post-release mortality (24%; 95% CI: 6-47%), we included tags that did not report as mortalities. These PSATs may fail to report for multiple reasons including biofouling, destruction of the tag by fishermen (usually illegal), failure to reach the surface, or damage or destruction of the tag from a real or attempted depredation attempt (Musyl et al. 2011; Luo et al 2020; Wildlife Computers, *personal communication*). We suggest biofouling is unlikely to be responsible for non-reporting given the relatively short scheduled deployment periods after the growing season (e.g., mid-October to mid-December) and proper antifouling paint application prior to tagging. In contrast, destruction of the tag by IUU fishing activities or depredation events are more plausible given that several fish reported in locations off south Texas during the non-reporting period and depredation was inferred for one Cobia based on archived sensor data. If non-reporting tags represent PRM, then the true post-release mortality rate might be significantly higher.

Fishing and handling practices could also have biased our estimate of post-release mortality lower than the true value for the GOM recreational fishery. For example, our field crews comprised avid anglers, a factor (i.e., skill level) that has been demonstrated to influence post-release mortality in other fisheries (Muoneke and Childress 1994; Stunz and McKee 2006). Furthermore, no Cobia were deep hooked – a factor known to cause high mortality for some marine fish (Stunz and McKee 2006), which may not be representative of the GOM fishery. All fish in this study were quickly transferred to the tagging cradle where gills remained covered during the short tagging process. Graves et al. (2016) provided strong evidence of the negative impact of air exposure on post-release survival of White Marlin (*Kajikia albida*). Air exposure time for Cobia in our study was likely minimized relative to what typically occurs on recreational vessels in the GOM. Finally, our study also demonstrates that netting is a viable catch and release method even for large individuals, given all fish were netted (up to 50 in TL) and high post-release survival was observed. Public testimony at Gulf Council meetings has revealed that at least some Cobia are gaffed and brought onboard only to realize the fish is sublegal and must be released. These fish would almost certainly experience higher post-release mortality than the fish in this study. Collectively, all of these factors may have resulted in a post-release mortality estimate that is biased low relative to the true value for the GOM fishery.

CONCLUSIONS

The data obtained in this study permitted the first direct estimate of post-release mortality for Cobia in the GOM recreational fishery while also providing new insights into the seasonal movements and overwintering areas for Cobia in the western GOM – improving our knowledge of stock structure for an understudied species and region of the GOM. A clear pattern of dispersal towards the south Texas shelf and potentially Mexican waters was observed; however, non-reporting tags and one fish that was harvested limited the number of PSATs reporting during the late winter, when migrations further south would most likely occur. Two more PSATs are scheduled to report in late-March and mid-April and should provide more data for this time period. While non-reporting tags limited data during this critical period, PSATs – specifically mrPATs due to their lower cost – remain the best tool for evaluating stock boundaries near the U.S.-Mexico Border given a lack of acoustic array infrastructure and probable subpar reporting of conventionally-tagged fish in Mexican waters. The movement of these fish towards the U.S.-Mexico Border is a concern for management, as fish overwintering in the area are likely subject to increased fishing mortality from IUU fishing activity in U.S. waters and additional removals in Mexican waters. These removals are not currently accounted for in the current stock assessment framework. Estimated post-release mortality from this study was slightly higher than the assumed value in the SEDAR 28 Update Assessment (SEDAR

2020). Non-reporting PSATs create additional uncertainty in our estimate and sway the estimate significantly (3.4 x higher) if they represent actual post-release mortalities. Having accurate and precise estimates of post-release mortality will be critical for upcoming assessments, especially considering the likely increase in discards from forthcoming regulatory changes (Draft Amendment 32). For these reasons, we recommend a directed post-release mortality study that incorporates cooperation with recreational anglers to ensure that fishing and handling practices represent the GOM fishery. Additional electronic tagging efforts are needed to corroborate the patterns observed in this study and increase confidence in and precision of the estimated post-release mortality rate. Our team will carry out additional acoustic and satellite tagging in 2021 to begin to address these needs.

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REFERENCES

Bartholomew, A., and J. A. Bohnsack. 2005. A review of catch-and-release angling mortality with implications for no-take reserves. Reviews in Fish Biology and Fisheries 15:129–154.

Burns, K. M., and J. T. Froeschke. 2012. Survival of red grouper (*Epinephalus morio*) and red snapper (*Lutjanus campechanus*) caught on J-hooks and circle hooks in the Florida recreational and recreational for-hire-fisheries. Bulletin of Marine Science 88:633–646.

Curtis, J. M., M. W. Johnson, S. L. Diamond, and G. W. Stunz. 2015. Quantifying delayed mortality from barotrauma impairment in discarded Red Snapper using acoustic telemetry. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 7:434-449.

Dippold, D. A., R. T. Leaf, J. S. Franks, and J. R. Hendon. 2017. Growth, mortality, and movement of cobia (*Rachycentron canadum*). Fishery Bulletin 115:460-472.

François, P., C. Sidonie, C. Caroline, and G. Jean-Marc. 2019. The effect of hook type and trailing gear on hook shedding and fate of pelagic stingray (*Pteroplatytrygon violacea*): new insights to develop effective mitigation approaches. Marine Policy 107:103594.

GMFMC (Gulf of Mexico Fishery Management Council). 2019. Framework Amendment 7 to the Fishery Management Plan for Coastal Migratory Pelagic Resources in the Gulf of Mexico and Atlantic Region – Modifications to Gulf of Mexico migratory group cobia size and possession limits. GMFMC, Tampa, FL.

GMFMC. 2020. Something's fishy with Cobia response summary. 2019-S28Update-WP-03. SEDAR, North Charleston, SC.

Goodyear, C. P. 2002. Factors affecting robust estimates of the catch-and-release mortality using pop-off tag technology. American Fisheries Society Symposium 30:172-179.

Graves, J. E., B. J. Marcek, and W. M. Goldsmith. 2016. Effects of air exposure on postrelease mortality rates of White Marlin caught in the U.S. Offshore Recreational Fishery. North American Journal of Fisheries Management 36:1221-1228.

Jensen, D. R., and J. E. Graves. 2020. Movements, habitat utilization, and post-release survival of cobia (*Rachycentron canadum*) that summer in Virginia waters assessed using pop-up satellite archival tags. Animal Biotelemetry 8:24.

Luo, J., J. S. Ault, B. T. Ungar, S. G. Smith, M. F. Larkin, T. N. Davidson, et al. 2020. Migrations and movements of Atlantic tarpon revealed by two decades of satellite tagging. Fish and Fisheries 21:290-318.

Matter, V. M., and M. A. Nuttall. 2020. Recreational survey data for Cobia in the Gulf of Mexico. 2019-S28Update-WP-02. SEDAR, North Charleston, SC.

Muoneke, M. I., and W. M. Childress. 1994. Hooking mortality: a review for recreational fisheries. Reviews in Fisheries Science 2:123-156.

Musyl, M. K., M. L. Domeier, N. Nasby-Lucas, R. W. Brill, L. M. McNaughton, J. Y. Swimmer, M. S. Lutcavage, S. G. Wilson, B. Gauardi, and J. B. Liddle. 2011. Performance of pop-up satellite archival tags. Marine Ecology Progress Series 433:1-28.

Musyl, M. K., C. D. Moyes, R. W. Brill, B. L. Mourato, A. West, L. M. McNaughton, W. C. Chiang, C. L. Sun. 2015. Postrelease mortality in istiophorid billfish. Canadian Journal of Fisheries and Aquatic Sciences 72:538-556.

Orbesen, E. S., C. A. Brown, D. Snodgrass, J. E. Serafy, and J. F. Walter III. 2019. At-vessel and postrelease mortality rates of bluefin tuna (*Thunnus thynnus*) associated with pelagic longline gear in the northern Gulf of Mexico. Fishery Bulletin 117:15-23.

SAFMC (South Atlantic Fishery Management Council). 2018. Amendment 31 to the Fishery Management Plan for Coastal Migratory Pelagic Resources in the Gulf of Mexico and Atlantic Region – Atlantic migratory group cobia management. SAFMC, North Charleston, SC.

Schlenker, L. S., R. J. Latour, R. W. Brill, and J. E. Graves. 2016. Physiological stress and post-release mortality of white marlin (*Kajikia albida*) caught in the United States recreational fishery. Conservation Physiology 4: cov066.

SEDAR (Southeast Data, Assessment, and Review). 2013. SEDAR 28 – Gulf of Mexico cobia stock assessment report. SEDAR, North Charleston, SC.

SEDAR. 2018. SEDAR 58 – Cobia stock ID process report compilation. SEDAR, North Charleston, SC.

SEDAR. 2020. SEDAR 28 – Gulf of Mexico Cobia update assessment report. SEDAR, North Charleston, SC.

Stunz, G. W., and D. A. McKee. 2006. Catch-and-release mortality of Spotted Seatrout in Texas. North American Journal of Fisheries Management.