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PERSPECTIVES AND NOTES

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Documentation of Atlantic tarpon (*Megalops atlanticus*) space use and move persistence in the northern Gulf of Mexico facilitated by angler advocates

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Abstract
Atlantic tarpon (*Megalops atlanticus*, hereafter tarpon) are facing a multitude of stressors and are considered Vulnerable by the IUCN; however, significant gaps remain in our understanding of tarpon space use and movement. From 2018 to 2019, citizen scientists facilitated tagging of 23 tarpon with SPOT tags to examine space use and movement across the northern Gulf of Mexico. Movement-based kernel densities were used to estimate simplified biased random bridge-based utilization distributions and a joint move persistence model was used to estimate a behavioral index for each fish. Tarpon showed consistent east–west movement from the Alabama/Florida border to Louisiana, and utilization distributions were highest in the Mississippi River Delta. Move persistence was highest in Alabama and Mississippi and lowest in Louisiana. Our examination of tarpon space use and movement indicates that Louisiana is a critical, yet understudied, part of their range.

KEYWORDS
citizen science, Louisiana, migration, satellite telemetry, SPOT tag

1 | INTRODUCTION

Atlantic tarpon (*Megalops atlanticus*, hereafter tarpon) is a highly migratory species with deep cultural and economic significance to anglers across the Atlantic Ocean (Ault, 2008), especially in the Gulf of Mexico (Davis, 2017). Unfortunately, tarpon populations in the Gulf of Mexico are experiencing multiple stressors including habitat loss and degradation, reductions in water quality, and lethal (and sublethal) effects from commercial and recreational fisheries (Adams et al., 2014). Compounding these stressors, tarpon embody a suite of life history characteristics, such as long life span, low adult mortality, and large body size, all of which lower compensatory capacity (Kindsvater, Mangel, Reynolds, & Dulvy, 2016). Consequently, tarpon are currently listed as Vulnerable by the International Union for the Conservation of Nature (IUCN, Adams et al., 2014).

Migration and movement of tarpon are well documented. A recent synthesis of multi-year tagging efforts has revealed large-scale movements and partial migrations by this species (Luo et al., 2020). By analyzing a combination of vertical habitat profiles and horizontal position estimates, the authors determined that areas in the western (Vera Cruz, Mexico) and eastern (Florida Straits) Gulf of Mexico long suspected as important may indeed serve as spawning locations (Luo et al., 2020); however, telemetered fish from Louisiana were lacking. Larval, juvenile, sub-adult, and adult tarpon have all been documented off the coast of Louisiana (Stein III, Shenker, & O'Connell, 2016), including concurrent male and female spawning-capable individuals (Stein III, Brown-Peterson, Franks, & O'Connell, 2012). Collectively, these lines of evidence suggest that the northern Gulf of Mexico, particularly Louisiana, represents an important, yet understudied, region for this species.

The northern Gulf of Mexico is home to several fishing rodeos, annual events that support large gatherings of recreational anglers. Increasingly, these anglers are recognized as conservation partners (Granek et al., 2008), often developing and voluntarily implementing resource-conserving guidelines such as catch-and-release (Cooke, Suski, Arlinghaus, & Danylchuk, 2013). Consequently, rodeo anglers afford unique opportunities for scientists to study fish movement. Since tarpon are notoriously elusive fish that require substantial angler expertise to capture, scientists can benefit from working in concert with organized tarpon fishing tournaments that provide access to fish, along with opportunities to interact with invested stakeholders (Humston, Ault, Schratwieser, Larkin, & Luo, 2008).

Given the cultural significance and inherent vulnerability of tarpon, we sought to further investigate this species by partnering with anglers from fishing rodeos and a tarpon-focused club in the northern Gulf of Mexico, all of which have implemented tarpon catch-and-release categories. In collaboration with these anglers, our objectives were to use satellite telemetry to examine tarpon space use and movement in the northern Gulf of Mexico.

2 | METHODS

2.1 | Tagging

Tarpon were captured in collaboration with anglers in the Alabama Deep Sea Fishing Rodeo tarpon catch-and-release category, anglers in the Mobile Rotary and Mobile-Sunrise Rotary Tarpon Tournament, and members of the Grand Isle Tarpon Club (Table 1) using hook-and-line gear. Once hooked, fish were brought alongside the boat as quickly as possible and secured anteriorly with a lip grip and posteriorly with a tailer. While the fish was submerged and oriented with its head into the current, fork length (FL) and girth (both in cm) were measured, and a scale was removed to facilitate tag insertion following Luo et al. (2020). Next, a towed Smart Position and Temperature (SPOT) tag (Wildlife Computers) was attached via a 60 cm stainless tether covered with medical grade Tygon tubing, terminating in a 64 mm titanium anchor (Fish 1–18) or a Domeier anchor (Fish 19–23), both from Wildlife Computers. The fish was then held alongside the vessel until it resisted, at which point it was released. A video detailing the cooperative tagging process can be viewed here.

2.2 | Data filtration

As facultative air-breathing fish, tarpon often come to the surface to gulp air in what is termed "rolling behavior" (Babcock, 1951). This behavior enabled the SPOT tags to transmit data to the Argos Satellite Platform (CLS America, Inc). Kalman filters were applied to Doppler-derived position estimates within the Argos platform. The resulting position estimates were then downloaded from the Wildlife Computers portal and filtered using a multi-step process. First, all Z position estimates were eliminated so that only position estimates with location classes A, B, 0, 1, 2, and 3 were retained. Next, land-based position estimates were removed, as were estimates indicating a swimming speed in excess of 2 m/s (Weng et al., 2005). To eliminate position estimates from floating SPOT tags that had detached from the fish, we followed criteria outlined in Hearn et al. (2013). Specifically, tags that repeatedly reached their maximum transmissions (250) during an approximate three-hour period, a period established by the hour the fish was originally tagged (i.e., the start of its 24-hr cycle), were deemed detached. This threshold was identified as the time needed for a tag in constant communication with a satellite to reach its maximum daily transmission limit and was indicative of a detached tag floating at the surface (Hearn et al., 2013). The first location after detachment was used as a final, or

TABLE 1 Summarized SPOT tag deployment information from 23 tagged tarpon

Fish ID	Angler	PTT	FL (cm)	Est. Weight (kg)	Deployment date	Deployment location	Last transmission date	Last transmission location	Days at liberty
1	Chris Tew	169305	155	34.9	7/20/2018	Gulf State Pier, AL	8/3/2018	Lake Borgne, LA	14
2	Chris Tew	169306	158	37.2	7/20/2018	Gulf State Pier, AL	8/5/2018	Mississippi River Delta	16
3	Larry Eberly	169307	160	46.7	7/20/2018	Gulf State Pier, AL	8/18/2018	Mississippi River Delta	29
4	Tom Eberly	169308	168	49.0	7/20/2018	Gulf State Pier, AL	8/22/2018	Breton Island, LA	33
5	Larry Eberly	169310	158	39.0	7/20/2018	Gulf State Pier, AL	8/8/2018	Mississippi River Delta	19
6	Tom Eberly	169311	148	37.6	7/20/2018	Gulf State Pier, AL	8/1/2018	Mississippi River Delta	12
7	Brad Caban	169303	164	39.0	7/21/2018	Gulf State Pier, AL	9/7/2018	Mississippi River Delta	48
8	Hayden Olds	169312	187	59.4	7/21/2018	Gulf State Pier, AL	7/23/2018	Petit Bois Pass, AL	2
9	Ernest Ladd	169302	175	49.4	7/28/2018	Gulf State Pier, AL	8/29/2018	Grand Island, LA	32
10	Brad Caban	169314	146	28.1	7/28/2018	Gulf State Pier, AL	8/17/2018	West Delta, LA	20
11	Hollie Tew	169304	157	38.1	7/19/2019	Gulf State Pier, AL	9/20/2019	Mississippi River Delta	63
12	Matt Leon	169313	157	39.5	7/19/2019	Gulf State Pier, AL	7/19/2019	Gulf State Pier, AL	0
13	Billy Wurzlow	169321	173	55.8	7/19/2019	Perdido Pass, AL	7/19/2019	Perdido Pass, AL	0
14	Joe Sherrill & Graham Taylue	151872	165	53.1	7/20/2019	Perdido Pass, AL	7/20/2019	Perdido Pass, AL	0
15	Larry Eberly	181908	145	29.9	7/21/2019	Gulf State Pier, AL	7/21/2019	Gulf State Pier, AL	0
16	Mitchell Lovell	169313	140	23.1	8/24/2019	West Delta, LA	10/4/2019	Mississippi River Delta	41
17	John DeBlieux	181908	168	53.1	8/24/2019	West Delta, LA	10/21/2019	Mississippi River Delta	58
18	Jeff DeBlieux	181911	142	30.4	8/24/2019	West Delta, LA	9/13/2019	Mississippi River Delta	20
19	Ivy Robichaux	181915	212	91.2	9/8/2019	east of Grand Isle, LA	9/8/2019	east of Grand Isle, LA	0
20	Jeff DeBlieux	169309	208	99.3	9/18/2019	east of Grand Isle, LA	9/18/2019	east of Grand Isle, LA	0
21	Kenny McGee	181912	150	33.1	9/25/2019	Southwest Pass, LA	11/13/2019	Isles Dernieres, LA	49
22	Jeff DeBlieux	181913	137	27.2	9/25/2019	Southwest Pass, LA	9/25/2019	Southwest Pass, LA	0
23	Mark Blanchard	181909	213	89.1	10/4/2019	Southwest Pass, LA	10/4/2019	Southwest Pass, LA	0

Note: Only fish that were tracked longer than 10 days ($n = 14$) were used in subsequent analyses. Fish 10 is depicted in the tagging video linked in Methods.

"pop-off," estimate. However, "pop-off" locations that were received at the start of a tag's 24-hr cycle were not included as these tags would have likely been floating in currents prior to giving a position estimate. Additionally, we examined the minimum values from the wet/dry sensor; position estimates with minimum wet/dry sensor values of 255 were considered suspect, and often indicated a tag that had detached from the fish and had washed ashore. To minimize uncertainty, tracks of position estimates with gaps greater than 3 days or less than 10 total transmission days were excluded from subsequent analyses.

2.3 | Space use

To examine space use, the movement-based kernel density estimation (MKDE) method was used to estimate simplified biased random bridge-based utilization distributions from daily position estimates for each tarpon (Benhamou, 2011). Movement-based kernel density estimates consider time and distance between position estimates and incorporate serially correlated movement, thus reducing bias when calculating space use for highly mobile species like tarpon. The utilization distributions for each tarpon were then summed and mapped in QGIS *v3.8.1* (Quantum GIS Development Team, 2019) to visualize areas of core habitat use (Rooker et al., 2019). The estimates were computed using the adehabitatHR package (Calenge, 2011) in the software program R *v3.6.3* (R Core Team, 2020, Vienna, Austria).

2.4 | Move persistence

To examine changes in movement behavior, a correlated random walk state-space model was used to interpolate and regularize data to a 24-hr interval using the FoieGras package (https://github.com/ianjonsen/foieGras) in R. Then, a joint move persistence model was fit to the regularized data to estimate a time-varying behavioral index for each tarpon. Move persistence is a parameter that encompasses both speed and directionality; thus, the move persistence model estimates a behavioral index that is comparable to the discrete behavioral states estimated in state-space switching models (Jonsen et al., 2019). Rather than discrete behavioral switches, time-varying move persistence is an alternative approach to objectively identify changes in movement pattern using the move persistence parameter (g_t), which ranges from low move persistence (where a value of 0 indicates slow speed and little directionality) to high move persistence (where a value of 1 indicates high speed and constant directionality) (Jonsen et al., 2019).

3 | RESULTS

From 2018 to 2019, 23 tarpon were fitted with towed SPOT tags. Fifteen of these fish were tagged in Alabama in July of 2018 and 2019, and 8 were tagged in Louisiana in August and September of 2019. The mean size of tagged tarpon was 165 cm FL (±4.6 cm SE), with a size range of 137–213 cm FL. Tarpon weight was estimated using FL and girth (Ault & Luo, 2013). The mean weight of tagged tarpon was estimated at 47 kg (±4.3 kg SE), and estimated weight ranged from 23 to 99 kg. Accordingly, most (17 of 23, 74%) individuals were considered sexually mature (i.e., >35 kg, Crabtree, Cyr, Chaćon Chaverri, McLarney, & Dean, 1997).

Time at liberty varied among individuals, but ranged from 0–63 days (mean 20 ± 4.3 days SE). Of the 23 tags deployed, 8 (35%) did not transmit any data due to failed deployments and 1 (4%) transmitted for less than 10 days. The remaining 14 tags (61%) transmitted for more than 10 days and generated 1,334 position estimates. After data filtration, 1,144 (86%) of these position estimates were used in subsequent analyses (Table 1).

The 14 tarpon examined in detail showed consistent east–west movement across the northern Gulf of Mexico from the Alabama/Florida border to the Mississippi River Delta. Filtered position estimates from these 14 tarpon are shown in Figure 1a. Clear space use patterns were evident. In particular, MKDEs were highest in the shallow waters surrounding the Pass a Loutre State Wildlife Management Area, followed by adjacent regions to the west (Figure 1b). Tarpon less frequently accessed areas around Breton Island and Lake Borgne (Figure 1b).

Move persistence models highlighted two primary changes in movement patterns, analogous to discrete behavioral switches (Jonsen et al., 2019). For tarpon tagged in Alabama, move persistence was highest during the initial portion of the track, particularly in July (e.g., Fish 5, 6, 7, 10, and 11), and generally decreased thereafter. In four instances, move persistence did not peak immediately after tagging. For example, two fish (Fish 1 and 4) made brief trips into Mobile Bay immediately after tagging. Tarpon tagged in Louisiana showed the opposite pattern, with low initial move persistence in August (e.g., Fish 17, 18, and 21) and increased move persistence in September (Figure 2a). Spatially, move persistence was highest off the coasts of Alabama and Mississippi and decreased notably to the southwest, particularly near the Chandeleur Islands and throughout the Mississippi River Delta (Figure 2b).

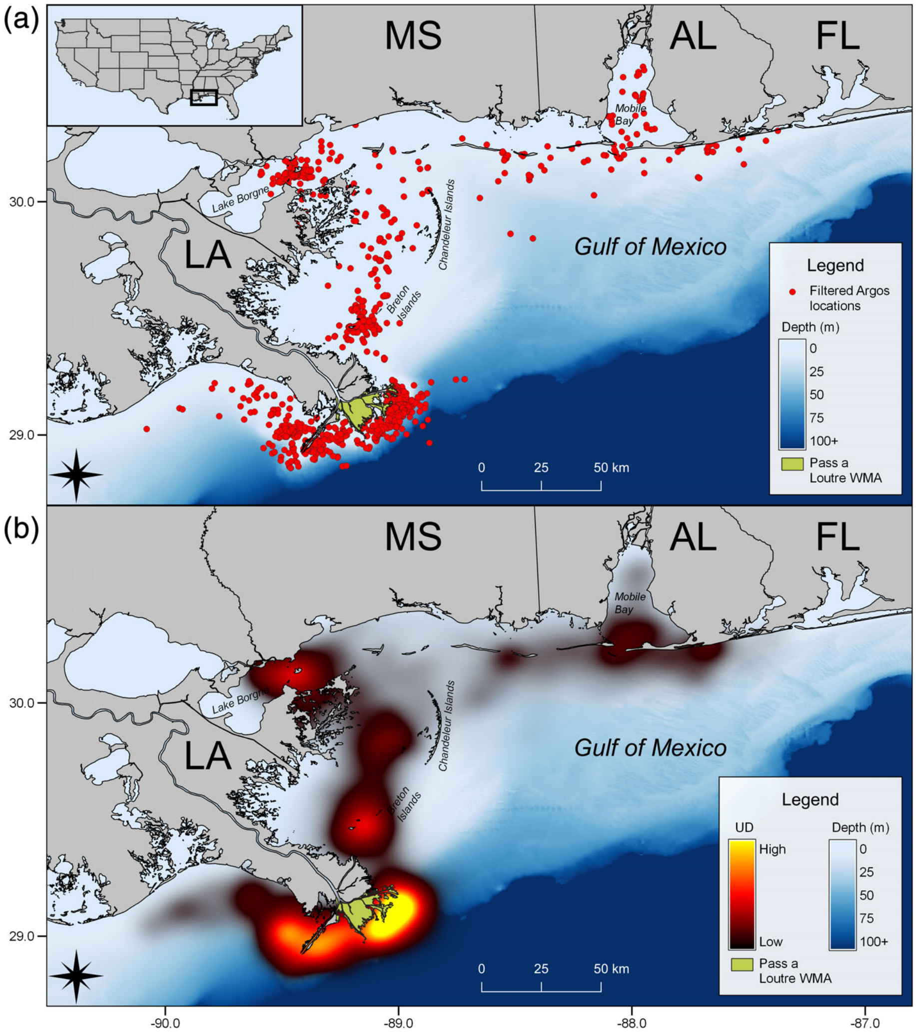

FIGURE 1 (a) Map displaying the raw filtered Argos position estimates from SPOT tagged tarpon used in this study. (b) Map displaying the movement-based kernel density estimation (MKDE) derived sum utilized distribution (UD) estimates of tarpon tagged in this study

4 | DISCUSSION

Our examination of tarpon space use and movement furthers the work of Luo et al. (2020) and indicates that Louisiana is a critical part of their range. Notably, all fish that were tracked for more than 2 days were last detected in Louisiana. More importantly, the movement model demonstrated high move persistence in Mississippi and Alabama waters, yet low move persistence in Louisiana, which aligns with the consistent low rates of movement previously shown for tarpon along the Louisiana coast (Luo et al., 2020). While Louisiana is clearly an important destination for these fish in the fall, identifying the specific value of this habitat for tarpon requires further investigation.

Foraging opportunities are perhaps the most likely explanation for the prevalence of tarpon in Louisiana. The Mississippi River Delta is characterized by highly enriched riverine discharge, which culminates in enhanced regional fishery production, particularly during the fall (Grimes, 2001). Not surprisingly, MKDE analysis identified the highest space use in and around Pass a Loutre Wildlife Management Area, a region characterized by frequent freshwater discharge. These highly eutrophic freshwater pulses reduce dissolved oxygen (reviewed in Rabalais et al., 2014), which creates an inhospitable environment for predators that lack the tarpon's air-breathing organ (Babcock, 1951) and may reduce competition for shared prey resources, as well as provide refuge from regionally-abundant tarpon predators like bull sharks (*Carcharhinus leucas*) (Blackburn, Neer, & Thompson, 2007; Calich, Estevanez, & Hammerschlag, 2018). Future investigations are needed to confirm the importance of the local prey assemblage to tarpon feeding ecology.

Not mutually exclusive of feeding, spawning presents an alternative explanation for the extensive space use of the Mississippi River Delta by tarpon. Although tarpon spawning has yet to be observed directly, spawning areas have been predicted by the presence of tarpon larvae in the eastern and western Gulf of Mexico (Smith, 1980). Individual tarpon across ontogeny, including larvae,

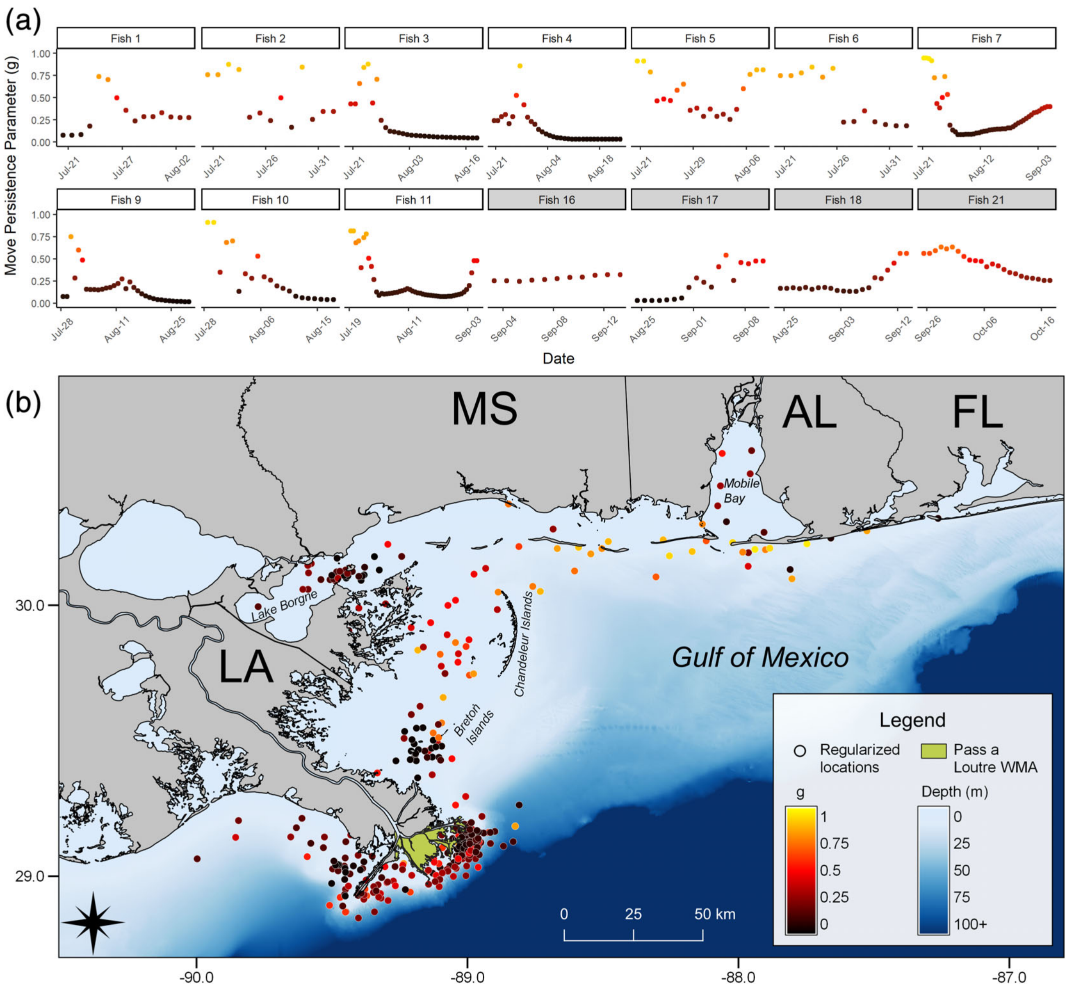

FIGURE 2 (a) The move persistence parameter (g_t) displayed as a time-series for the state-space model filtered tarpon data, with white and grey name templates indicating fish tagged in Alabama verses Louisiana, respectively. (b) Map displaying the move persistence parameter (g_t) for each of the state-space model filtered tarpon locations

young-of-the-year, juveniles, subadults and spawning capable adults, have all been documented off southeastern coastal Louisiana (Stein III et al., 2012; Stein III et al., 2016). Moreover, larval tarpon are routinely captured in the inshore waters of the Mississippi Sound, leading Graham, Franks, Tilley, Gibson, and Anderson (2017) to suggest a likely spawning area in the northern Gulf of Mexico. Most recently, Luo et al. (2020) correlated deep-diving behavior with lunar cycles to provide the most comprehensive evidence of tarpon spawning areas in Mexico and Florida. Luo et al. (2020) further predicted potential tarpon spawning habitat in the areas just offshore Pass a Loutre Wildlife Management Area, the same region where we documented greatest space use. Our move persistence model indicates that tarpon move quickly through Mississippi waters and are thus unlikely to be actively spawning; therefore, we suggest that the northern Gulf of Mexico spawning area hypothesized by Stein III et al. (2012), Stein III et al. (2016), Graham et al. (2017) and Luo et al. (2020) is most likely near the Mississippi River Delta. Future work to validate coastal Louisiana as a tarpon spawning area could model tarpon larval transport (sensu Shenker et al., 2002) and make use of acoustic tags with pressure (i.e., depth) sensors, which could document deep dives possibly associated with spawning.

Regardless of the mechanism underpinning the importance of the Mississippi River Delta to tarpon, citizen scientists are clearly part of the conservation solution. Several recent advances in our understanding of tarpon population structure (Guindon et al., 2015), movement and migration (Luo et al., 2020), and nursery habitat use (Wilson, Adams, & Ahrens, 2019) have been facilitated by citizen science efforts, particularly in Florida. For example, tarpon anglers from nine southeastern US states (Texas through Virginia) collected nearly 24,000 tarpon tissue samples in support of a genetic mark-recapture study; 96% of these were collected in

Florida (Guindon et al., 2015). Despite comprising a smaller community of anglers, the Alabama, Mississippi, and Louisiana citizen scientists who participated in the current study were vital in identifying exactly when tarpon first begin their westward migration across the northern Gulf of Mexico, and are no less invested than their Florida counterparts. Rather, these anglers have reached one of the pinnacles of stakeholder involvement and stewardship, acting as advocates capable of effecting change across their relatively small-scale fisheries (Granek et al., 2008). Future studies seeking to further identify the importance of the Mississippi River Delta for tarpon should continue to collaborate with these critical conservation partners.

Our analyses suggest the importance of the Mississippi River Delta to northern Gulf of Mexico tarpon, but future investigations in this region should expand upon the limitations of the technology used in the current study. Across marine taxa, deployed Argos tags often do not transmit data, most commonly due to failure of the salt-water switch or premature detachment (Hays, Bradshaw, James, Lovell, & Sims, 2007). The same was true for tarpon tagged in this study. Notably, the SPOT tag success rate, defined as the number of tags that provided data for at least 10 days, in this study (61%) was nearly identical to previous efforts employing towed SPOT tags on tarpon (60% and 63% for Hammerschlag, Luo, Irschick, and Ault (2012) and Luo et al. (2020), respectively). Moreover, results from these same studies suggest that towed SPOT tags rarely stay attached to tarpon for longer than 6 weeks. Thus, while valuable, these "movement snapshots" raise nearly as many questions as they answer. Of particular interest is identifying when northern Gulf of Mexico tarpon begin their fall migration, and whether or not these fish return to Florida. Notably, of the nearly 300 tarpon tracks reported in Luo et al. (2020), no tarpon tagged east of the Mississippi River migrated west of Louisiana, or vice-versa. Unfortunately, our tags detached before we could gain insight into these patterns. Rather than employing a single tag type, future efforts to examine tarpon movements in this area might consider taking a multi-tag approach; for example, an acoustic tag with a pressure sensor, combined with a mark-recapture tag programed to pop-off several months after deployment, and/or an accelerometer to explore the influence of the capture event on movement. This strategy would enable long-term monitoring of individuals and possibly aid in identifying spawning areas and movement patterns across the Mississippi River Delta.

Tarpon are unique and vulnerable fish, and the Mississippi River Delta is a unique and imperiled habitat. Throughout the last century, coastal habitat in Louisiana has receded at an alarming rate, accelerated by frequent natural (e.g., hurricanes, Day et al., 2007) and anthropogenic (e.g., river diversions, Day et al., 2000) disturbances. Counterintuitively, fisheries production has not declined accordingly (Cowan Jr, Grimes, & Shaw, 2008), corroborating the complex (and yet unknown) relationship between fish and the habitats they use. For tarpon in the northern Gulf of Mexico, it remains unclear whether the Mississippi River Delta functions as feeding or spawning habitat, although a combination of both is possible. Despite this uncertainty, our study clearly emphasizes the vital role that angler advocates play in the conservation of this iconic species.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

J. Marcus Drymon, Andrea M. Kroetz, and Sean P. Powers conceived the study; J. Marcus Drymon, Matthew B. Jargowsky, Michael A. Dance, Mitchell Lovell, Crystal LouAllen Hightower, and Andrea M. Kroetz performed the fieldwork; J. Marcus Drymon, Matthew B. Jargowsky, and Amanda E. Jefferson analyzed and interpreted the data; J. Marcus Drymon wrote the first draft of the article, and all coauthors contributed to subsequent versions.

ETHICS STATEMENT

No ethics review was required for this study.

DATA AVAILABILITY STATEMENT

The telemetry data from this study are available upon request from the corresponding author.

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