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Angler and guide perceptions provide insights into the status and threats of the Atlantic tarpon (*Megalops atlanticus*) fishery

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ABSTRACT

Atlantic tarpon (*Megalops atlanticus*) support an economically important fishery, yet there is limited information on the status of their fishery and population. A survey consisting of anglers and fishing guides was administered to help address these data deficiencies and to better understand the current and historical status of the recreational Atlantic tarpon fishery. An additional goal was to assess perceived threats to Atlantic tarpon and understand what anglers and fishing guides view as priorities for improved conservation and management efforts. Respondents (n = 918 completed surveys) indicated a significant decline in fishing quality since the 1970s. Respondents perceived water and habitat quality as the greatest threats to Atlantic tarpon populations and restoration of those as the top conservation priorities. Respondents also supported regulations that prohibit harvest (i.e., catch-and-release only), increased science efforts to understand Atlantic tarpon ecology for conservation solutions, and spatial management, such as pole-troll zones (i.e., where high speed motorboat travel is prohibited). Support for conservation solutions varied between those that targeted Atlantic tarpon with spin and fly gear, with fly gear anglers having higher support for increased regulatory oversight. With individual guides losing, on average, 2–7 Atlantic tarpon per year to sharks over the last five years, shark encounters appear to be increasing and are located in areas where Atlantic tarpon seasonally aggregate, such as passes. Given the chronic data-limited situation, local ecological knowledge derived from recreational anglers and fishing guides provide an important source of knowledge for the current and future conservation of Atlantic tarpon populations.

1. Introduction

The Atlantic tarpon (*Megalops atlanticus*), is a long-lived and late-maturing mesopredator found within the Atlantic Ocean, Caribbean Sea, and Gulf of Mexico [1]. Many of these fish seasonally migrate between their foraging and spawning areas, which can be over 1000 kilometers apart [2]. In more temperate regions, productive estuarine systems putatively provide abundant prey sources (e.g., *Clupeidae*, *Mugilidae*, *Caridea*, *Portunidae*) needed to sustain subsequent spawning migrations [3–5]. During the spawning season, Atlantic tarpon will form inshore pre-spawning aggregations, composed of thousands of fish, before moving offshore for deeper waters to spawn during new/full moons [3,6]. Currently, Atlantic tarpon are listed as Vulnerable by the International Union for Conservation of Nature (IUCN) due to historical and current commercial/subsistence harvest, water quality and habitat degradation, and angling-related mortality (e.g., physiological stress, shark predation/depredation) [3,8–11].

Across their range, Atlantic tarpon are also a prized gamefish and support a multi-million-dollar recreational fishery. For example, for just three Atlantic tarpon angling destinations in Florida, United States (i.e., The Everglades, Charlotte Harbor, and St. Lucie River), the total economic impact of the fishery was estimated to exceed $300 million USD annually [12–14]. Atlantic tarpon, along with other coastal fisheries, i.e., for bonefish (*Albula vulpes*) and permit (*Trachinotus falcatus*), also contribute to multiple regional economies, such as the Florida Keys, United States ($465 million USD) and Belize ($55 million USD) [15].

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Although some commercial, subsistence, and trophy harvest still exists for Atlantic tarpon, the fishery is primarily catch-and-release [8]. As with many marine recreational catch-and-release fisheries, Atlantic tarpon have had no formal stock assessment and related population monitoring making it difficult to quantify abundance trends.

In recent decades, local ecological knowledge (LEK) has become popular in helping to address gaps for recreational fisheries devoid of stock assessments [16]. Approaches include angler diary and tournament records [17–19], key informant interviews [18,20,21], and angler/guide surveys [22]. These approaches, either by themselves or combined [23], help establish baseline trends and avoid 'shifting baseline syndrome' [24], when stakeholders or scientists misidentify biological reference points due to collective memory loss. Further, when compared to quantitative stock assessment series, LEK has reliably captured the status of fish stocks and their levels of exploitation [25,26]. For example, for the bonefish fishery in the Florida Keys, multiple LEK-oriented studies have documented the decline in abundance and its extent across both space and time [19,20,22,27–29]. These data enabled resource managers to monitor the recovery of the fishery and identify management opportunities [30].

Considering the contribution of the Atlantic tarpon recreational fishery to local economies, understanding the population status and related trends in the fishery, as well as management and conservation needs, are essential to ensure its sustainability. Such information is particularly important for Atlantic tarpon since their life history characteristics, including being long-lived, late maturing, and highly migratory, may make their population quite vulnerable to exploitation and may contribute to low resilience to anthropogenic disturbance. Given the deep history of the Atlantic tarpon recreational fishery, dating back to 1885 [31], participants possess extensive knowledge of the Atlantic tarpon population status and changes over time. Thus, using a survey-based approach with predominately closed-ended questions, the objective of this study was to acquire and interpret LEK related to the current and historical (from the 1970s to the 2010s) status of the recreational Atlantic tarpon fishery across multiple regions (Africa, Caribbean, Central America, Gulf of Mexico, South America, Southeastern United States). The perceived threats of anglers and guides and their priorities for improved management and conservation efforts across gear types (fly gear vs. spinning gear) were also assessed. The last objective was to evaluate a prominent and emerging threat of shark depredation and post-release predation in the Atlantic tarpon fishery [32]. This threat has anecdotally increased over the last decade and warranted additional examination. The intent is that these findings, obtained from LEK, are incorporated in future Atlantic tarpon research, management, and conservation efforts.

2. Material and methods

2.1. Sampling frame and distribution

To better understand the current and historical status of the Atlantic tarpon fishery, we constructed and implemented an online survey that took approximately 12-minutes to complete. Anglers and guides were eligible to participate in the survey if they were 18 years or older and had Atlantic tarpon angling experience. The survey was only available in English which is noteworthy given that the primary language in some areas the Atlantic tarpon fishery occurs is Spanish (e.g., Mexico, Cuba). The survey was launched on September 09, 2020 and closed on August 8, 2021. Survey distribution relied on a snowball sampling approach using social media and relevant e-newsletters to reach Atlantic tarpon anglers. While it can introduce a bias toward digitally literate individuals, online survey distribution and snowball sampling are valuable tools for reaching relatively wide-spread and niche populations [32,33], like recreational Atlantic tarpon anglers and fishing guides. The survey was shared on Twitter, Instagram, and Facebook by the authors as well as relevant angling organizations, including Bonefish & Tarpon Trust (https://www.bonefishtarpontrust.org) and fishing clubs (e.g., Cape Coral Tarpon Hunters, https://www.capecoraltarponhunters.com). The survey was also shared regularly in the monthly Bonefish & Tarpon Trust e-newsletter. An incentive raffle reward was also included as an option in the survey (i.e., a Patagonia Roll Top Backpack, Patagonia Inc., Ventura, California, US). The survey was administered via Qualtrics, and the survey mechanism and methodology were approved by the University of Massachusetts Amherst Institutional Review Board (Protocol ID: 2019–2196).

2.2. Survey instrumentation

The survey was divided into three sections to collect data regarding 1) angler behavior, 2) Atlantic tarpon fishing quality and conservation concerns, and 3) angler demographics (see Appendix I for the complete survey). The survey flow gave respondents access to all three parts of the survey, regardless of initial responses. The focus of section one was to gather basic information about the fishing habits of the respondent, including where they fish (geographic region and specific habitats), when they fish (month of the year), years of experience, annual days on the water, if they are a fishing guide, gear type used (spin or fly gear), and the number of Atlantic tarpon hooked and landed. Section three collected general demographic information, including age, gender, and country of residence. To explore the potential link between personal identity and environmental stewardship [34], this section also asked all respondents to rate the importance of a series of six personal identities (environmentalist, outdoorsperson, catch-and-release angler, angler, hunter, conservationist) on a five-point Likert scale ranging from 1 - "Not at all important" to 5 - "Very important."

Section two was the most extensive section of the survey and focused on potential changes in Atlantic tarpon fishing quality, potential threats to the Atlantic tarpon population, and favored conservation efforts. First, the survey asked respondents if they had observed any changes in the timing of the Atlantic tarpon migration in the last five years, with the option to select earlier arrival, later arrival, or no change. Respondents were then asked to rate on a five-point Likert scale the potential changes to overall Atlantic tarpon fishing quality since they started fishing, ranging from 1 - "Dramatically declined" to 5 - "Greatly improved." Subsequently, they could evaluate Atlantic tarpon fishing quality by decade from the 1970s to the 2010s on a five-point Likert scale ranging from 1 - "Very poor" to 5 - "Very good" with the option to select not applicable. A free response question followed, where respondents could share the major factors affecting Atlantic tarpon fishing quality. Following Atlantic tarpon fishing quality questions, we collected data on threats to the Atlantic tarpon population, first by allowing respondents to evaluate a series of potential threats (habitat decline, angling pressure, angler ethics, non-angling recreational activities, predation by sharks related to angling events, water quality, differing harvest regulations, insufficient regulations) on a Likert scale ranging from 1 - "Very low threat" to 5 - "Very high threat." This was followed by specific questions regarding shark encounters while Atlantic tarpon fishing, including the number of Atlantic tarpon lost to sharks per season, if the number of Atlantic tarpon lost to sharks has changed in the last five years, and in which habitats shark encounters were most likely to occur. Finally, respondents were asked to indicate their degree of support for a series of Atlantic tarpon conservation efforts (catch-and-release only for Atlantic tarpon, strict Atlantic tarpon handling guidelines, water quality management solutions, increased pole-troll zones, banning dead bait use, no Atlantic tarpon angling around select bridges and/or passes, expanded commercial and recreational shark harvest, targeted shark culls near Atlantic tarpon aggregations, license fees for out of state Atlantic tarpon guides, increased science efforts to understand Atlantic tarpon ecology for their conservation, no efforts needed for Atlantic tarpon conservation) from 1 - "Very low support" to 5 - "Very high support" as well as indicate which managing bodies (federal government, state or provincial governments, non-governmental conservation organizations, guide associations, individual angler) were responsible for Atlantic tarpon conservation and management from 1 - "Very low responsibility" to 5 - "Very high responsibility."

2.2.1. Data preparation and analysis

All data preparation and analyses were conducted in R [35] via R Studio [36]. Only respondents who progressed through the entire survey were retained for analysis. Likert scale data collected in this survey were visualized using the *HH* package [37].

2.2.2. Fishing habits and demographic information

Fishing behavior and demographic information were summarized to generate a general overview of the surveyed population. When asked which habitats they fished in most frequently, respondents were allowed to select "other" and supply a habitat if they felt their preferred fishing locations were not listed. Often, these habitats did fall into an already listed category; for example, "jetties" were reclassified as the provided "nearshore (e.g., flats, beaches, sandbars)" option, and "mangrove creeks" were reclassified as "estuaries." Two new habitat categories were generated from common "other" responses that did not fit into a pre-existing category: canals/docks/boat ramps and coastal/open ocean (for those that reported fishing 3–5 mi offshore).

2.2.3. Changes in perceived Atlantic tarpon fishing quality

Detailed analyses were conducted to quantify observed changes in Atlantic tarpon fishing quality over time that could be tied to population health and changing climate. Respondents were asked to rate overall change in Atlantic tarpon fishing quality since they started fishing as well as rate the fishing quality by applicable decade from the 1970s – 2010s. For the decadal analysis, anglers who had been fishing from the 1970s to present day were selected to determine how fishing quality changed over time. The five-point Likert scale of 1 - "Very poor" to 5 - "Very good" was converted to numerical and an overall change was calculated for each individual. A two-sample t-test was used to determine if there were significant differences between guide and angler perceptions of overall change. A second two-sample t-test was run to determine if mean Atlantic tarpon fishing quality changed significantly from the 1970s to the 2010s. In addition, Mann-Whitney U tests were conducted to determine if there were significant differences in how anglers and guides or fly and spin respondents perceived Atlantic tarpon fishing quality across decades.

Finally, responses to observed changes in the timing of the annual Atlantic tarpon migration were analyzed using ordinal logistic regression [38]. A forward stepwise approach built towards the global model:

$$\widetilde{Y}_{Seasonality\ Change} = b_1(Guide\ Status)_1 + b_2(Years\ of\ Experience)_2 + b_3(Yearly\ Days\ on\ the\ Water)_3 + b_4(Angling\ Location)_4 + \varepsilon$$

Where $\widetilde{Y}$ is the latent continuous variable of the ordered categorical variable Y, b is the contrast between thresholds of the ordered variable, and ε represents the remaining unexplained variation in the cumulative model [39].

Using the *ordinal* package [40], candidate models were constructed, and Akaike information criterion (AIC) was used to select the best performing model from the candidate set using *AICcmodavg* [41]. If necessary, post-hoc pairwise comparisons were generated for significant variables in the best performing model using least-square means in the *emmeans* package [42]. Model fit was assessed with the Nagelkerke pseudo R^2 value [43] as well as the Pulkstenis-Robinson and Hosmer-Lemshow tests [44] using the *generalhoslem* package [45].

2.2.4. Perceptions of threats to and conservation strategies for Atlantic tarpon

Mann-Whitney U tests were run to determine if there were significant differences between how anglers and fishing guides perceived threats to the Atlantic tarpon population and the importance of various conservation efforts. Differences in threat perception and valued conservation efforts were also examined by gear type (fly gear vs. spinning gear). We used respondent's personal identity scores and reported years of angling experience to understand the mechanisms that may have driven differences in values between gear preferences. Principal components analysis with an 'oblimn' oblique rotation and post hoc Chronbach's alpha tests (minimum threshold $\boldsymbol{\alpha} = 0.6$) were conducted using the *psych* package [46] to determine if personal identity questions could be collapsed into aggregate groups (e.g., an encompassing category to explain similar responses). Mann-Whitney U tests were then run to test for significant differences in personal identity and fishing experiences between gear types.

2.2.5. Shark encounters

To better quantify issues related to shark encounters in the Atlantic tarpon fishery, both depredation and post-release predation, the average number of Atlantic tarpon lost by guides for each gear type was estimated first. Only guides were selected because they likely spend the greatest amount of time fishing for Atlantic tarpon. Additionally, anglers often charter fish with guides to catch Atlantic tarpon, which could confound the estimate of lost fish. Because respondents were given binned ranges to report the number of Atlantic tarpon lost to sharks, they were converted into values to generate a low and high mortality estimate. For example, those who selected the "1–4 Atlantic tarpon lost" option received two values, with the low estimate being one and the high estimate being four. In another example, for those who reported losing 20 + Atlantic tarpon received a low estimate of 20 and a high estimate of 25. In this latter example of using 25 as a high estimate, it is worth noting this likely produced an underestimate of the actual number of Atlantic tarpon lost to sharks. An average for each gear type was then generated for the low and high values. Subsequently, ordinal logistic regression, as is appropriate for Likert scale data [46], was used to model variation in the number of Atlantic tarpon lost to sharks and trends (increase, no change, decrease) in the number of Atlantic tarpon lost to sharks in the last five years. The global model for each individual regression was as follows:

$$\widetilde{Y}_{Number\ or\ Trend} = b_1(Guide\ Status)_1 + b_2(Years\ of\ Experience)_2 + b_3(Yearly\ Days\ on\ the\ Water)_3 + b_4(Angling\ Location)_4 + b_5(Gear\ Type)_5 + b_6(Yearly\ Number\ of\ Atlantic\ Tarpon\ Landed)_6 + b_7(Fishing\ Habitat)_7 + \varepsilon$$

Finally, anglers were asked to rank the habitats where they were most likely to lose an Atlantic tarpon to sharks while angling given the options: bridges within 100 yards (i.e., approximately 90 m), passes and inlets, nearshore (e.g., flats, beaches, sandbars), rivers and estuaries, and bays and backcountry. A Plackett-luce model for ranks was used to determine which habitats anglers felt were the highest risk for Atlantic tarpon using the *PlackettLuce* package [47]. Again, AIC was used to select the best performing model, and post-hoc least-square means pairwise comparisons were used for significant multilevel categorical variables when needed.

3. Results

3.1. Fishing habits and demographic information

Of 1128 responses, 918 were fully completed and retained for full analyses. Of those, 90% (n = 824) were anglers not employed as fishing guides, 71.87% (n = 654) fished primarily with fly rods, and primary targeted Atlantic tarpon across the Caribbean (n = 44), Central America (n = 82), Gulf of Mexico within USA (n = 589), and Southeastern USA (n = 159) (Table 1). Respondents were predominantly men over the age of 45 whose primary residence was in the United States (n = 881). Other countries of residence included Belize (n = 5), Bahamas (n = 2), Costa Rica (n = 2), Mexico (n = 2) (Table 2). Overall, respondents fished most often in the Gulf of Mexico along the coastal United States, followed by the Southeastern Atlantic Coast of the United States (Fig. 1, Fig. 2a). Throughout the year, and across fishing locations, fishing pressure was highest in May and June, largely driven by fishing pressure in the Gulf of Mexico. Fishing pressure was highest in the Southeastern United States from June through August (Fig. 2b). Within the United States, respondents fished primarily in Florida (Table S1), mainly the Florida Keys (n = 240), West Florida (between Marco Island and Apalachee Bay; n = 212), and the Everglades (n = 94). Most anglers in the Florida Keys targeted tarpon in the Lower Keys (n = 105) followed by the Middle Keys (n = 87). Within West Florida, the most popular regions were between Venice and Marco Island (n = 129) and between Tarpon Springs and Venice (n = 35).

3.2. Changes in perceived Atlantic tarpon fishing quality

Overall perceived changes in Atlantic tarpon fishing quality were best modeled by variation in guide employment status, years of Atlantic tarpon angling experience, number of days Atlantic tarpon fishing, angling location, and gear type (Nagelkerke pseudo $R^2 = 0.29$, Pulkstenis-Robinson and Hosmer-Lemeshow tests $p < 0.05$). Compared to guides, anglers believed Atlantic tarpon fishing quality was significantly better ($p = 0.025$). Further, respondents using spin gear felt fishing quality was better than those using fly gear ($p = 0.017$). Respondents who fished less than 5 years or 5–9 years had significantly different perceptions of fishing quality than anglers who fished 15–19 years or 20 or more years ($p < 0.01$). Those with more fishing experience were more likely to report Atlantic tarpon fishing quality declines and less likely to report that fishing quality had improved (Fig. 3). Respondents in the Caribbean ($p = 0.03$) and Southeastern United States ($p < 0.001$) were more likely to report that fishing quality had improved than those fishing in the Gulf of Mexico (Fig. 4). Overall, the majority of respondents felt that Atlantic tarpon fishing quality had remained the same, with the exception of guides with more than 20 years of Atlantic tarpon angling experience, who were more likely to report that fishing quality had declined.

Regardless of the decade, respondents generally felt that Atlantic tarpon fishing quality was good to very good, though the proportion of respondents who felt the fishing quality was fair to very poor did increase over time (Fig. 5). Of the 918 survey respondents, 158 provided information on decadal Atlantic tarpon fishing quality from the 1970s through the 2010s. These respondents reported a significant decline in Atlantic tarpon fishing quality (Two sample t-test: $t = 8.81$, $df = 307.99$, $p < 0.001$) from good to fair (Fig. S1). There were no significant differences in the perceived change in fishing quality between anglers and guides who had been fishing from the 1970s through 2019 (two sample t-test: $t = -0.49$, $df = 31.86$, $p = 0.63$). No significant differences were found in perceived Atlantic tarpon quality across decades based on gear preference (results of five Mann-Whitney U tests: n range: 202–875, U range:1468 - 60,098, $p > 0.05$). There were also no differences in how anglers and guides perceived decadal fishing quality (results of four Mann-Whitney U tests: n range: 202–875, U range: 649.5–28,666, $p > 0.05$), with the exception of the 1990s, where a larger proportion of guides felt fishing quality was very good (Mann-Whitney U test: $n = 387$, $U = 3349$, $p = 0.013$).

Observed changes in the timing of the Atlantic tarpon migration were best modeled using ordinal logistic regression including guide employment status, years of angling experience, days on the water, and angling location (Nagelkerke pseudo $R^2 = 0.20$, Pulkstenis-Robinson and Hosmer-Lemeshow tests $p < 0.05$). Anglers that had fished for less than five years had significantly different perceptions of Atlantic tarpon migration seasonality than those with 10–14 years ($p = 0.030$) or 15–19 years ($p = 0.011$) of experience. Specifically, anglers with more fishing experience were more likely to report observing the Atlantic tarpon migration earlier than previous years compared to those with less fishing experience, who were more likely to report that the migration was occurring later than previous years (Fig. 6). This was especially prevalent in the USA Gulf of Mexico ($p = 0.013$) and Southeastern USA ($p = 0.016$), where angler perceptions were significantly different from those in Central America.

Table 1
Summary of angler and guide fishing habits collected from section one of the survey presented as count (n) and percent (%) of respondents to each question.

	n	%
Employed as a Fishing Guide (n = 914)		
No	824	90.15
Full time guide	64	7.00
Part time guide	16	1.75
Seasonal guide	10	1.09
Years of Angling Experience (n = 890)		
Less than 5 years	137	15.39
5–9 years	169	18.99
10–14 years	152	17.08
15–19 years	89	10.00
20 + years	343	38.54
Days per Year Atlantic tarpon Fishing (n = 811)		
Less than 15 days	435	53.64
15–49 days	310	38.22
50–99 days	14	1.73
100–149 days	30	3.70
150–199 days	14	1.73
200–249 days	3	0.37
250 + days	5	0.62
Primary Fishing Location (n = 874)		
Africa	0	0.00
Caribbean	44	5.03
Central America (including Mexico)	82	9.38
Gulf of Mexico within USA (including Florida Keys)	589	67.39
South America	0	0.00
Southeastern USA (Atlantic Ocean)	159	18.19
Primary Gear Type (n = 910)		
Fly fishing	654	71.87
Spin fishing, artificial lures	72	7.91
Spin fishing, bait	184	20.22

Table 2
Summarized demographic information collected in part three of the survey presented as count (n) and percentage (%) of total respondents to each question. Top responses for "other" country of residence included Canada (n = 10), Puerto Rico (n = 4), and Argentina (n = 3).

	n	%
Age (n = 906)		
18–24	29	3.20
25–34	87	9.60
35–44	82	9.05
45–54	160	17.66
55–64	239	26.38
65 +	309	34.11
Gender (n = 875)		
Female	31	3.54
Male	842	96.23
Other	2	0.23
Country of Residence (n = 915)		
Bahamas	2	0.22
Belize	5	0.55
Cuba	0	0.00
Costa Rica	2	0.22
Mexico	2	0.22
Other	23	2.51
USA	881	96.28

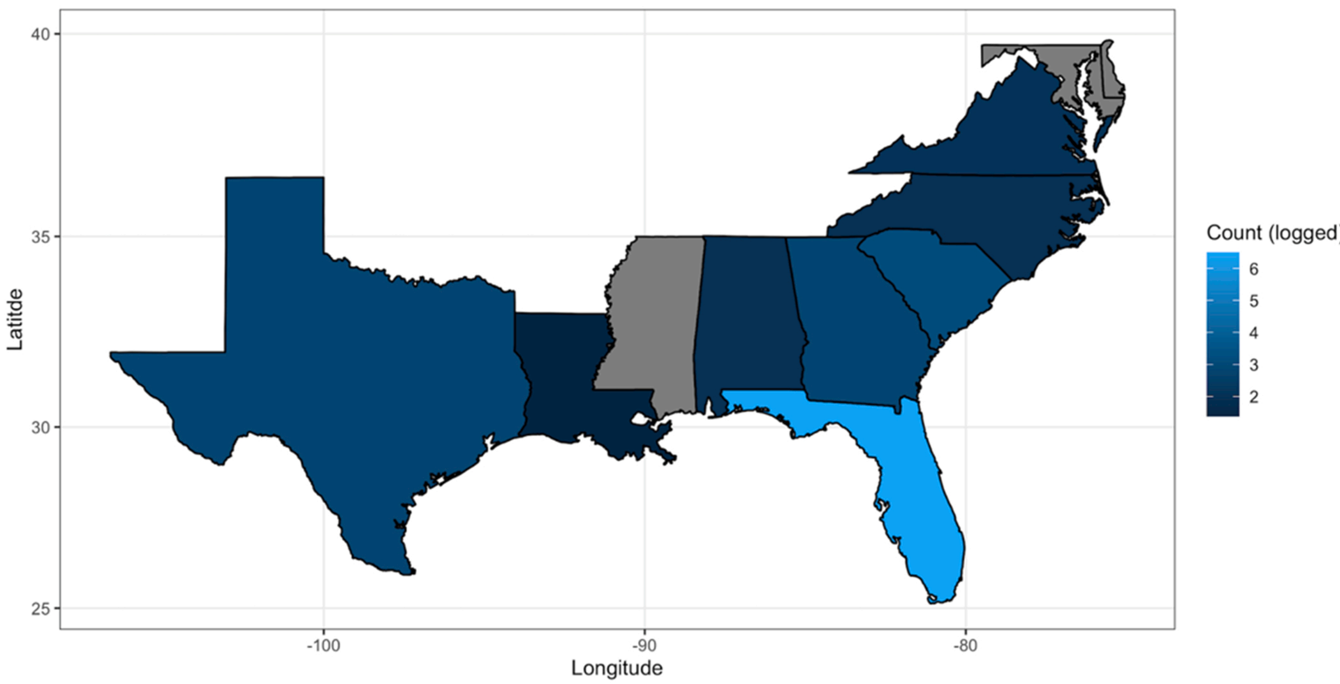

Fig. 1. Distribution of primary Atlantic tarpon fishing locations in the United States. Counts were logged and states in grey had zero respondents.

3.3. Perceptions of threats to and conservation strategies for Atlantic tarpon

No significant differences were found between guide and angler perceived threats to the Atlantic tarpon population (results of seven Mann-Whitney U tests: $n = 918$, U range: 32,982–40,477, $p > 0.05$). Declining water and habitat quality were identified as the greatest concern to both anglers and guides, while they were least concerned about differing harvest regulations across state and country boundaries (Fig. 7). The threat of predation by sharks related to angling events was marginally significant (Mann-Whitney U test: $n = 918$, $U = 32,247$, $p = 0.058$) with guides expressing that this was a very high threat more often than anglers.

Anglers and guides also frequently expressed similar support for various Atlantic tarpon conservation efforts (unless otherwise stated, results of six Mann-Whitney U tests: $n = 918$, U range: 32,258–35,495, $p > 0.05$). Both anglers and guides almost unanimously expressed very high support for regulations making Atlantic tarpon angling exclusively catch-and-release, developing water quality management solutions, and increased science efforts to understand Atlantic tarpon ecology for conservation solutions, while they strongly disagreed that no conservation efforts were needed (Fig. 8). Most expressed medium to very high support for increased pole-troll zones (i.e., where high speed motorboat travel is prohibited) in Atlantic tarpon angling locations, while opinions on area closures around select bridges and passes were evenly split across all levels of support. Anglers and guides differed in support for strict Atlantic tarpon handling guidelines, expanded commercial/recreational shark harvest, targeted shark culls (e.g., killing sharks nearby Atlantic tarpon aggregations), and guide license fees for those that Atlantic tarpon guide outside of their resident state with a larger proportion of guides expressing very high support for each item (results of four Mann-Whitney U tests: $n = 918$, U range: 26,387–31,168, $p < 0.01$). Compared to guides, a larger proportion of anglers expressed very high support to cease use of dead bait for Atlantic tarpon angling, (Mann-Whitney U test: $n = 918$, $U = 41,818$, $p = 0.018$). Overall, anglers and guides both felt the individuals, guide associations, and state governments were more responsible for the conservation and management of Atlantic tarpon than federal governments and nongovernmental organizations (Fig. S1).

In contrast, when differences in perceived threats to the Atlantic tarpon population were examined across gear types, many more differences arose. Both fly and spin respondents agreed that water quality issues were a very high threat to the current status of Atlantic tarpon populations, and most felt shark predation related to angling events was a medium threat (results of two Mann-Whitney U test: $n = 918$, U range $= 81,606$–$87,591$, $p > 0.05$) (Fig. 7). A larger proportion of fly respondents felt that habitat decline was a high or very high threat, while more spin respondents felt this was a medium threat (Mann-Whitney U test: $n = 918$, $U = 93,968$, $p < 0.001$). Similarly, fly respondents felt other non-angling recreational activities were a greater threat than spin respondents did (Mann-Whitney U test: $n = 918$, $U = 100,000$, $p < 0.001$). Spin respondents were generally less concerned about angling pressure (e.g., angler boat traffic, number of anglers), angler ethics (e.g., handling, motoring after Atlantic tarpon schools, etc.), differing Atlantic tarpon harvest regulations across state and country boundaries, and insufficient regulations (e.g., handling practices, harvest limits, and lack of enforcement) than fly anglers (results of four Mann-Whitney U tests: $n = 918$, U range: 91,463 - 100,404, $p < 0.001$).

While spin and fly respondents generally agreed on which conservation issues were important to them, there were significant variations between adjacent levels of support. A larger proportion of fly respondents expressed very high support for exclusive catch-and-release regulations, pole-troll only zones, increased applied ecological research, strict handling guidelines, and water quality management solutions, but spin anglers also largely supported these efforts (results of five Mann-Whitney U tests: $n = 918$, U range: 88,496–99,958, $p < 0.01$). A larger proportion of spin anglers expressed very low support for out-of-state guide license fees (Mann-Whitney U test: $n = 918$, $U = 88,340$, $p = 0.030$). The two conservation issues that were most polarizing for respondents using different gears were banning the use of dead bait to target Atlantic tarpon (Mann-Whitney U test: $n = 918$, $U = 130,332$, $p < 0.001$) and targeted bridge or pass area closures (Mann-Whitney U test: $n = 918$, $U = 124,172$, $p < 0.001$), which spin anglers largely opposed and fly anglers largely supported. The only issues that both groups did not differ on were expanded commercial/recreational shark harvest and targeted shark culls (results of two Mann-Whitney U

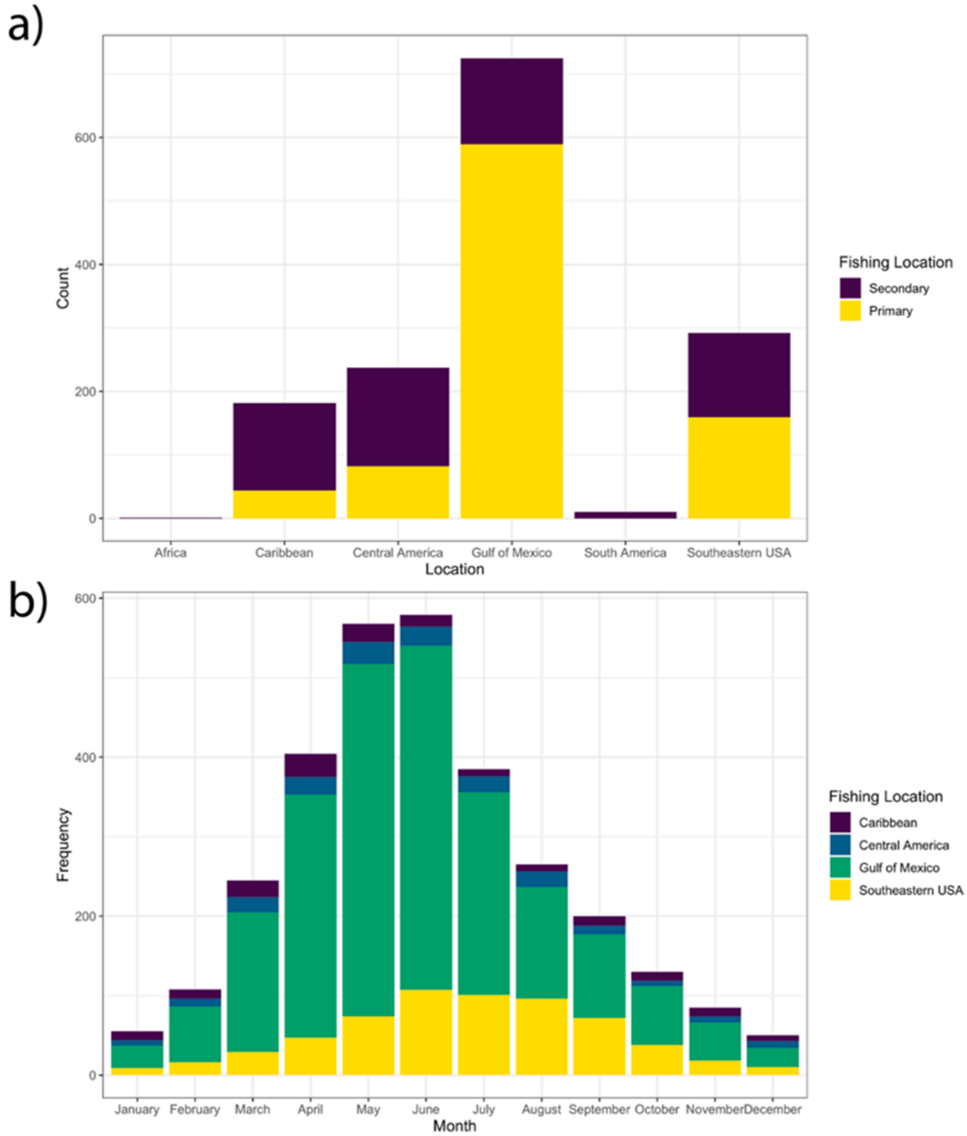

Fig. 2. a) Distribution of Atlantic tarpon fishing pressure separated by reported primary and secondary fishing location. b) Temporal distribution of Atlantic tarpon fishing pressure by month and primary fishing location.

tests: n = 918, U range: 75,586–80,436, $p > 0.05$), with the majority of both groups expressing very low or low support for these efforts (Fig. 8).

To understand what may be driving these differences in preference for various conservation actions between respondents using different gear types, variations in angling experience and personal identity by gear preference were examined. The respondents in the survey using fly gear had significantly more experience targeting Atlantic tarpon than those that used spin gear, with a larger proportion of fly respondents having 20 + years of experience (Mann-Whitney U test: n = 918, U: 86,873, $p = 0.03$). Results from the principal components analysis allowed us to combine the environmentalist, conservationist, and catch-and-release angler identities into an aggregate conservation identity value (Chronbach's alpha = 0.68). The hunter, outdoorsperson, and angler identities were retained as individual metrics. Respondents that fished with fly gear had a significantly higher conservation identity value than those that fished with spin gear (Mann-Whitney U test: n = 918, U: 97,964, $p < 0.001$). There were no significant differences between hunter, outdoorsperson, and angler identities based on gear preference (results of three Mann-Whitney U tests: n = 918, U range: 76,242–81,524, $p > 0.05$).

3.4. Shark encounters

For 58 fly guides, between 111 and 242 Atlantic tarpon were lost to sharks during an average fishing season (within the last five years), resulting in an average of 1.9–4.1 Atlantic tarpon per guide and season. For 32 spin gear guides, between 133 and 219 Atlantic tarpon were lost to sharks during an average fishing season (within the last five years), resulting in an average of 4.2–6.8 Atlantic tarpon per guide and season.

The best performing ordinal logistic regression model showed that the average number of Atlantic tarpon lost to sharks in the last five years, either while still hooked or post-release, varied with guide employment, years of Atlantic tarpon angling experience, number of days on the water per year, primary angling location, gear type, and the number of Atlantic tarpon landed per year (Nagelkerke pseudo $R^2 = 0.31$, Pulkstenis-Robinson and Hosmer-Lemeshow tests $p > 0.05$). After post hoc pair-wise comparisons, only the number of Atlantic tarpon landed per year and guide employment significantly influenced the number of shark encounters. The likelihood of experiencing depredation was significantly higher for guides ($p = 0.0053$). Those that landed less than five Atlantic tarpon a year were significantly more likely to have zero shark encounters than those that landed more than five Atlantic tarpon (results

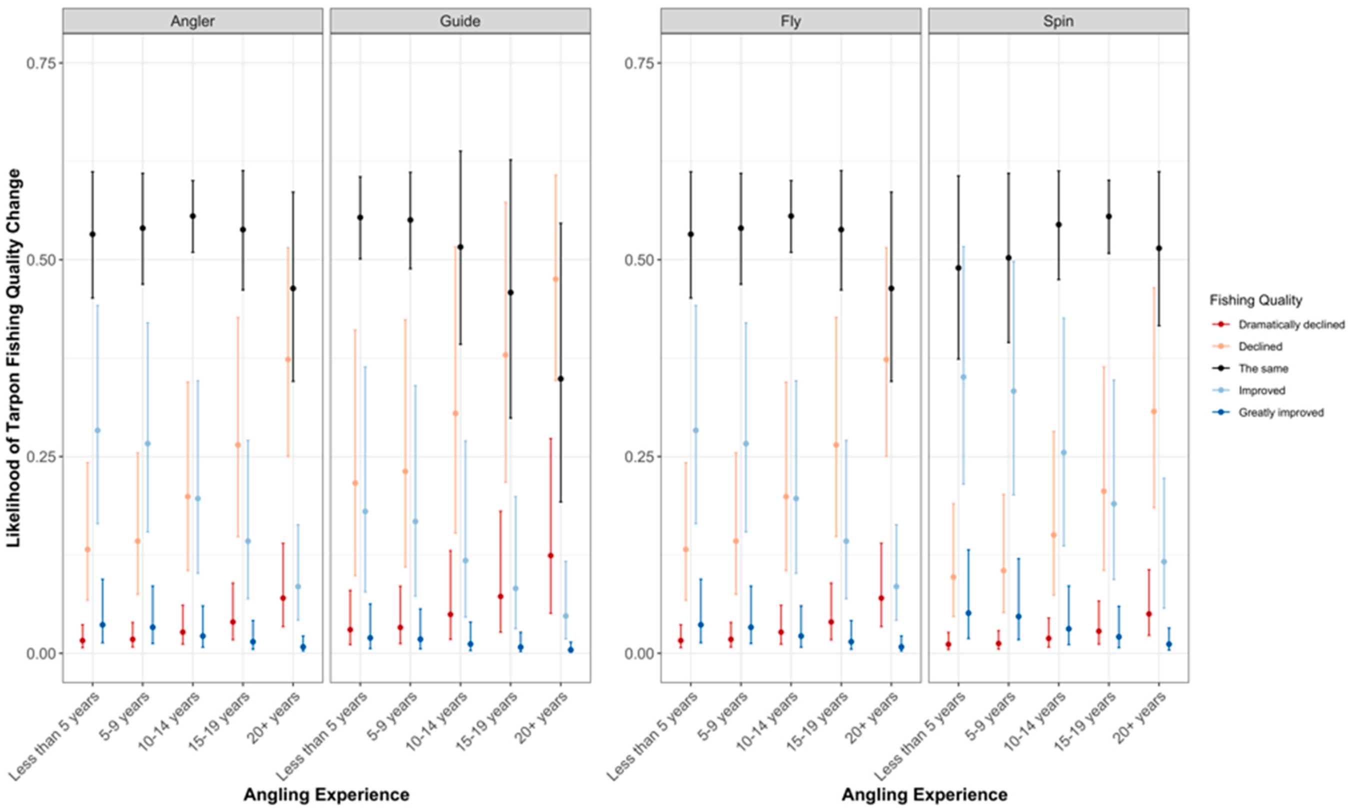

Fig. 3. Predictive plots for the best ordinal logistic regression model of overall changes in fishing quality as a function of guide employment (guides vs. anglers) and gear type (fly vs. spin) across years of experience targeting Atlantic tarpon.

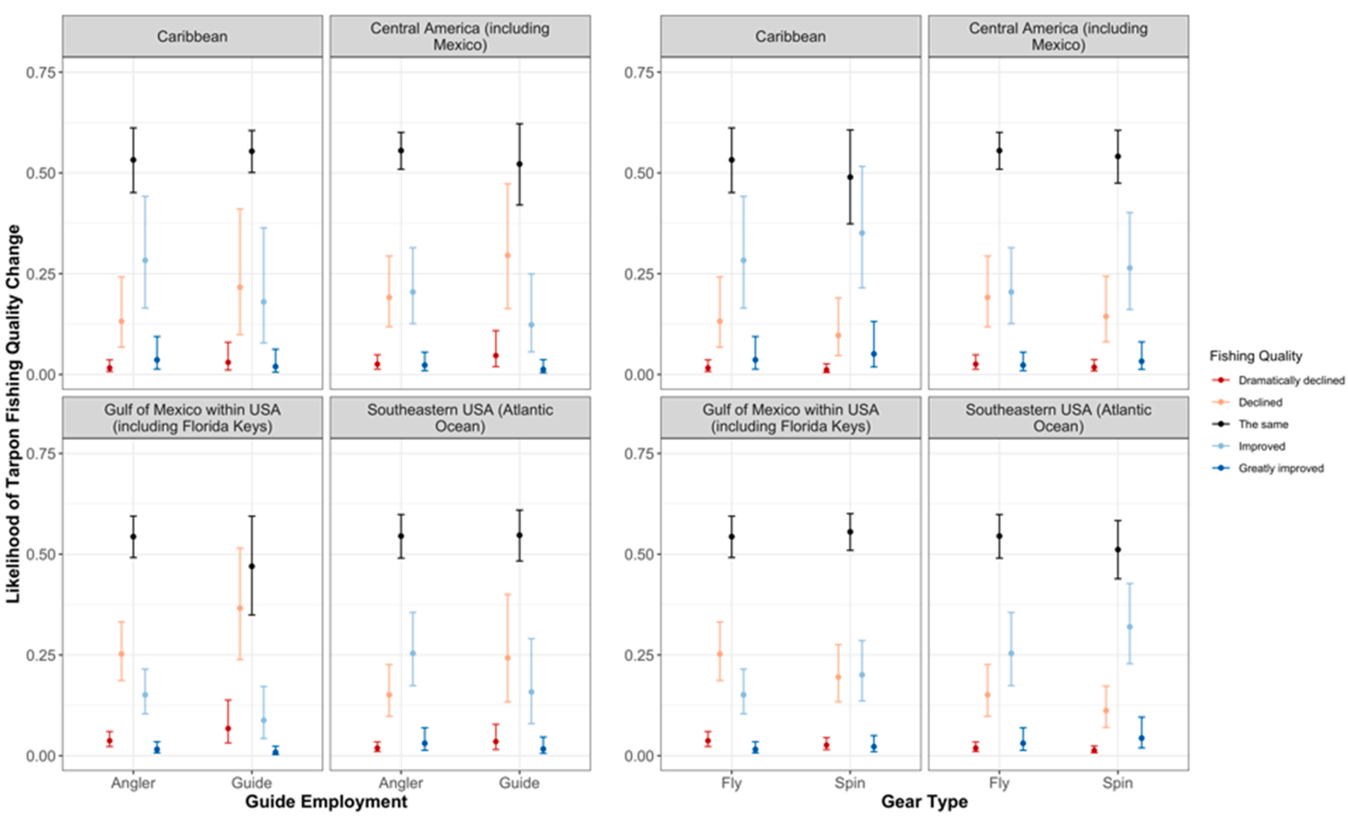

Fig. 4. Predictive plots for the best ordinal logistic regression model of overall change in fishing quality, presented divided by guides vs. anglers and fly vs. spin gear across fishing location.

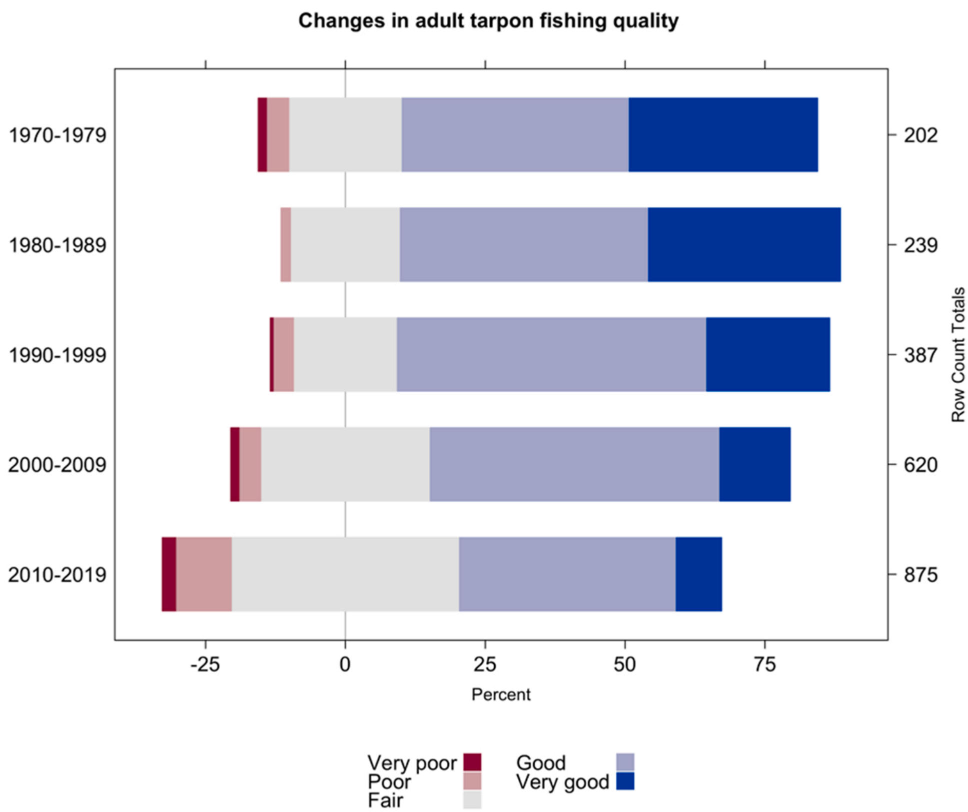

Fig. 5. Responses to observed changes in Atlantic tarpon fishing quality by decade presented as a proportion of total responses. Row count totals are the total number of responses for each decade.

of six post-hoc pairwise comparisons: $p < 0.03$). Further, the likelihood of having 1–4 or 5–9 shark encounters per season increased with an increasing number of Atlantic tarpon landed (Fig. 9).

Ordinal logistic regression was also used to determine trends in how many Atlantic tarpon are lost to sharks in the fishery over time, with the best performing model including guide employment, years of Atlantic tarpon angling experience, number of days on the water per year, primary angling location, and gear type (Nagelkerke pseudo $R^2 = 0.18$, Pulkstenis-Robinson and Hosmer-Lemeshow tests $p > 0.05$). Of those, gear type and angling location were the only significant variables after pairwise comparisons, with anglers in Central America significantly less likely to report change than those in the Southeastern United States ($p = 0.031$) and those fishing with spin gear more likely to report change than those fly fishing ($p = 0.007$). Across all regions, most anglers reported no difference in the number of Atlantic tarpon lost to sharks and very few reported that these encounters decreased. Likelihood of an increase in Atlantic tarpon lost to sharks was highest in the Southeastern USA and Gulf Coast of the USA (Fig. 10).

A plackett-luce model for ranked data was used to determine what habitats were most prone to losing Atlantic tarpon from shark encounters. This resulted in a rank from one to five, most likely to least likely, of passes > bridges = nearshore > estuaries = rivers ($p < 0.001$ for significant ranks; Fig. S2).

4. Discussion

Through an online survey, angler and fishing guide LEK provided new insights into the current and historical status of the Atlantic tarpon fishery. Further, anglers and fishing guides identified perceived critical priorities for better management and conservation of Atlantic tarpon throughout their range. With the majority of respondents primarily targeting Atlantic tarpon in the Southeastern USA and Gulf Coast of the USA, more experienced anglers generally reported Atlantic tarpon fishing quality had declined and migrations had begun earlier. While anglers and guides largely agreed on which threats were greatest for the Atlantic tarpon population and which conservation efforts were most important for management, those targeting Atlantic tarpon using spin gear opted for fewer regulatory actions compared to those that used fly fishing. Lastly, shark encounters were more likely to occur when using spin gear, in passes, and in the Southeastern USA and Gulf Coast of the USA. Collectively, for a fishery that lacks biological monitoring, these data provide additional reference points for monitoring the Atlantic tarpon fishery and its management.

4.1. Changes in Atlantic tarpon fishing quality

Overall, respondents perceived Atlantic tarpon fishing quality had remained the same; however, guides with more than 20 years of experience were more likely to report that fishing quality had declined. Specifically, respondents that provided information on fishing quality from the 1970s through the 2010s reported that fishing quality declined from good to fair. Indeed, based on global landings of Atlantic tarpon, Adams et al. [10] estimated a 30% decline in population estimates across their range and even a 60% decline in some regions (i.e., Brazil). These responses not only support anecdotal information from more experienced anglers about the decrease in the Atlantic tarpon population [10] but also demonstrate how newer anglers are less likely to note a difference in fishing quality. With the loss of intergenerational knowledge transfer, this recreational fishery is likely affected by shifting baseline syndrome [24]. Without regular or historical surveys/population monitoring, shifting baselines can easily mask population declines within recreational fisheries [48]. Known as hyperstability [49], overfishing/population declines can also be difficult to detect if catch per unit effort remains stable or increases while actual abundance continues to decline. Interestingly, respondents using spin gear believed fishing quality was better than those using fly gear. While this could be in-part

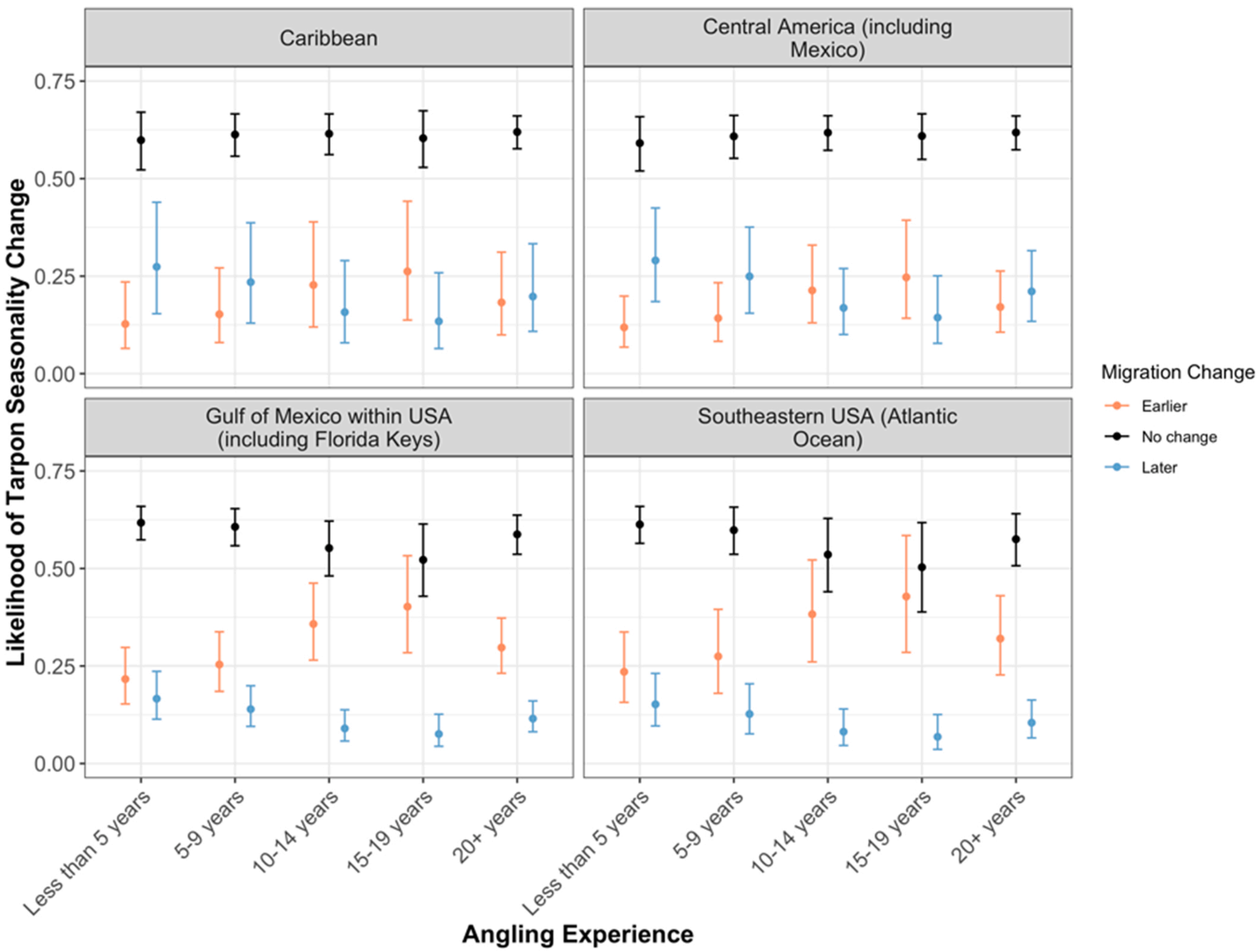

Fig. 6. Predictive plots presented the results of the best ordinal logistic regression model of changing Atlantic tarpon seasonality varied by years of Atlantic tarpon fishing experience and fishing location. The Gulf of Mexico and Southeastern USA were more likely to report earlier Atlantic tarpon arrivals with increasing years of fishing experience when compared to other regions.

due to spin gear anglers having fewer years of experience, compared to fly gear anglers, a large portion of spin gear anglers target Atlantic tarpon in larger aggregations, thus, it may be more difficult to perceive a difference in relative changes in quality or abundance. Considering Atlantic tarpon are highly migratory and anglers specialize in targeting them across their range and migration corridors [50], they are particularly susceptible to issues of hyperstability if fishing jeopardizes their ability to reproduce and survive [51]. In addition, since many anglers predominantly practice catch-and-release, it is likely that anglers are repetitively encountering and/or catching the same fish across their migration.

While not all anglers recognized a dramatic decline in fishing quality, management efforts should follow precautionary approaches, especially since biological reference points for Atlantic tarpon abundance are largely unknown across their range. If monitoring and management efforts are ignored, the population may continue to collapse regionally, as seen in the Texas Atlantic tarpon recreational fishery pre-1990s [52] and documented in other recreational fisheries [53,54]. Regular re-administration of surveys like the one used in the current study would be beneficial for detecting negative or positive trends in the fishery regionally. Further, deploying sonar-acoustics in pre-spawning aggregation areas (e.g., Boca Grande Pass, Charlotte Harbor, Florida; Bahia Honda, Florida Keys, Florida) to estimate Atlantic tarpon abundance may be beneficial. For example, in 1993, Hedgepeth et al. [55], using acoustics, estimated approximately 25,000 Atlantic tarpon visited Boca Grande Pass in one season. Such techniques may have promise and should be explored to establish baseline abundance numbers if only at proxy sites.

4.2. *Perceptions of threats to and conservation values for Atlantic tarpon*

Anglers and guides agreed that declining water and habitat quality were the greatest threats and conservation priorities for Atlantic tarpon populations. These two threats are often intertwined and are exemplified in Florida, the Atlantic tarpon fishing capital of the world. For example, historical freshwater regimes within The Everglades, Florida, have been greatly altered, resulting in hypersaline conditions in Florida Bay, leading to largescale seagrass die-offs and nutrient-laden runoff elsewhere, i.e., Charlotte Harbor, Indian River Lagoon, resulting in eutrophication and harmful algal blooms [56,57]. Beyond the associated habitat degradation with both conditions, specific to Atlantic tarpon, harmful algal blooms on the west coast of Florida, driven in part by these high-nutrient freshwater outflows [57], have led to mortality events for Atlantic tarpon and their prey [18]. Ultimately, with continued human-coastal development and habitat declines, upwards of 50% for salt marshes [58], 35% for mangroves [59], and 29% for seagrass meadows [60], the vital adult and juvenile Atlantic tarpon habitats are in jeopardy [61].

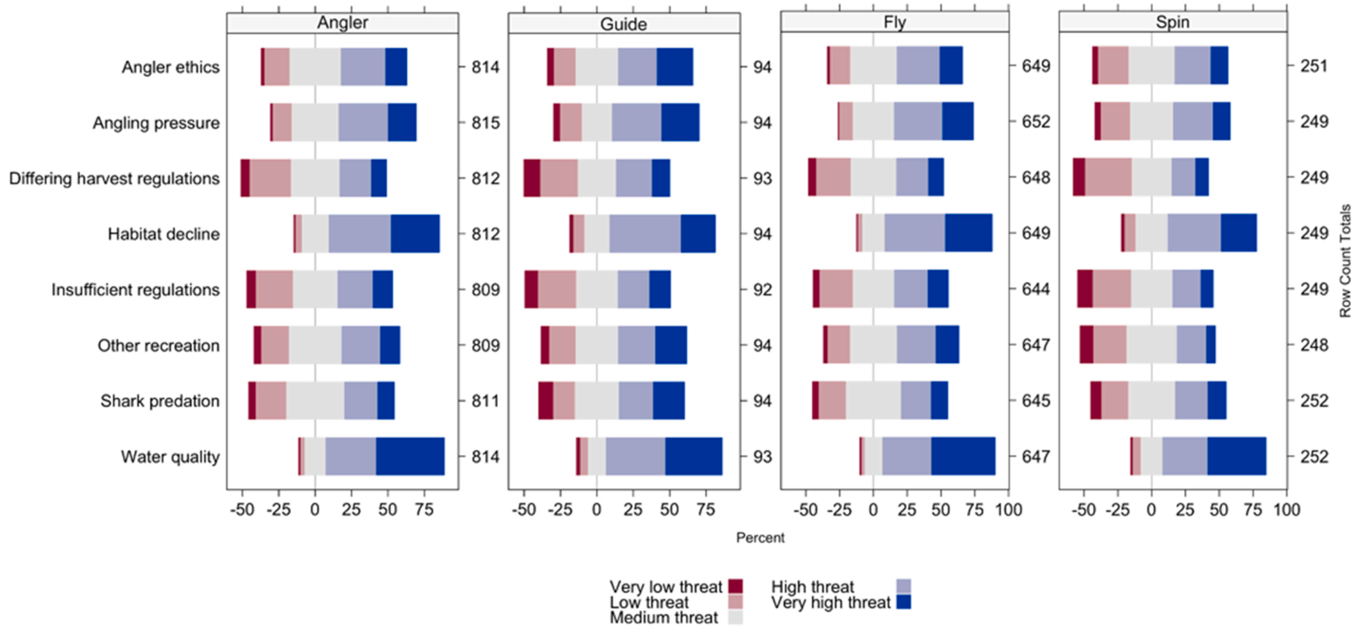

Fig. 7. Perceived threats to the Atlantic tarpon population rated on a five-point Likert scale from Very low threat to Very high threat. The overall surveyed population was divided into anglers and fishing guides as well as fly and spin gear for comparison between groups.

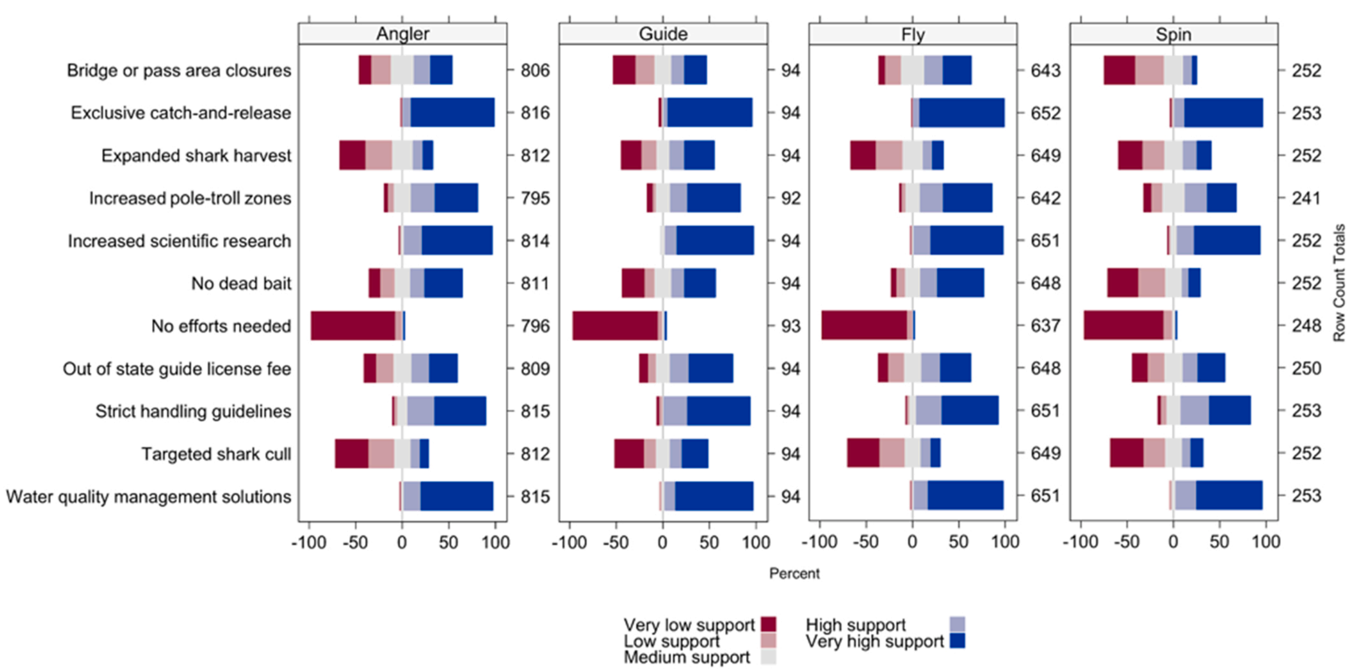

Fig. 8. Atlantic tarpon conservation issues valued by respondents rated on a five-point Likert scale from Very low support to Very high support. The overall surveyed population was divided into anglers and fishing guides as well as fly and spin gear for comparison between groups.

Anglers and guides also expressed very high support for three conservation strategies that, if embraced, should improve the fishery. These included establishing catch-and-release-only practices, increased science efforts to understand Atlantic tarpon ecology for applied conservation solutions, and medium to high support for pole-troll zones. Within the United States, Atlantic tarpon management regulations vary from state to state, ranging from no harvest limits at all (e.g., Louisiana), to limited harvest (e.g., Texas, Mississippi, Alabama, Georgia, South Carolina), to catch-and-release only (e.g., Florida, North Carolina, Virginia). With Atlantic tarpon seasonally migrating across jurisdictional boundaries [2,3,7] and the angling community's high support for catch-and-release only, expanding catch-and-release only regulations should be encouraged. Considering respondents' emphasis on the responsibility of individual anglers to conserve tarpon, stakeholder-driven initiatives towards catch-and-release best practices and peer-to-peer sanctioning could move faster than legislation towards this goal [62].

Although applied science efforts have increased for Atlantic tarpon, anglers still recognize the importance of continued research for this species. In agreement with Adams and Cooke [61], additional research needs for Atlantic tarpon include a better understanding of spatial ecology to understand their vulnerabilities to existing and future threats, habitat science in the context of restoration strategies, and

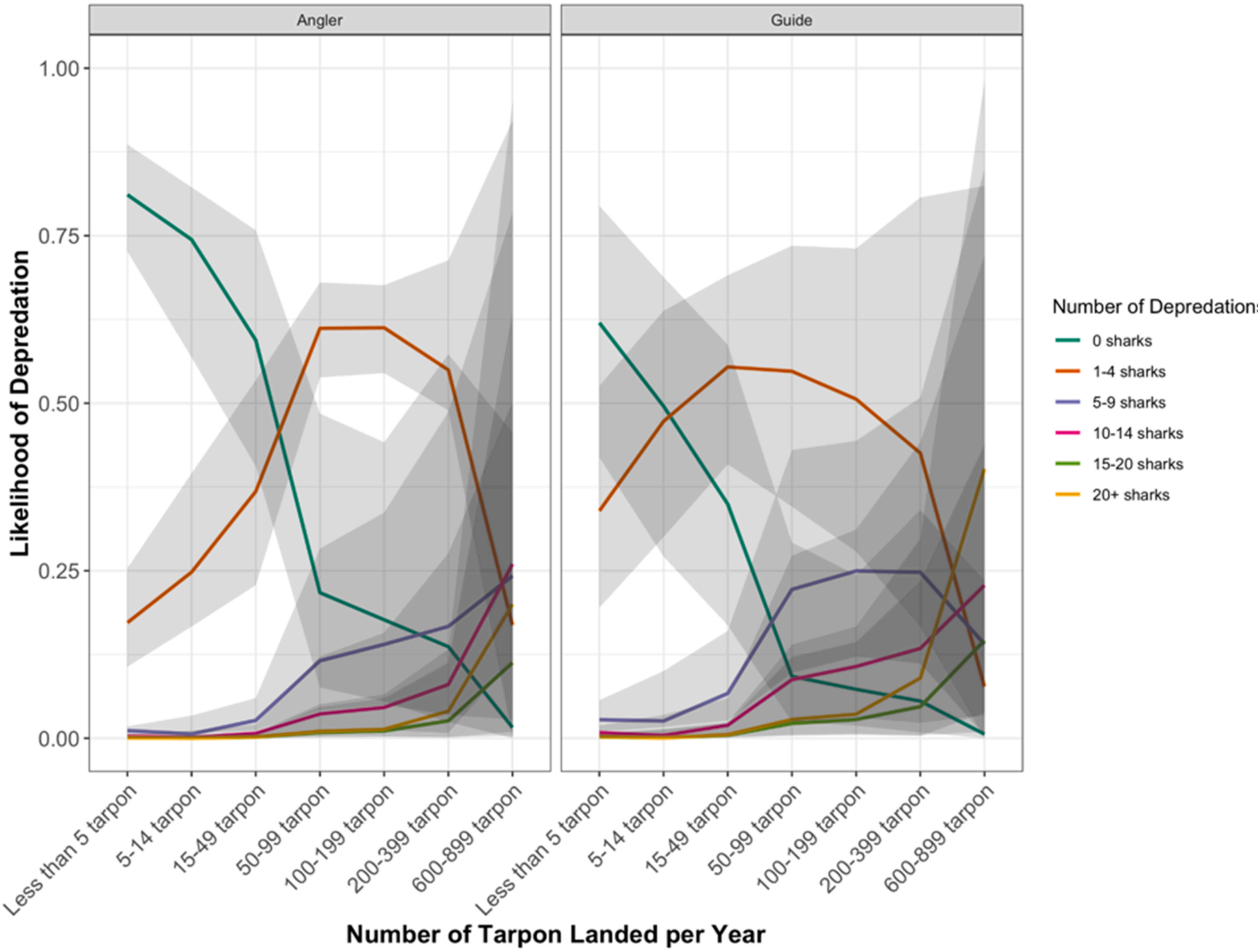

Fig. 9. Model predictor plot for the ordinal logistic regression model for shark encounters in the recreational Atlantic tarpon fishery, which varied significantly with the number of Atlantic tarpon landed per year as well as fishing guide employment status.

catch-and-release science to mitigate depredation and post-release mortality. One considerable additional gap in knowledge remains on the role of prey abundance and diversity on Atlantic tarpon migration and movement patterns. Previous telemetry data [2,7] show that after spawning, many Atlantic tarpon will undergo extensive northward migrations, sometimes > 1000 kilometers, where they putatively rely heavily on rivers flowing into the southeastern USA and the Gulf of Mexico. Forage fish (e.g., mullet, *Mugil spp.*, and menhaden, *Brevoortia spp.*) populations within northern temperate habitats, such as productive estuarine systems from Georgia to Virginia or the Mississippi Delta [63, 64], are believed to be vital for adult Atlantic tarpon during their migrations [5]. Establishing this link through increased science will be imperative since many of these prey sources are overfished and could have cascading effects on Atlantic tarpon populations. Lastly, since respondents with more fishing experience noted migration timing was earlier than in previous years, climate change's impact on Atlantic tarpon should be further investigated. As with other flats-oriented fisheries, climate change is and will continue to have large-scale physiological, habitat, and ecosystem-level consequences [65].

Establishing pole-troll zones to minimize habitat and fish disturbance may also benefit Atlantic tarpon. With high angler and guide support, these designated areas would only allow un-powered propulsion using a push pole or battery-operated trolling motor [66]. One major benefit of pole-troll zones would prevent propeller scarring in fragile habitats that support the Atlantic tarpon fishery, such as seagrass beds in South Florida [67–69]. Further, although not yet understood fully, anecdotal evidence suggests when in shallow water, Atlantic tarpon are easily disturbed by the presence and noise of boats, as seen in other recreational fisheries [70].

Although there was much agreement between anglers and guides, interestingly, differences in perceptions of threats to and conservation values for Atlantic tarpon varied substantially by gear type. Those who used fly gear for Atlantic tarpon ranked higher threats involving other recreational activities, angler pressure and ethics, and regulatory oversight. This could be because respondents who used fly gear generally had more experience than those who used spin gear, allowing them to form stronger opinions on the issue. Fly fishers also identified more strongly as conservationists, environmentalists, and catch-and-release anglers. If these values are significant components of fly fisher's personal identity, they may be predisposed to having very strong feelings about conservation issues. The greatest difference was that fly respondents supported banning the use of dead bait and Atlantic tarpon fishing near bridges, while spin respondents were mainly opposed to both potential management actions. However, it is worth noting these two regulations would, in some instances, greatly affect spin anglers compared to fly anglers. Acknowledging these differences in values will be critical in promoting Atlantic tarpon-oriented stewardship by anglers [34] and for developing potential management strategies that require stakeholder communication, trust, and cohesive agreement [71].

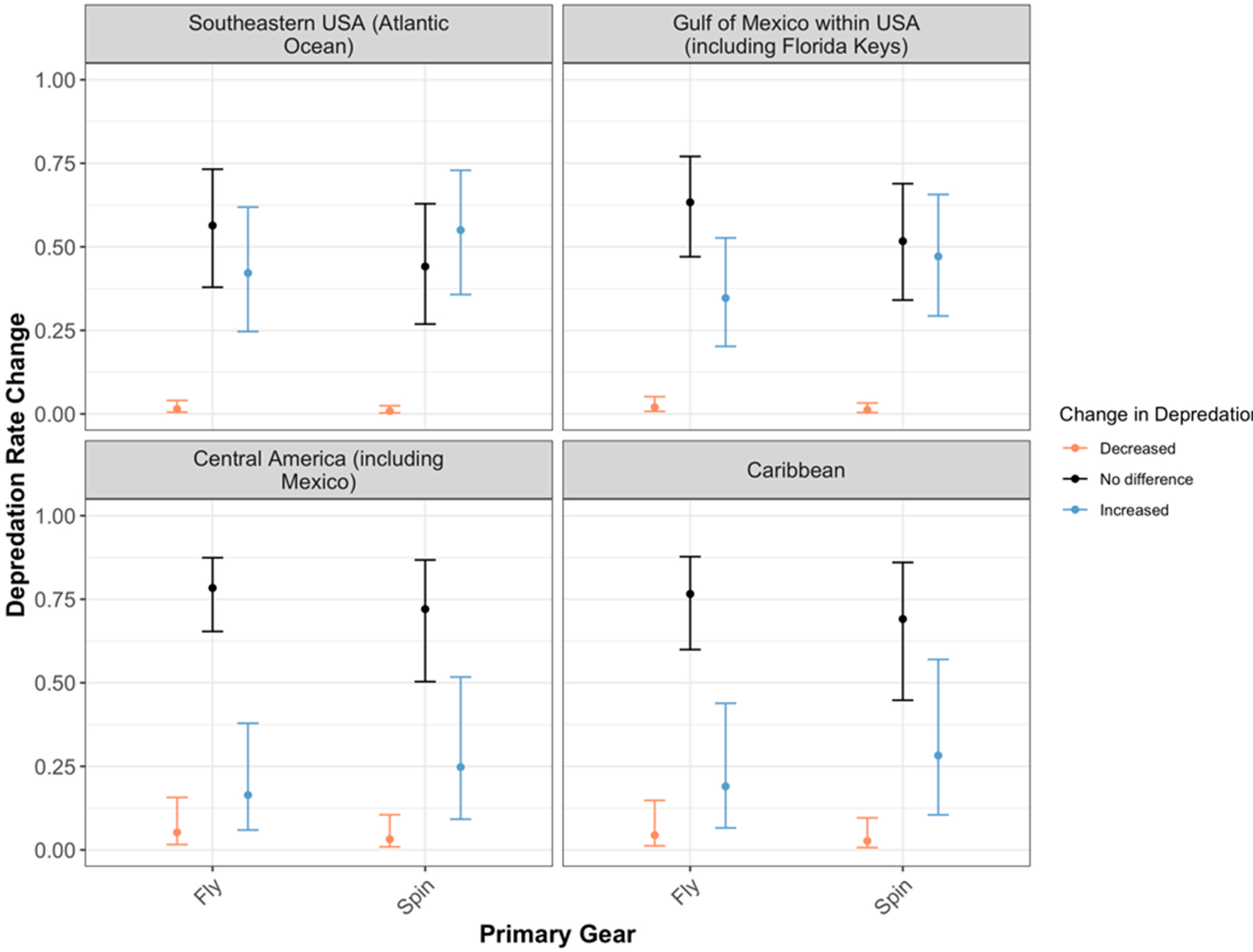

Fig. 10. Model predictor plot for the ordinal logistic regression model of depredation change over time, which varied significantly with fishing location and gear type.

4.3. Shark encounters

Assuming respondents are representative of the larger guiding community, fishing guides were estimated to have conservatively lost, on average, 2–7 Atlantic tarpon to sharks per guide per season, depending on gear type. While most respondents reported no difference in the number of Atlantic tarpon lost to sharks, those that regularly caught Atlantic tarpon were more likely to have had shark encounters. Further, those using spin gear and primarily fishing passes, bridges, and nearshore habitats were more likely to encounter sharks and note an increase in lost Atlantic tarpon to sharks within the last five years. Although respondents ranked shark predation as a medium threat, multiple sources of evidence suggest this may be a significant conservation concern for this fishery [3, Casselberry et al. in review]. Since Atlantic tarpon tend to aggregate in schools of 1000′s of fish within passes and deep channels prior to moving offshore to spawn [7,72], they are vulnerable to high angling pressure. Recent evidence showed great hammerhead (*Sphyrna mokarran*) and bull (*Carcharhinus leucas*) sharks actively pursue these areas for likely foraging opportunities [73]. In some pre-spawning aggregations, like those in the Florida Keys, it has been estimated that 15% of Atlantic tarpon fought for more than five minutes are depredated by great hammerheads (Casselberry et al. in review). Further, because shark predation may occur immediately or hours after release [3, Casselberry et al. in review], anglers are likely underestimating how many Atlantic tarpon are lost to sharks. For example, using acoustic tags, Guindon et al. [74] estimated that the post-release mortality rate related to sharks was 8.3%. Although tag burden was not accounted for, more troublesome, Luo et al. [3], using satellite tags, estimated a post-tagging mortality rate related to sharks as nearly 28% (>90% occurring within 3 h of post-release). Collectively, shark encounters prior to or after landing should be addressed within a management framework or through individual angler stewardship. Both spin and fly anglers had low support for expanded commercial/recreational shark harvest and targeted shark culls. While spin anglers, who more often fish near passes and bridges, were resistant to closures in these areas, fly anglers supported these measures. Gear modifications such as heavier and stronger rods to reduce fight times with Atlantic tarpon and the application of emerging shark deterrent technologies are warranted and should be considered first steps for this emerging issue [32].

4.4. Potential caveats

As with any data collection method, angler and guide surveys may have biases and limitations [75]. Though respondents in this survey used both spin and fly gear, over 70% of respondents primarily fished with fly gear. Although not uncommon with virtual snowball sampling designs [76], this potential sampling bias is largely reflected by having the fly fishing-oriented non-governmental organization, Bonefish & Tarpon Trust (https://www.bonefishtarpontrust.org), primarily responsible for survey distribution. Further, since this conservation organization regularly advocates for Atlantic tarpon conservation, responses may be biased toward this organization's mission and priority conservation concerns (e.g., water and habitat quality). However, as the largest advocate for Atlantic tarpon conservation globally, distribution in collaboration with Bonefish & Tarpon Trust was essential for reaching this relatively niche group of anglers and fishing guides. Moreover, given the importance of groups like Bonefish & Tarpon Trust as habitat-dependent outdoor recreation and conservation organizations that are essential drivers of incorporating anglers into conservation [77], the tradeoff between the potential bias and management applicability of LEK is acceptable. While the proportion of the Atlantic tarpon angling population the survey was able to reach is unknown, it is worth noting that the bulk of completed surveys came from residents living within the continental United States. Comparatively only a few respondents to none were from the Caribbean, Central America, South America, and Africa, despite having existing Atlantic tarpon fisheries in those areas. This survey was only conducted in English yet was distributed in some areas where English is not the primary language, so it is difficult to know how it may have affected the overall response rate. Lastly, recall or memory bias (i.e., the tendency to forget or attribute an event to the wrong time period), may also have affected the results, as is commonly recognized in angler surveys [78,79]. However, in such a data-limited fishery, LEK is invaluable and has been shown to accurately capture decadal trends when compared to stock assessments [25].

From an analytical standpoint, surveys conducted using a Likert scale generate categorical and ordered data that is best analyzed using ordinal logistic regression when these data are the response variable in the model [80]. Fagerland and Hosmer [44] have developed three tests to assess goodness-of-fit in ordinal models, with the Hosmer-Lemeshow test and Pulkstenis-Robinson test identified as the most appropriate for models with categorical covariates. Given the sample size was large ($n > 400$) a significance threshold of $p < 0.05$ is acceptable [81]. While the model for trends in shark interactions in the tarpon fishery passed these tests, the ordinal models for changes in tarpon fishing quality and migration timing yielded significant values for both tests. This indicates that these models may be missing an independent covariate or an interaction between categorical covariates [44]. Given the extensive covariates in the global model, it is likely that there is an underlying mechanism that was not collected in the survey that could explain the additional variation and improve model fit. Further, an increased sample size may have alleviated some of these discrepancies.

5. Conclusions

In summary, this survey revealed that anglers and guides reported that Atlantic tarpon fishing quality has significantly declined since the 1970s. With limited population monitoring, these concerns from more experienced anglers and guides reflect the suspected decreasing population trend stated in Adams et al. [10]. While the greatest threats, along with management and conservation preferences, differed between gear types, ultimately, water and habitat quality were deemed of greatest concern for Atlantic tarpon populations. In addition, this survey highlighted the need for increased biological monitoring initiatives, habitat and water regulations, pole-troll zones, applied science, and engagement with anglers (e.g., angler ethics involving handling and sharks). Ultimately, these data should be incorporated and considered for future Atlantic tarpon research, management, and conservation efforts.

CRediT authorship contribution statement

Lucas P. Griffin: Conceptualization, Methodology, Data curation, Writing – original draft, Writing – review & editing. **Grace A. Casselberry:** Conceptualization, Methodology, Formal analysis, Data curation, Writing – original draft, Writing – review & editing, Ezra M. Markowitz: Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Jacob W. Brownscombe:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Aaron J. Adams:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Bill Horn:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Steven J. Cooke:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Andy J. Danylchuk:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing.

Declarations of interest

None.

Data Availability

The data that has been used is confidential.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2023.105569.

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