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When fishing bites: Understanding angler responses to shark depredation

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ABSTRACT

Shark depredation, the full or partial removal of a hooked fish by a shark before it is landed, is anecdotally increasing in the United States. Perceptions of depredation by anglers and fishing guides may influence their behavior and have cascading effects on sharks and recreational fisheries. However, to date, these perceptions have not been broadly quantified. To better understand how anglers and guides respond to shark depredation in recreational fisheries, we used an online survey open to saltwater anglers in North America, distributed electronically via social media and online platforms. Of the 541 respondents, 77% had experienced depredation in nearshore and pelagic fisheries in the last five years, with depredation more commonly reported in the southeastern United States. Emotional responses to depredation were significantly different between anglers and guides, with the latter feeling more intense negative emotions. Behavioral changes in response to depredation, such as targeting and harvesting sharks, were driven largely by negative emotional responses and perceptions of sharks as threats to target species, while changes to protect target species varied with positive emotional responses and angler demographics. Guides were predominantly concerned about increased mortality to their target species and loss of trophy fish from the population. In fact, 87% of guides experienced depredation when fishing with clients and overwhelmingly reported that depredation has a negative effect on their livelihood. Overall, these results can be used to help inform strategies to reduce depredation while accounting for the values of stakeholder groups, particularly anglers and those advocating for shark conservation.

1. Introduction

Sharks are often perceived as a threat to human activities in saltwater, largely due to the nature of reporting on and popular media coverage of negative shark-human interactions (Neff, 2014, 2015; Panoch and Pearson, 2017). To date, most research has focused on the broader human perception of sharks (reviewed in Panoch and Pearson, 2017), as a threat or otherwise, rather than specific perceptions of stakeholder groups, like recreational anglers and fishing guides (see Press et al., 2016; Drymon and Scyphers, 2017 for exceptions). Despite this, shark interactions with these user groups are anecdotally increasing, particularly through depredation in recreational fisheries (see popular media for examples: Peralta, 2012; Memmott, 2013; Good Morning America, 2019; Miller, 2021). Shark depredation is the full or partial removal of a hooked fish before it is landed and can occur in recreational and commercial fisheries. How depredation affects various stakeholders (e.g., recreational anglers; professional guides) remains largely unstudied and unknown, despite anecdotal evidence that such events may powerfully shape angling behavior. Thus, there is a clear need for research on this issue.

Shark depredation is an understudied area of human-wildlife conflict, particularly with respect to recreational fisheries (Mitchell et al., 2018a, 2018b, 2019; Carlson et al., 2019). While depredation can be committed by other species, including marine mammals, seabirds, and other fish, sharks are an especially stigmatized group of potentially depredating species who could experience retaliation in response to depredation (Powell and Wells, 2011; Ferrari et al., 2015; Shideler et al., 2015). Depredation is a multifaceted issue that can affect the target species of the fishery, the depredating sharks, and the anglers. With increasing participation in saltwater recreational fisheries in the United States (U.S.) (Ihde et al., 2011, US DOI et al., 2018), their high economic value (Lovell et al., 2016, 2020), and concerted management efforts to re-establish healthy shark populations (NMFS, 2006; Shiffman and Hammerschlag, 2016; Dulvy et al., 2017), understanding the ecological

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and social consequences of depredation in these fisheries is emerging as a pressing fisheries management need.

Depredation represents an unquantified source of mortality for target species in recreational fisheries that, if frequent, could have serious implications for stock assessments and species management (Sippel et al., 2017; Peterson and Hanselman, 2017; Tixier et al., 2020b). Some research also suggests that depredation could be a learned behavior in sharks, altering natural foraging behavior in response to the presence of fishing activity (Mitchell et al., 2020). Depredation could also result in financial loss for anglers, in the form of damaged fishing gear, losing trophy fish in a tournament, or the potential loss of return clients for charter fishing guides. Considering sharks are often a highly polarizing topic among anglers, with some seeing sharks as a threat to their catch and others valuing the importance of sharks to marine ecosystems (Press et al., 2016; Drymon and Scyphers, 2017), the potential for varied responses to depredation is high.

Angling allows participants across demographic groups to collect food while connecting more strongly with nature and each other, promoting improved psychological well-being (Toth and Brown, 1997; Freudenberg and Arlinghaus, 2010; Cooke et al., 2017; Wolsko et al., 2019). Recreational fishing efforts are currently increasing in the U.S. (Midway et al., 2021), even relative to commercial harvest (Ihde et al., 2011), with harvest from recreational fishing as the dominant source of fishing mortality for 17 of 22 species managed by the South Atlantic Fishery Management Council (Shertzer et al., 2019). Recreational angling also provides significant economic benefits to coastal communities in the U.S., supporting over 350,000 jobs and generating \$7.9 - \$49.6 billion of income and added economic value annually (Lovell et al., 2016, 2020). Given the social and economic importance of recreational fisheries in the U.S., changes in recreational angler behavior have the potential for wide reaching economic effects across multiple industries, not just those tied directly to recreational fishing (Lovell et al., 2016).

Behavioral changes in response to shark depredation could have serious management and economic implications varying from redistributions of fishing effort, including location and target species, deciding not to hire a charter guide in the future due to a negative depredation experience, or targeting and harvesting sharks. Retaliation in response to shark depredation is of particular concern for larger bodied species that could be responsible for depredation, including but not limited to black tip (*Carcharhinus limbatus*), bull (*Carcharhinus leucas*), hammerhead (*Sphyrna* spp.), and white (*Carcharodon carcharias*) sharks, because they largely have k-selected life histories (Cortés, 2000). A fundamental lack of understanding of shark biology and ecological importance combined with fear was partially responsible for dramatic increases in recreational harvest of sharks in the U.S. through the 1970s and 1980s (Philpott, 2002; Babcock, 2008). Though targeted commercial harvest and incidental bycatch are largely responsible for the precipitous global declines in shark populations (Stevens et al., 2000; Pacoureau et al., 2021), recreational harvest can still impact shark populations (Young et al., 2014; Gallagher et al., 2016). In countries like the U.S., strict individual species or species complex management has helped to stabilize declining population trends and allowed some coastal species to show signs of recovery (Curtis et al., 2014; Peterson et al., 2017), but populations have not returned to historic levels of abundance (Jiao et al., 2009; Pacoureau et al., 2021). If shark depredation is perceived as a significant threat to anglers and guides, it could lead to unreported and/or illegal retaliatory harvest of sharks, in belief that shark populations are too abundant and mismanaged (Carlson et al., 2019). Calls for these kinds of actions are happening increasingly often on social media, with groups forming to lament the loss of depredated fish, display harvested sharks, and organize to petition regulatory changes from state and federal managers (Anonymous, 2020). Indeed, shark depredation was a main agenda item at management meetings on both the state and federal level in 2020 and 2021.[1] The need to quantify and better understand angler response to depredation is imperative as the potential for shark-angler conflict can only increase with continued successful shark management.

To date, depredation research has focused largely on quantifying depredation rates in commercial and recreational fisheries (Mitchell et al., 2018a, 2018b, 2019), while largely ignoring the social and behavioral human dimensions of this issue (Gillman et al., 2007; Iwane et al., 2021). The response of anglers to depredation could vary widely based on their potential employment as a fishing guide, previous experience on the water, motivations for fishing, perceptions of the health of their target species, and perceptions of the importance of sharks to marine ecosystems. To understand how anglers and fishing guides respond to depredation and how widespread this issue might be, we conducted an online survey targeting saltwater recreational anglers in North America. The goals of this survey were to: 1) develop a baseline understanding of which target species are being depredated most frequently; 2) quantify the emotional and behavioral responses of anglers and guides to depredation and determine how these responses may vary based on angler demographics, fishing experience, and motivations for fishing; 3) determine the role that pre-existing perceptions of sharks may play in angler and guide responses to depredation; and 4) understand how fishing guides perceive the effects of depredation on their industry.

2. Methods

2.1. Sampling frame and distribution

This study aimed to reach North American anglers over the age of 18 who had fished in saltwater and potentially interacted with sharks. Having experienced depredation was not a qualification for survey eligibility. The stated aims of the survey were to better understand experiences of saltwater anglers in North America. Survey advertisements mentioned better understanding angler interactions with sharks but stated that we wanted to hear from all anglers, including those who had never seen a shark while fishing before. Survey distribution took place between July 28, 2019 and January 31, 2020, and participation was completely anonymous. A snow-ball sampling technique relying primarily on social media was used to help distribute the survey. The survey launched during Discovery Channel's Shark Week 2019 to capitalize on social media attention to sharks and was shared primarily on Twitter, Facebook, and Instagram by the co-authors and outlets with large recreational angler followings (e.g., Moldy Chum blog, Keep Fish Wet, and The Venturing Angler). While snowball sampling design and online survey distribution through social media can bias results towards young and digitally literate individuals, it is a valuable tool for reaching widespread but relatively niche groups (Griffiths et al., 2010; Baltar and Brunet, 2012; Leighton et al., 2021), like saltwater anglers who have interacted with sharks. The social media launch and a press release from the University of Massachusetts Amherst Office of News and Media Relations generated interest from traditional media outlets both in print, online, and radio who shared the survey with their audiences. Finally, to counteract selection bias from distribution over the social internet, e-mails advertising the survey were sent to all fishing clubs registered as members of the International Game Fish Association and all organizers of NOAA-registered highly migratory species fishing tournaments. Points of contact were asked to forward the survey advertisement to club members or tournament participants. The survey was administered

[1] Meetings of the NOAA Atlantic Highly Migratory Species Advisory Panel (May 19, 2020 and December 7, 2020) and Meeting of the Florida Fish and Wildlife Conservation Commission (May 12, 2021).

using the Qualtrics platform and was approved by the University of Massachusetts Institutional Review Board (Protocol ID: 2019-5417).

2.2. Survey instrumentation

The survey consisted of four sections: 1) fishing behavior; 2) depredation-specific questions; 3) perceptions of sharks questions; and 4) demographic information (Appendix 1). Section one gathered basic information about the angler taking the survey, including how often they fish, where they fish, species they target, their motivations for fishing (catch-and-release, harvest, trophy), if they have experienced depredation, and if they were a fishing guide. Affirmative or negative answers to the depredation and fishing guide questions dictated the structure of section two that the participant received. Anglers who had experienced depredation in the last five years received specific questions about the depredation events they had experienced, including how often they experienced depredation, which species they lost most often, and if they saw the shark during the depredation event. In addition to specific questions about the depredation, these anglers were asked a series of questions to quantify the emotional responses to depredation with both negative and positive emotions. They were also asked how depredation altered future fishing decisions, including if they continued to fish for the same species, fish in the same location, hire a fishing guide, stop fishing, or begin fishing for sharks by targeting them recreationally and/or harvesting them. These questions were presented in a matrix where respondents were asked to rank the strength of their response on a five-point Likert scale ranging from 1 = Not at all to 5 = Extremely, for emotional responses, and 1 = Much less likely to 5 = Much more likely, for behavioral responses. Anglers that had not experienced depredation received only the emotional and behavioral response questions in a hypothetical context. In section two, fishing guides received additional questions related to guiding, including if they experienced depredation with clients, how they felt clients perceived depredation, and if they believe sharks have a positive or negative effect on their livelihood. Throughout the survey, anglers were allowed to skip questions and still advance through the survey flow. Lack of response to the depredation question or the fishing guide employment question was treated as a negative response.

All participants (anglers and guides) received the same questions for sections three and four. To allow for comparisons with prior research on angler perceptions of sharks and interest in shark conservation, the perceptions of sharks questions in section three were modeled from those used in Press et al. (2016) and Drymon and Scyphers (2017). These questions sought to understand an angler's prior knowledge of the role of sharks in the ecosystem and perception of sharks as a threat to their target species (ranked on a five-point Likert scale ranging from 1 = Strongly disagree to 5 = Strongly agree). All anglers were also asked if they had experienced a depredation event with any other species and given the opportunity to indicate which species. Additionally, all respondents were asked to indicate how important or unimportant various social identities were to them as an individual, including: angler, conservationist, outdoorsman, environmentalist, catch-and-release angler, and hunter. The demographic information requested in section four was similar to Drymon and Scyphers (2017) and included country of residence, sex, age, and household income.

2.3. Data preparation and analysis

In preparation for data analysis, respondents who completed less than 50% of the survey were excluded from all analyses. This threshold eliminated respondents who had not progressed sufficiently through the fishing behavior and depredation specific sections of the survey. All analyses were conducted in R version 3.6.3 (R Core Team, 2020). Respondents were allowed to report fish species they targeted and lost to depredation in text boxes, which resulted in a combination of scientific and common names. These responses were consolidated to accurately reflect one species of fish based on common names in FishBase (Froese and Pauly, 2019) or relevant information from managing bodies based on the respondent's fishing location (e.g., striped bass, stripers, and *Morone saxatilis* became striped bass). Fishing guides often listed more than one species when reporting depredated species. Frequently, these species were from disparate groups that could not be easily categorized into one umbrella grouping (e.g., haddock, red drum, cusk). To accurately document species being depredated, these responses were counted for each species listed. To analyze geographic differences in response to depredation, states where anglers reported they fished most frequently were aggregated into regions of the U.S. as defined by the U.S. Census Bureau in 2010 (census.gov). Summary information of the surveyed population was then generated from the fishing behavior and demographic sections.

Emotional and behavioral responses to depredation on the Likert scale were visualized using stacked bar graphs in the *HH* package (Heiberger and Robbins, 2014). From these data, Mann-Whitney *U* tests were run to test for significant differences between guide and angler responses to each emotional and behavioral response question. Subsequently, linear models or ordinal logistic regression, where necessary, were used to better understand which factors most influenced angler and guide responses to depredation, including perceptions of sharks, fishing behavior, and demographic information. Principal components analysis (PCA) with 'oblimn' oblique rotation was conducted to determine if Likert scale emotional and behavioral response questions, perceptions of sharks questions, and angler personal identity questions could be reduced to form aggregate metrics for use in linear models. PCA and post-hoc Cronbach's alpha tests were conducted in the *psych* package (Revelle, 2020), and a minimum Cronbach's alpha cutoff of 0.6 was deemed acceptable. After accounting for potential collinearity of explanatory variables (Zuur et al., 2015), linear models were generated using the 'lm' command in *stats* (R Core Team, 2020) to understand the factors that influence emotional and behavioral responses for both guides and anglers who had experienced depredation, with the global models being:

Emotion ~ Aggregate Perceptions of Sharks Score + Income + Age + Sex + Depredation Frequency + Recreational Fishing Frequency + Perceived Health of Target Fishery + Catch-and-Release Angler + Past *Experience Shark Fishing + See Depredating Shark + Geographic Region*

– *Behavior ~ Aggregate Perceptions of Sharks Score + Income + Age + Sex + Depredation Frequency + Recreational Fishing Frequency + Perceived Health of Target Fishery + Catch-and-Release Angler + Past Experience Shark Fishing + See Depredating Shark + Geographic Region + Aggregate Negative Emotion Score + Aggregate Positive Emotion Score*

For models requiring ordinal logistic regression, when aggregate metrics could not be generated from PCA, the 'clm' command in the *ordinal* package was used for the same candidate model set (Christensen, 2019). Candidate model sets for both model types were constructed using a forward selection stepwise approach, and best models were selected using Akaike's information criterion (AIC; Akaike, 1974) comparisons generated by *AICcmodavg* (Mazerolle, 2020). For ordinal models, model fit was assessed by generating the Nagelkerke pseudo R^2 value (Nagelkerke, 1991) as well as the Lipsitz goodness of fit and Hosmer-Lemshow tests (Fagerland and Hosmer, 2017) using the *generalhoslem* package (Jay, 2019). Tukey's HSD post hoc tests were used to determine significant differences among categorical variables with the *multcomp* package (Hothorn et al., 2008) for linear models. For pairwise comparisons in ordinal logistic regression models, least-squares means were generated in the *emmeans* package (Lenth, 2021).

Additional analyses were conducted to understand how perceptions of sharks may differ between those that have or have not experienced depredation, and how this may influence angler concerns regarding shark-angler encounter issues. A set of candidate linear models were constructed with the global model being:

Aggregate Perceptions of Sharks Score ~ *Experienced Depredation* + *Employed as Guide* + *Extractive Identity* + *Conservation Identity* + *Experienced Depredation* * *Employed as Guide*

where extractive and conservation identity represented the composite scores generated from responses to angler personal identity questions. The best model was selected using AIC comparisons. Based on these results, Mann-Whitney *U* tests were run for each response to the question, "How important or unimportant do you believe the following issues are in relation to shark encounters?" for comparisons between those that had or had not experienced depredation and among those that had experienced depredation, for guides and anglers. The output tables of all best performing linear and ordinal logistic regression models, as well as AIC model selection tables, can be found in the regression section of the Supplemental materials.

Considering fishing guides have extensive knowledge of their target fisheries and are vested stakeholders in the saltwater recreational fishing industry, those that had experienced depredation were asked additional questions regarding the potential effects of depredation on their livelihood. These questions included: if they had experienced depredation with clients, if they felt they had experienced depredation more frequently in the last five years, if they felt sharks changed their behavior around recreational fishing activities, and if they felt sharks affect their livelihood. Summary statistics were generated for the Likert scale questions and qualitative analyses were conducted to summarize results of the open response explanations.

3. Results

3.1. Summary demographic and fishing behavior information

The survey received 640 responses, of which 541 were sufficiently completed and retained for data analysis. Most respondents were male (88.9%) between the ages of 25 and 44 (51.2%) and considered themselves avid anglers, with 67.8% fishing more than 30 times a year (Tables 1, S1). Of those respondents, the vast majority were from the U.S. (98.8%), with 64.6% from the south, and 24.4% from the northeast. Because of limited responses from anglers outside of the U.S., only anglers who reported fishing primarily in the U.S. were included in modeling analyses. Twenty-seven percent of respondents were currently or previously employed as fishing guides in the last five years (Table 1). More than 77% of respondents had experienced shark depredation at least once in the last five years (Table 1). Of those, 90.3% (n = 374) had experienced more than one shark depredation, with 52.4% (n = 217) experiencing 20 or more depredation events in the last five years (Table S2; Fig. 1).

Targeted and depredated species spanned a wide variety of fisheries comprising both inshore and pelagic species (Table S3). The most frequently targeted species included mahi (*Coryphaena hippurus*), king mackerel (*Scomberomorus cavalla*), and striped bass (*Morone saxatilis*), while the most frequently and most recently depredated species included various tunas (*Thunnus* spp.), king mackerel (*Scomberomorus cavalla*), and various snappers (*Lutjanus* spp.; Table S3). Overall, the most frequently depredated species was driven primarily by the large number of respondents from the southeastern U.S., particularly Florida. In other regions of the U.S., the most frequently depredated species were striped bass, black sea bass (*Centropristis striata*), and pollock (*Pollachius virens*) in the northeast and tunas on the West Coast (Fig. S1).

All anglers who had experienced depredation were asked if they saw the shark committing the depredation, as well as if they had experienced depredation from any other species. Overall 72.1% (n = 272) of respondents reported seeing the shark during their depredation event, with 80.5% (n = 99) of guides and 68.1% (n = 173) of anglers seeing the shark. This large percentage of anglers and guides seeing the shark during a depredation event allowed us to be confident that respondents were sharing experiences from shark depredation and not depredation committed by another species but attributed to sharks due to potential underlying bias against these predators. Further 68.5% of respondents (n = 343), including those who had not experienced shark depredation, had experienced depredation from another species, including dolphins (n = 103), grouper (n = 87), seals (n = 69), birds (n = 42), and barracuda (n = 41).

Table 1
Summary of fishing behavior information collected from the survey, presented as count (n) and percentage (%) of respondents to each question.

	n	%
Recreational Fishing Frequency (n = 541)		
Once a year	16	2.96
Between 2 and 5 times a year	36	6.65
Between 6 and 15 times a year	51	9.43
Between 16 and 30 times a year	71	13.12
More than 30 times a year	367	67.84
Employed as a Fishing Guide (n = 541)		
Yes	148	27.36
No	393	72.64
Experienced Depredation (n = 538)		
Yes	418	77.70
No	120	22.30
Primary Fishing Practice (n = 541)		
Catch-and-release	270	49.91
Harvest	271	50.09
Been Recreational Shark Fishing (n = 540)		
Yes	294	54.44
No	246	45.56
Frequently Fished Region of U.S. (n = 511)		
Northeast	130	25.44
South	330	64.58
Midwest	6	1.17
West	43	8.41
Territories	2	0.39

3.2. Modeling emotional and behavioral responses to depredation

3.2.1. Differences between anglers and guides

Significant differences in emotional responses to depredation between fishing guides and anglers were found for all emotions (Mann-Whitney *U* test: n = 418, U range 11,840–19,447, $p < 0.01$), excluding feeling nothing (n = 418, U = 11929, p = 0.85). Guides felt negative emotions, including sadness, distress, and anger, much more extremely than anglers (Fig. 2). Additionally, guides reported feeling excitement or awe less than anglers. Significant differences were also present between guides' and anglers' responses to questions regarding behavioral changes (Mann-Whitney *U* test: n = 418, U range 13,087–20,889, $p < 0.01$), with the exception of fishing for a different species after experiencing depredation (n = 418, U = 18,064, p = 0.39) and stopping fishing recreationally (n = 418, U = 18,708, p = 0.13). While many anglers reported that they would not change their behavior after experiencing depredation, guides were much more likely to target sharks recreationally and harvest sharks in the future than anglers, and much less likely to fish in the same area again (Fig. 3).

3.2.2. Aggregate metrics for modeling

PCA was run separately for guides and anglers who had experienced depredation for part two and across all respondents for part three. For fishing guides who had experienced depredation, two components emerged: "negative emotions" (items: Sad, Distress, and Anger) and "positive emotions" (items: Awe, Excitement, and Happy). Both had a Cronbach's alpha score greater than 0.6 (negative emotions α = 0.74, positive emotions α = 0.67), so aggregate scores of positive and negative emotions were used for further analyses. The same positive (α = 0.77) and negative (α = 0.81) emotional aggregates were generated for anglers who had experienced depredation. For guides who had

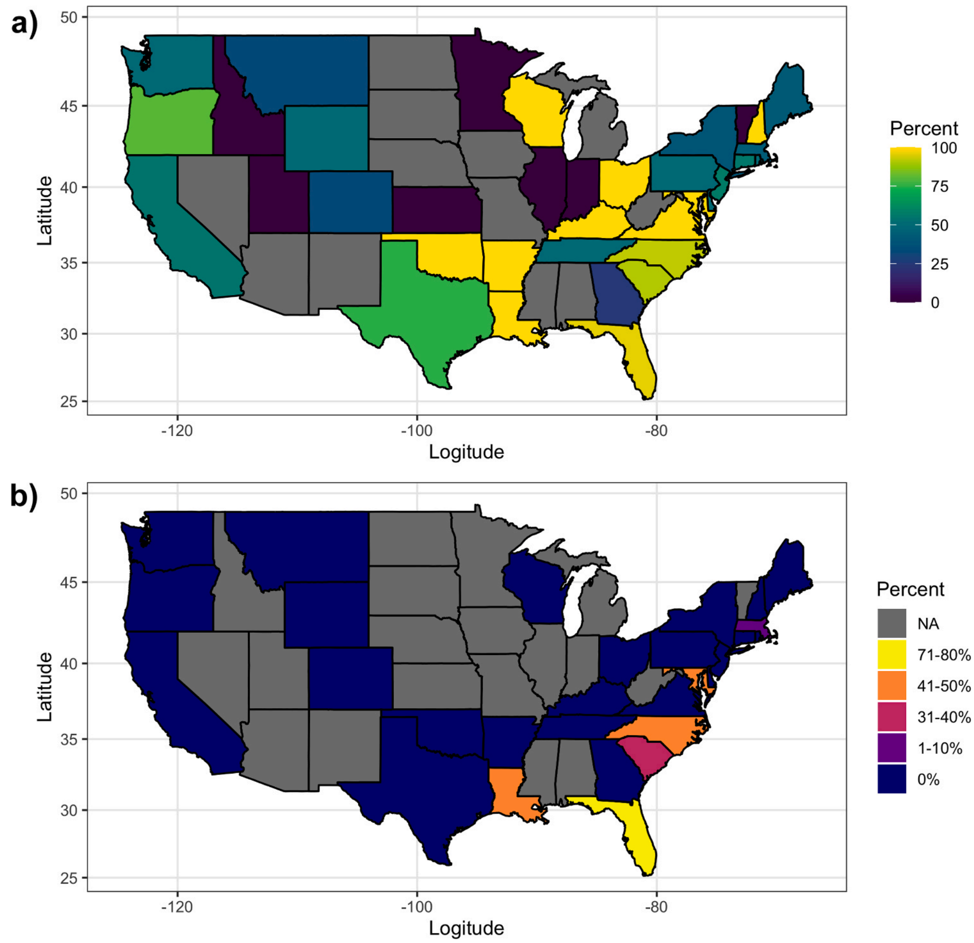

Fig. 1. a) The percentage of survey respondents from each state who had experienced shark depredation, and, b) of respondents who had experienced depredation, the percentage who experienced the highest level of depredation, losing fish more than 20 times in the last five years. Grey states received no responses (a and b) or had no respondents that had experienced depredation (b). Alaska (not pictured) had one respondent who had not experienced depredation.

experienced depredation, two components were identified within behavioral responses to depredation: "target species protection" (items: fish in the same area again (Area), bring clients to fish in the same area again (Clients), fish for the same species again (Species), and stop fishing recreationally (Stop) ($\alpha = 0.72$)) and "shark retaliation" (items: harvesting sharks and targeting sharks recreationally ($\alpha = 0.57$, $r = 0.39$)). Similar results were seen for anglers who had experienced depredation, with "target species protection" (items: Area, Stop, and Species ($\alpha = 0.64$)) and "shark retaliation" (items: harvesting sharks, targeting sharks recreationally, and hiring a fishing guide ($\alpha = 0.50$)) emerging as components. Because of the low Cronbach's alpha scores for "shark retaliation" in each group, these variables were analyzed separately with ordinal logistic regression. The "hiring a fishing guide" variable was dropped from regression analyses due to a low number of respondents initially reporting having done so.

Results of the PCA for perceptions of sharks questions from part three revealed two components. One pertained to "sharks as a threat" (items: "Having fewer sharks in the ocean would be better for other fish populations" (FishPops), "There are too many regulations protecting sharks" (Regulations), "Sharks are a threat to my recreational fishing catch" (ThreatCatch), "I enjoy seeing sharks in the ocean" (Enjoy), "It is important to have viable shark populations" (ViablePops), "Sharks are a sign of a healthy ecosystem" (Ecosystem), "Sharks are a threat to humans" (ThreatHumans) ($\alpha = 0.90$)) and the other to "sharks and recreational fishing" (items: "Recreational fishing can change shark behavior" (Behavior) and "Recreational fishing does not affect the health of shark populations" (PopHealth) ($\alpha = 0.35$, $r = 0.22$)). Based on the loading value scores of the variables in PC1 and on the language of the items, Enjoy, ViablePops, Ecosystem, and PopHealth were reverse coded before averaging to calculate a mean perceptions of sharks score for each individual, with increasing scores representing an increasing negative perception of sharks as a threat to both target species and humans.

Finally, two components were identified by PCA for aggregate analysis of the social identities of respondents. The "extractive identity" included items: Angler, hunter, and outdoorsman ($\alpha = 0.70$), while the "conservation identity" included items: catch-and-release angler, conservationist, and environmentalist ($\alpha = 0.69$).

3.2.3. *Modeling fishing guide response*

For fishing guides, both positive and negative emotional responses to depredation were best explained by separate linear models including geographic region, the aggregate perceptions of sharks score, and the frequency of depredation ($n = 129$, F-statistic $= 12.92$ (9, 119 degrees of freedom (df)), $R^2 = 0.49$ for positive emotions; $n = 129$, F-statistic $= 9.95$ (9, 119 df), $R^2 = 0.43$ for negative emotions). Positive emotions decreased significantly with increasingly negative perceptions of sharks as a threat ($p < 0.01$; Fig. S2) and increasing depredation frequency, with those who had experienced depredation more than 20 times in the last five years being significantly less likely to feel positive emotions than those who experienced depredation 10–20 times (Tukey's HSD $p < 0.01$; Fig. S3). In addition, guides who fish in the south are less likely to feel positive emotions than those that fish in the northeast and U.S. territories, specifically Puerto Rico and the U.S. Virgin Islands

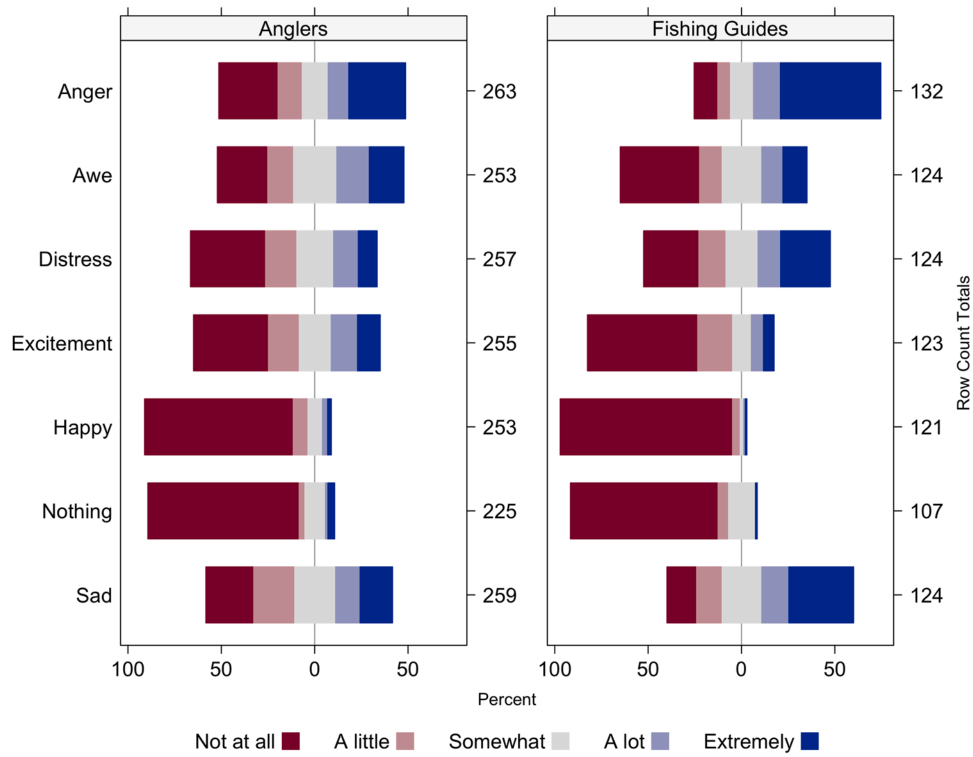

Fig. 2. Responses to the question "How much or how little did you feel each of the following upon witnessing your most recent depredation event?" for both anglers and fishing guides. Respondents were presented with the seven emotions on the left y-axis and rated emotions on a five-point Likert scale. Responses for each emotion are presented as a percent of total responses for each emotion, with total number of responses for each emotion on the right y-axis.

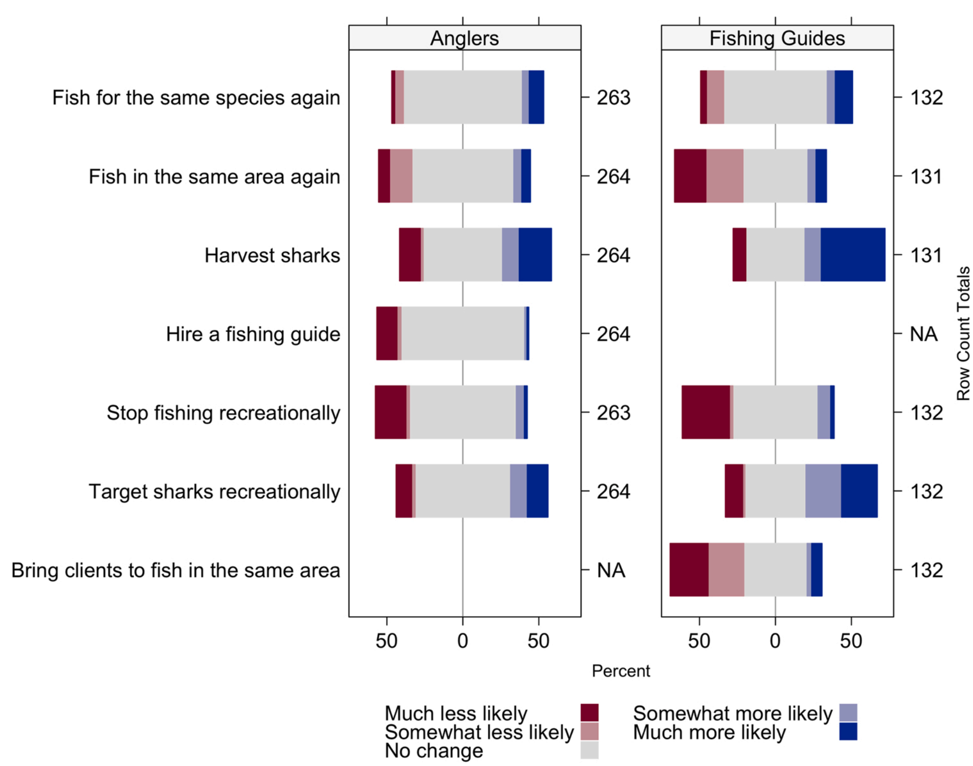

Fig. 3. Responses to the question "Has experiencing a depredation event made your more or less likely to do the following?" for both anglers and fishing guides. Respondents were presented with the seven emotions on the left y-axis and rated emotions on a five-point Likert scale. Responses for each emotion are presented as a percent of total responses for each emotion, with total number of responses for each emotion on the right y-axis.

(Tukey's HSD $p < 0.01$; Fig. S4). In contrast, the level of negative emotional response increased significantly with an increasingly negative perceptions of sharks score ($p < 0.01$; Fig. S5) and increasing depredation frequency (Tukey's HSD $p < 0.01$; Fig. S6). Guides fishing in the south were more likely to have a higher negative emotional response than those fishing in the northeast (Tukey's HSD $p < 0.01$; Fig. S7).

These emotional responses to depredation events translate directly to how fishing guides modify fishing behavior following depredation. The model predicting guide behavioral change to protect their target species included only the degree of positive emotional response ($n = 129$, F-statistic $= 12.2$ (1, 127 df), $R^2 = 0.088$), with increasing positive emotions increasing the likelihood of changing behavior ($p < 0.01$; Fig. S8). In contrast, the level of negative emotional response played a significant role in the likelihood of fishing guides targeting and harvesting sharks after experiencing depredation. The best performing ordinal logistic regression model of likelihood to harvest sharks included the level of negative emotional response and aggregate perceptions of sharks score ($n = 129$, Nagelkerke pseudo $R^2 = 0.39$, Lipsitz goodness of fit test and Hosmer-Lemshow test $p > 0.1$). Guides were significantly more likely to harvest sharks with increasing negative emotional response ($p < 0.01$) and perception of sharks as a threat ($p < 0.01$; Fig. 4). Similarly, guides were significantly more likely to target sharks with increasing negative emotional response ($p < 0.01$; Fig. 4), based on ordinal logistic regression ($n = 129$, Nagelkerke pseudo $R^2 = 0.11$, Lipsitz goodness of fit test and Hosmer-Lemshow test $p > 0.1$).

3.2.4. Modeling angler response

Perceptions of sharks as a threat played a significant role in how anglers responded emotionally to depredation. The level of positive emotional response was best modeled by the aggregate perceptions of sharks score and geographic region ($n = 258$, F-statistic $= 23.94$ (5, 252 df), $R^2 = 0.32$), with positive emotions inversely correlated with perceptions of sharks as a threat ($p < 0.01$; Fig. S9). Similar to guides, anglers from the northeast were significantly more likely to have a positive response than anglers from the south (Tukey's HSD $p < 0.01$; Fig. S10). The level of negative emotional response to depredation was best modeled by the aggregate perceptions of sharks score and the frequency of depredation ($n = 258$, F-statistic $= 38.67$ (6, 251 df), $R^2 = 0.48$). There was a significant positive correlation between negative emotions and angler perception of sharks as threats ($p < 0.01$; Fig. S11) as well as increasing depredation frequency (Tukey's HSD $p < 0.01$ more than 20 times, $p = 0.02$ 11–20 times; Fig. S12).

Modeling behavioral response to depredation for anglers was more complex than modeling responses for fishing guides. The best ordinal logistic regression model used to predict the likelihood of harvesting sharks included both positive and negative emotional response as well as the frequency of depredation and the aggregate perceptions of sharks score ($n = 258$, Nagelkerke pseudo $R^2 = 0.54$, Lipsitz goodness of fit test $p = 0.02$, Hosmer-Lemshow test $p = 2.1 \times 10^{-9}$; see Supplemental materials for further details on model selection). The likelihood of harvesting sharks increased significantly with increasing negative emotional response ($p < 0.01$), perception of sharks as a threat ($p < 0.01$; Fig. 5), and depredation frequency (Least-squares means pairwise comparisons $p < 0.01$; Fig. 5). The likelihood of targeting sharks was best modeled using a more parsimonious ordinal logistic regression model, with the likelihood of targeting increasing significantly with increasing perception of sharks as a threat ($p < 0.01$; Fig. 5; $n = 258$, Nagelkerke pseudo $R^2 = 0.08$, Lipsitz goodness of fit test $p = 0.48$, Hosmer-Lemshow test $p = 0.002$; see Supplemental materials for further details on model selection). Modeling behavioral change to protect the target species required log transforming this aggregate metric to meet normality assumptions and included multiple demographic explanatory variables (income, age, and sex), as well as the level of positive emotional response and the aggregate perceptions of sharks score ($n = 258$, F-statistic $= 3.95$ (17, 240 df), $R^2 = 0.22$). Increasing positive emotions significantly increased the likelihood of

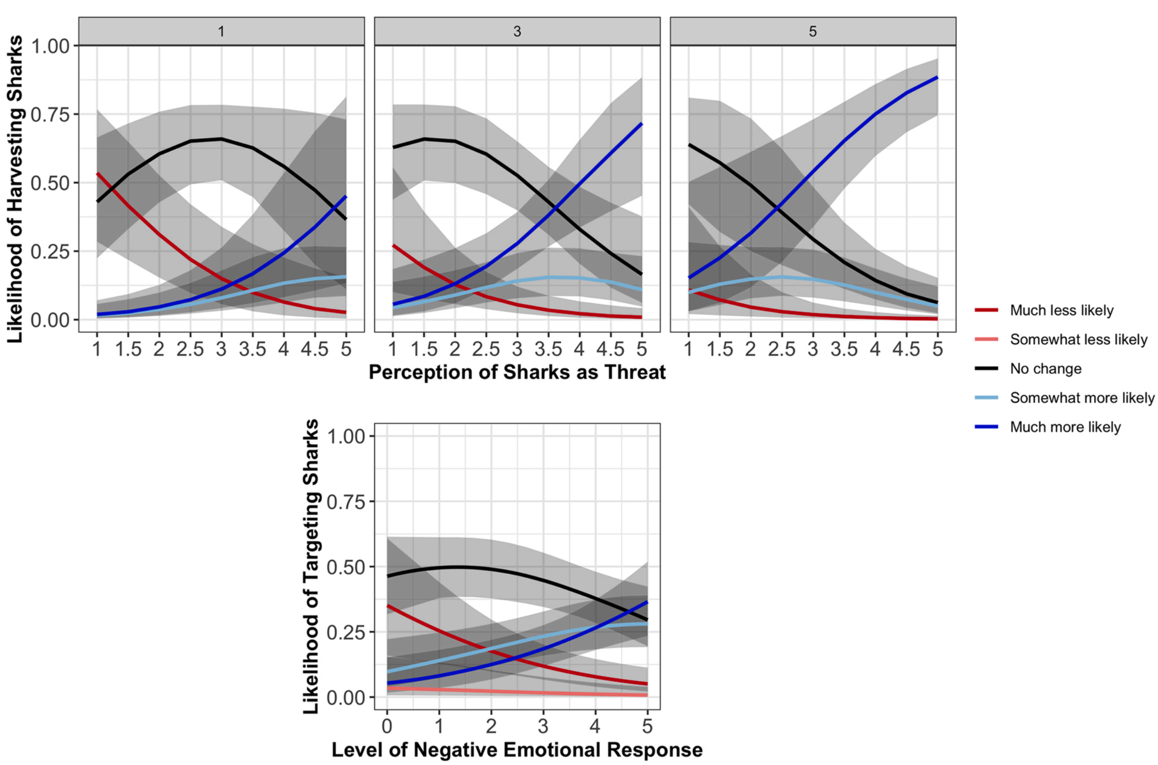

Fig. 4. Predictive plots from the best ordinal logistic regression models of guide likelihood to harvest sharks (top row) in response to shark depredation as a function of guide perceptions of sharks as a threat (x-axis) and negative emotional response (constant for each panel, ranging from one to five with one feeling weak negative emotions and five feeling strong negative emotions). Guide likelihood of targeting sharks (bottom row) in response to shark depredation as a function of negative emotional response. Means for each possible response on the Likert scale are presented bounded by 95% confidence intervals.

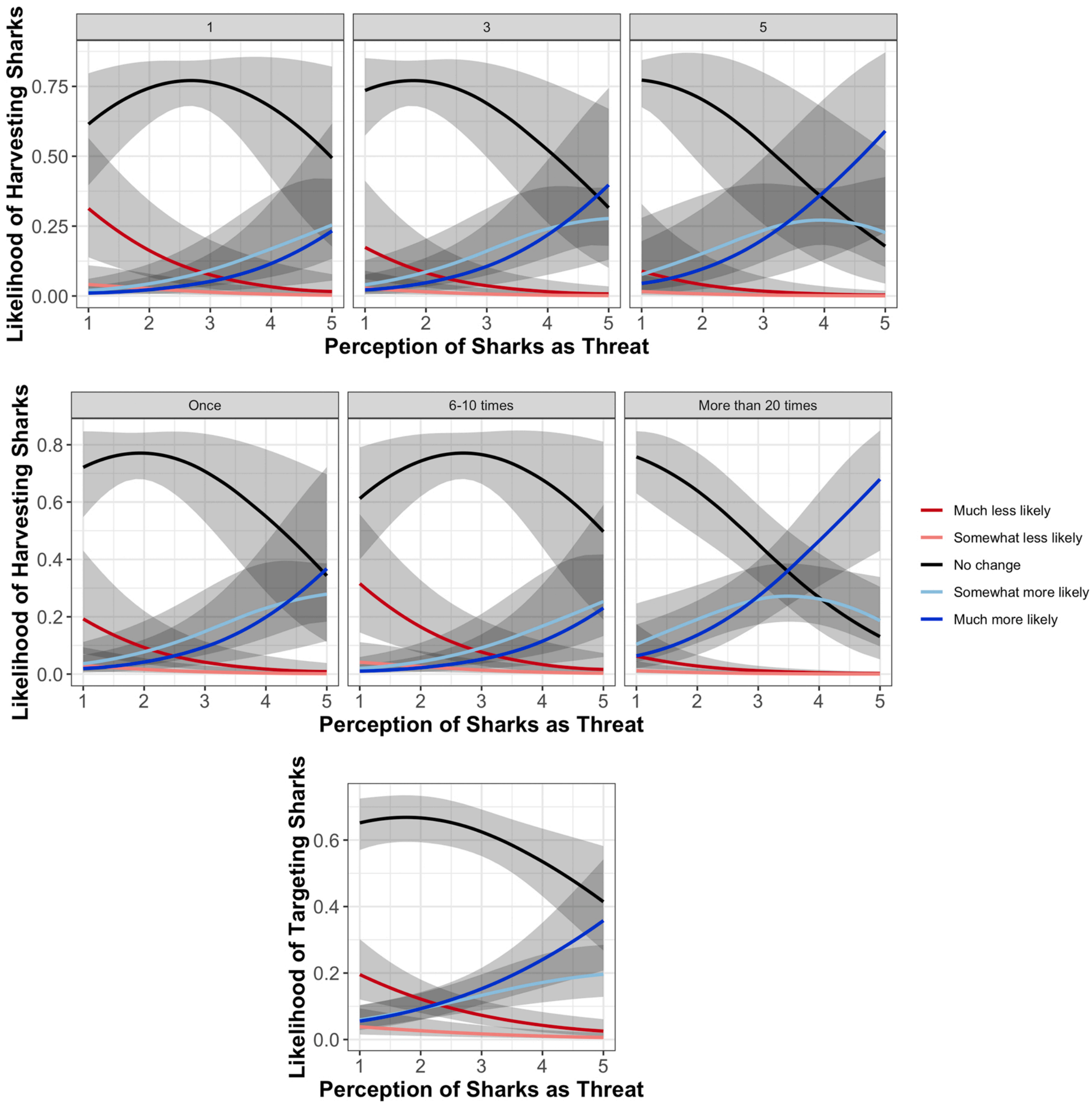

Fig. 5. Predictive plots from the best ordinal logistic regression model of angler likelihood of harvesting sharks in response to shark depredation as a function of perceptions of sharks as a threat (x-axis) and negative emotional response (top row; constant for each panel, ranging from one to five with one feeling weak negative emotions and five feeling strong negative emotions) or frequency of depredation in the last five years (middle row; constant for each panel). Angler likelihood of targeting sharks (bottom row) in response to shark depredation as a function of perception of sharks as a threat. Means for each possible response on the Likert scale are presented bounded by 95% confidence intervals.

behavioral change to protect the target species ($p < 0.01$; Fig. S13), as did being female ($p < 0.01$; Fig. S15), and 18–24 years old (Tukey's HSD $p = 0.02$; Fig. S14). While perceptions of sharks ($p = 0.39$) and income (Tukey's HSD $p > 0.19$) were included in the best model, they were not significant predictors.

3.3. Effects of depredation on perceptions of sharks

Since perceptions of sharks played a key role in predicting emotional and behavioral responses to depredation, we assessed if perceptions of sharks varied between those that had and had not experienced depredation. The best model for predicting differences in perceptions of sharks between groups was an additive linear model including whether or not the respondent experienced depredation, if they were a guide, the level of extractive identity, and the level of conservation identity ($n = 541$, F-statistic = 71.86 (4, 493 df), $R^2 = 0.37$). Those that experienced depredation and fishing guides were significantly more likely to perceive sharks as a threat to their target species ($p < 0.01$; Fig. S16). Additionally, perceiving sharks as a threat increased significantly when individuals identified strongly with extractive identities, like hunters, and decreased significantly when individuals identified strongly with more conservation focused identities, like catch-and-release anglers ($p < 0.01$; Fig. S16).

All respondents were also asked to indicate how important or unimportant they felt a number of issues were in relation to shark encounters, including harm to the shark from entanglement in fishing gear, increased mortality of the target species, and loss of return customers for fishing guides. Mann-Whitney *U* tests found significant differences for all issues between those that had and had not experienced depredation ($n = 541$, U range: 171.5–30,165, $p < 0.01$). Most notably, those that had not experienced depredation placed more importance on shark injury from entanglement than those that had experienced depredation. Those that had experienced depredation were more concerned about increased mortality to their target species and losing trophy fish (Fig. 6).

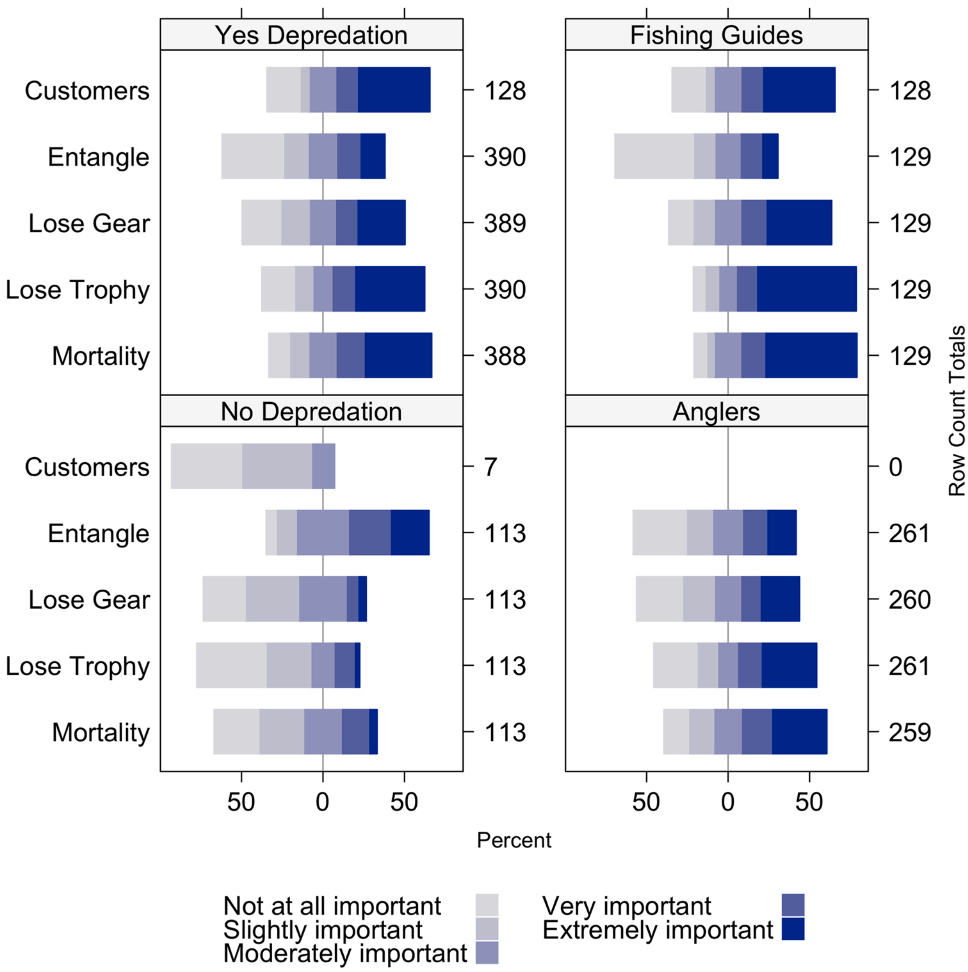

Fig. 6. Responses to the question "How important or unimportant do you believe the following issues are in relation to shark encounters?" compared between those that had and had not experienced depredation (left) and between guides and anglers who had experienced depredation (right). All respondents were presented with the options: harm to the shark from gear entanglement, losing expensive fishing gear, losing a trophy fish, and increased mortality of my target species, while only guides were asked about loss of return customers.

It should be noted that guides who had experienced depredation were quite concerned about losing return customers, but very few guides who took the survey had not experienced depredation ($n = 7$). Mann-Whitney U tests also found significant differences in importance of all encounter issues between fishing guides and anglers who had experienced depredation ($n = 418$, U range: 11,188–19,838, $p < 0.01$). Guides placed more importance in losing trophy fish, increased mortality of the target species, and losing expensive fishing gear than anglers (Fig. 6). Guides also felt shark injury due to entanglement was much less important than anglers.

3.4. *Fishing guide perspectives on depredation*

The additional questions posed to fishing guides revealed that 87.2% had experienced depredation with clients onboard, and 76.5% felt that depredation had increased dramatically in the last five years (Table 2). Of those that had experienced depredation with clients, 44.3% felt that depredation exclusively had a negative effect on their client's fishing experience and 40.9% said that some clients had a positive experience and others had a negative experience with depredation. Guides were given the opportunity to share why they felt that the experience of their clients was affected by depredation. Of those that responded ($n = 59$), 33.9% mentioned that clients were excited by the shark, 23.7% said that the more times depredation happens to a client the worse the reaction is, and 22.0% said that clients were upset because they had lost fish intended for harvest (Table S4). A total of 82.6% of guides said that they had witnessed sharks changing their behavior when encountering recreational anglers, with 73.1% stating that they experienced sharks following their boat, 30.8% feeling that sharks are associating boats with food, and 25.0% stating that chumming practices by dive boat tourism are enhancing this (Table S5). All guides who raised concerns about dive boat tourism fished primarily in Florida, except for one who fished in South Carolina. When asked if they thought sharks affected their livelihood, 59.9% of guides said sharks had a negative effect, while only 14.4% felt sharks had a positive effect (Table 2).

4. Discussion

Shark depredation presents a multifaceted issue in the face of shark conservation success and increasing human use of ocean resources (Carlson et al., 2019). Herein, we provide evidence that shark depredation in recreational fisheries occurred throughout the coastal U.S., reported most often by survey respondents in the south and spanning the eastern seaboard of the Atlantic Ocean to the Gulf of Mexico (Fig. S17, Table S6). Seventy-seven percent of survey respondents had experienced shark depredation in the last five years, which is comparable to an Australian survey of commercial, charter, and recreational fishers, 69% of whom had experienced depredation (Ryan et al., 2019), and higher than the one-year depredation rate of 38.7–41.9% of recreational fishing trips in Ningaloo Marine Park and Exmouth Gulf, Western Australia (Mitchell et al., 2018b).

Our survey respondents participated in a wide range of coastal and pelagic fisheries, but the most targeted species were not necessarily the most frequently depredated species. Notably, mahi was the most commonly targeted species but was not a frequently depredated species, with only six respondents listing mahi as their most recently lost species and four respondents listing mahi as their most frequently lost species. While there is the potential for recall bias when asking anglers to report

Table 2
Responses to questions posed specifically to fishing guides who had experienced depredation regarding experiencing depredation with clients and their experiential knowledge of shark-angler encounters presented as count (n) and percent of total respondents to each question (%).

	n	%
Have you experienced a depredation event with clients? (n = 133)		
No	17	12.78
Yes	116	87.22
How do you think your clients perceived this shark encounter? (n = 115)		
It had a negative effect on my client's fishing experience	51	44.35
I'm not sure	1	0.87
It had a positive effect on my client's fishing experience	9	7.83
Some clients had a positive experience, while others had a negative experience	47	40.87
It had no effect on my client's fishing experience	7	6.09
In your experience, how has depredation increased, decreased, or not changed in the last five years? (n = 132)		
Decreased dramatically	0	0.00
Decreased some	2	1.52
No change	16	12.12
Increased some	13	9.85
Increased dramatically	101	76.52
Some guides report that sharks change their behavior when recreational fishing is happening nearby. Have you ever experienced anything like this? (n = 132)		
No	14	10.61
Not sure	9	6.82
Yes	109	82.58
Do you feel sharks affect your livelihood? (n = 132)		
Definitely has a negative effect	63	47.73
Probably has a negative effect	16	12.12
I'm not really sure	5	3.79
Probably has a positive effect	3	2.27
Definitely has a positive effect	16	12.12
Might or might not have an effect	14	10.61
There is no effect	15	11.36

the details of depredation events that took place within the last five years, 86.1% of respondents who had experienced depredation reported that their most recent depredation event was within a year of the survey launch, and only 4.2% could not recall the month of their most recent depredation, indicating that depredation is a memorable event for anglers. Fishing guides are especially affected by depredation, experiencing strong negative emotional responses and expressing concern that shark depredation is a threat to their livelihood. Those that experience depredation, particularly fishing guides, are more likely to target and harvest sharks recreationally, supporting the potential for depredation to have lasting management implications for both target species and shark populations.

4.1. Stakeholder responses to depredation

Though depredation rates have been studied extensively for marine mammals in recreational and commercial fisheries (Powell and Wells, 2011; Hamer et al., 2012; Peterson et al., 2013; Werner et al., 2015) and, to a lesser extent, sharks in commercial fisheries (Mitchell et al., 2018a; Ryan et al., 2019; Tixier et al., 2020b), this is the first study to quantify emotional and behavioral responses to shark depredation exclusively in recreational fisheries. Ryan et al. (2019) surveyed commercial, charter, and recreational fishers who had experienced depredation and found that participants in all fishing sectors were satisfied or very satisfied with their overall fishing experience in the last year but did not ask questions specific to satisfaction surrounding a depredation event. Fishers across sectors in Hawaii viewed sharks as competitors, in part because of depredation (Iwane et al., 2021). Our survey showed that both emotional and behavioral responses to depredation varied significantly between guides and anglers, but both groups reported negative emotions surrounding depredation. Guides generally had lower mean levels of positive emotions and higher mean levels of negative emotions than anglers. In addition to the potential financial repercussions of depredation, this could be because guides overwhelmingly experienced high levels of depredation (with 77.5% of guides experiencing > 20 depredation events in the last five years compared to only 39.9% of anglers (Table S2)), reducing the level of positive emotions felt, while anglers had more varied experiences in terms of depredation frequency. A close encounter with a predator appears to retain its novelty for those who experience depredation infrequently.

The emotional responses to depredation significantly influenced the likelihood of subsequent behavioral changes, as did perceptions of sharks as a threat, for both guides and anglers. Though this finding is to be expected, the influence of emotions is often left unexplored in social science studies of depredation where research is more focused on predator perceptions, particularly in terrestrial systems (Amit and Jacobson, 2017). However, our findings are similar to Cooke et al. (2015) who found that fishing guides in southern California experiencing California sea lion (*Zalophus californianus*) depredation were more likely to favor relaxed protections of marine mammals and lethal control programs for sea lions, in particular. Similarly, lethal retaliation against sharks in response to depredation is not uncommon in commercial fisheries globally (Gillman et al., 2007; Tixier et al., 2020b; Iwane et al., 2021).

Our models showed that both guides and anglers were unlikely to respond with proactive behaviors to protect their target species in response to depredation. Fishing guides were more likely to change their fishing behavior with increasing positive responses, but this model had low explanatory power. This could be because very few guides felt strong positive emotions after depredation. Anglers were similarly unlikely to make non-lethal behavioral changes to protect their target species, though more variation was explained with additional demographic information. Female and young anglers were more likely to change than older and male anglers. Increasing sample size of these groups of anglers in future studies of depredation could reveal further drivers behind differing behavioral motivations in these groups. Additionally, while 87% of guides had experienced depredation with clients, only 22 anglers reported hiring a fishing guide. This limited sample size prohibited us from drawing conclusions about how depredation could influence future angling behavior in regard to hiring a guide. Reaching this demographic should be a priority of future studies to better understand the potential economic impacts of depredation.

Comparable human-wildlife conflict research has been conducted more widely in terrestrial settings (Tixier et al., 2020a), particularly focusing on rancher response to predator depredation on livestock (Boulhosa and Azevedo, 2014; Scasta et al., 2017; Amit and Jacobson, 2017; Waters and Mars, 2021). Lethal retaliation in response to depredation is a common response among ranchers across predator types, including mammals (Lindsey et al., 2005; Zimmermann et al., 2005; Romañach et al., 2007; Scasta et al., 2017; Amit and Jacobson, 2017) and avian predators (Margalida et al., 2014). While government sponsored programs have focused specifically on lethal control to mitigate terrestrial human-wildlife conflict (Scasta et al., 2017), little evidence supports that these programs effectively reduce depredation (Berger, 2006). Despite this, and often in belief that terrestrial predator control programs are effective (G.A. Casselberry pers. obs.), this study found that fishing guides and, to a lesser extent, anglers are increasingly likely to harvest and target sharks with increasing negative emotional response, increasing perception of sharks as a threat, and more frequent depredation. While intent does not always lead to action, the motivation to retaliate against sharks in response to depredation clearly exists, highlighting the need for managers to work towards mitigating depredation before guides and anglers take action. Outside of recreational fisheries, often lethal harvest of predators in defense of resources goes unreported (Romañach et al., 2007; Treves and Bruskotter, 2014), representing an additional source of unquantified mortality in the instance of shark depredation. Future research could focus on guide and angler intent for harvested sharks, for instance if guides would shift target species, bringing clients shark fishing, and if sharks would be harvested for consumption.

Given the potential for unsustainable shark harvest in response to depredation, exploration into effective non-lethal predator management, like shark deterrent devices for recreational anglers, is essential. While anglers could take direct action to mitigate depredation of their target species by moving to a new location after a depredation or stopping fishing that day, these solutions are not always feasible for fishing guides who have been chartered for a full day, and are unlikely actions based on our results. Currently, most non-lethal shark deterrent development has focused on reducing shark bites by generating electromagnetic fields (Kempster et al., 2016; Huveneers et al., 2018; Thiele et al., 2020), with varying degrees of success (Egeberg et al., 2019), while others have tested the effects of natural and manmade sounds, lights, or chemicals (Gobush and Farry, 2012; Stroud et al., 2014; Ryan et al., 2018; Chapuis et al., 2019). Fewer studies have attempted to develop deterrents in a recreational or commercial fisheries context (Robbins et al., 2011; Rabearisoa et al., 2012; O'Connell et al., 2014; Hamer et al., 2015; Hart and Collin, 2015; Howard et al., 2018; Richards et al., 2018). Successful deterrents could be modified for use in fisheries, but further research is needed to understand how effective deterrents may be when a shark is exposed to live prey, as opposed to dead bait, and how these devices affect catch rates.

4.2. Management implications of depredation for targeted species

Overall, fishing mortality due to shark depredation could have significant implications for fish stocks and, if mortality is high enough, could result in population declines, even in closely managed stocks (Sippel et al., 2017; Peterson and Hanselman, 2017; Tixier et al., 2020a, 2020b). A clear pattern emerged among the species most frequently and most recently lost to depredation, highlighting vulnerabilities particularly for tunas, king mackerel, snapper, bonefish (*Albula vulpes*), striped bass, and blackfin tuna (*Thunnus atlanticus*). This is particularly concerning because many of these species are currently overfished (some ICCAT-managed tunas (Anonymous, 2019), striped bass (Northeast Fisheries Science Center NEFSC, 2019; Atlantic States Marine Fisheries Commission ASMFC, 2019), and some snappers (SEDAR, 2017, 2018b)), recovering from overfishing (some snappers (SEDAR, 2018a) and some ICCAT-managed tunas (Anonymous, 2019)), or lacking a formal assessment (blackfin tuna (Fenton et al., 2015), bonefish (Santos et al., 2017; Brownscombe et al., 2019), and some snappers (SEDAR, 2016)). Others are fished sustainably (some snappers (SEDAR, 2008, 2020a, 2020b, 2018c) and king mackerel (SEDAR, 2020c, 2020d)). The variety of species and fisheries reported as most frequently and most recently depredated demonstrates the need to proactively quantify and manage depredation in both established (e.g., tunas, striped bass, snapper) and growing recreational fisheries (e.g., blackfin tuna) for both harvest and catch-and-release (e.g., bonefish) species. Specific research to quantify depredation mortality in these fisheries, in particular, is needed to ensure existing management regulations are sufficient.

Shark depredation appears to be a documented and emerging issue for king mackerel, in particular. Survey results showed that king mackerel were the second most frequently depredated species, behind tunas, and the most recently depredated species. Recreational landings of king mackerel have declined substantially since the mid 2000's in the Atlantic (South Atlantic Fishery Management Council SAFMC, 2018, Personal communication from the National Marine Fisheries Service, Fisheries Statistics Division). The South Atlantic Fishery Management Council recently noted that sharks are a "big problem" contributing to lower landings during the spring mackerel run, particularly in northeastern Florida (South Atlantic Fishery Management Council SAFMC, 2018). However, king mackerel tournaments are increasing in Florida and comprise a substantial amount of fishery effort (South Atlantic Fishery Management Council SAFMC, 2018). These tournaments present an opportunity for quantifying depredation in the king mackerel fishery, which would not only improve mortality estimates for assessments, but allow for the testing of solutions for depredation, including the potential use of shark deterrent devices.

While most anglers surveyed did not specify snapper species, red snapper, mangrove snapper, and mutton snapper were highlighted. Of those, red snapper are currently overfished and overfishing is occurring in the Atlantic (SEDAR, 2017), while the stock is not overfished and recovering from overfishing in the Gulf of Mexico (SEDAR, 2018a). Depredation mortality may not have a significant impact on stock health for some snappers, but high depredation in fisheries with depleted stocks could hinder species recovery and, in the case of the red snapper fishery, heighten an already tense environment between managers and stakeholders (Cowan et al., 2011). Indeed, shark depredation in the commercial and recreational red snapper fishery is a well-documented occurrence (Drymon et al., 2019, 2020), and has been shown to influence angler willingness to support shark conservation efforts (Drymon and Scyphers, 2017).

4.3. Management implications for sharks

Significant differences in perceptions of sharks and concerns related to shark encounters could have implications for shark management for state and federal agencies. Experiencing depredation increased angler likelihood to view sharks as a threat to their target species and humans, which translated directly to issues anglers were most concerned about in relation to shark encounters. Those that had not experienced depredation were very concerned about sharks being harmed by entanglement in fishing gear after a depredation, while those that had experienced depredation were much more concerned about mortality of their target species and losing trophy fish. Guides who had experienced depredation were also very concerned about losing customers because of depredation and, to a lesser extent, losing fishing gear.

Though entanglement was a top concern for anglers who had not experienced depredation, guides overwhelmingly felt that entanglement was not an important issue. Limited research has been conducted regarding shark entanglement in marine debris, particularly recreational fishing gear (Parton et al., 2019). Mitchell et al. (2019) found that 2% of sharks observed in the Ningaloo region of Western Australia, where depredation in recreational fisheries occurs regularly, had retained fishing gear. Often studies that quantify shark encounters with hook and line gear focus more heavily on damage due to hook placement (Bansemer and Bennett, 2010; Bègue et al., 2020), as opposed to trailing line which could entangle the body and impede movement (Sepulveda et al., 2015). Guides may feel that entanglement is not an issue because they rarely lose significant amounts of line to sharks, or because of a lack of concern for wellbeing of sharks given their propensity to view sharks as threatening. Further research is needed to understand the potential for shark mortality through depredation mediated entanglement.

Moving forward, managers should consider and incorporate that anglers who had experienced depredation placed high value on target species and trophy fish mortality when addressing issues surrounding shark-angler encounters and depredation. Education efforts that emphasize the value of sharks for healthy ecosystems could help to change negative perceptions of sharks among this user group, but this should be done in conjunction with addressing the specific concerns of anglers. Fishing guides, in particular, are highly concerned about depredation and feel it will harm their businesses. They are noticing changes in shark behavior, indicating that sharks may associate fishing vessels with food, particularly in areas where dive tourism is popular. Sharks could be capable of associative learning, as classical conditioning, memory retention, and spatial learning have been documented in sharks of multiple taxa (Guttridge et al., 2009; Schluessel and Bleckmann, 2012). While results on the effects of dive operations on shark behavior are mixed (Bradley et al., 2017), diving operations can increase shark residency and reduce activity space, focused around dive sites

(Brunnschweiler and Barnett, 2013; Brena et al., 2015; Araujo et al., 2020), validating these guides' concerns. Further, in Ningaloo Marine Park, Western Australia, a location with quantified depredation rates in its recreational fisheries (Mitchell et al., 2018b), sharks have been shown to arrive faster and in higher numbers at heavily fished sites than areas closed to fishing (Mitchell et al., 2020), meaning that changes in the distribution of angler fishing effort could be a way to reduce depredation rates.

4.4. Caveats and next steps

Though our survey reached anglers from throughout the U.S., over 50% of respondents were from the south, particularly Florida. Further, only five of the 234 Floridian respondents had not experienced depredation. This potential for sampling bias is not uncommon in virtual snowball sampling design, which relies mainly on respondents sharing within their networks to increase sample size (Baltar and Brunet, 2012). Though survey advertisements did not mention depredation specifically, and it was clear that having interacted with a shark was not a requirement for participation, it is likely that those who completed the survey and had experienced depredation were more inclined to share the survey with others. This outcome not only highlights Florida as an area with high shark-angler conflict, but also emphasizes the need to further explore depredation in other areas of the U.S., like the West Coast, to better characterize responses in these regions.

Another potential source of bias was launching the survey on social media during Shark Week. To minimize this bias, the survey was repeatedly shared on social media, particularly Twitter, subsequent to the Shark Week launch from Aug. 2, 2019 to Oct. 31, 2019 using various fishing focused hashtags. On Twitter, the survey was shared by shark advocacy groups, like Shark Advocates International, and angler advocacy groups, like Stripers Forever and Fisheries Conservation Foundation, allowing us to have a broader reach to anglers who likely have varying views about shark conservation and management. No mention of Shark Week was made for survey distribution on other social media platforms (Facebook and Instagram) or angler related blogs. Additionally, email distribution of the survey to IGFA fishing clubs and NOAA HMS tournament participants occurred in the winter of 2019–2020. Because responses to the survey were received throughout the study period, the influence of Shark Week biasing our results is minimal.

Recall bias and latency effects are two common factors that can occur in surveys relying on a respondent's memory to collect data (Glenberg et al., 1983; Bell et al., 2019). Given many angler's ability to recall the date of their most recent depredation event, including anglers who experienced depredation five or more years prior, shark depredation is clearly a memorable event. The degree to which a depredated species is memorable may vary based on an angler's motivation for fishing. For instance, those fishing with the intent to harvest, may recall losing a food fish like snapper more clearly than an angler targeting trophy species would. However, an angler's fishing motivation can vary from trip to trip and our record of depredated species spanned harvest, catch-and-release, and trophy fisheries.

The latency, or recency, of the depredation event could influence how salient various emotions were for anglers at the time they completed the survey. Studies of emotional duration indicate that sadness followed by enthusiasm have the longest duration out of a suite of 27 emotions (Verduyn and Lavrijsen, 2015). Both of these long-lasting emotions were included in our analysis of potential positive and negative emotional responses to depredation. While an angler who had recently experienced depredation could have stronger feelings recalling the event than an angler who had experienced depredation years ago, the vast majority of respondents were recalling depredation events that had occurred within the last year when gauging their emotions. Only 21 respondents (17 anglers and 4 guides) were recalling events that had occurred five or more years ago. Generally, respondents who had not experienced depredation recently also experienced depredation infrequently, which our models showed significantly influenced the level of emotional response for both anglers and guides, helping to account for this potential latency effect in our models.

Though we were able to confidently model guide behavioral changes with respect to targeting and harvesting sharks through ordinal logistic regression, our model for guides changing their behavior to protect their target species had a poor goodness of fit. It could be that decision making by guides is highly individualized based on the desires and skill level of their clients, limiting our ability to model these changes. More detailed interviews with guides would provide further insights into this decision making. Interestingly, guides had higher personal identity scores for both the extractive and conservation identity than anglers. Guides who identify strongly as catch-and-release anglers appear to perceive sharks as less of a threat and subsequently may be more inclined to collaborate with researchers on future depredation research. An open dialogue between anglers, researchers, and managers will be essential for addressing depredation issues, as human-wildlife conflicts can easily become conflated with human-human conflicts between managers and stakeholders (Dickman, 2010).

The willingness of guides to target and harvest sharks in the future after experiencing depredation indicates that they are highly invested in their fisheries and not hesitant to take action, even if this action will not immediately stop depredation. Depredation was reported throughout the coastal U.S., and the concept that a single problem individual is responsible for depredation in a fishery is unlikely, as there is no scientific support for "rogue shark" theories (Neff and Hueter, 2013; Pepin-Neff, 2018). Further, attempts at lethal control to reduce depredation to a satisfactory level for anglers are more likely to lead to perilous declines in local shark populations, threatening species persistence, before they would lower depredation rates, as has been seen in efforts for lethal shark control to reduce shark bite incidence (Wetherbee et al., 1994; Ferretti et al., 2015; Gibbs et al., 2019).

In this survey, we did not ask respondents to identify the species of shark committing depredation. Even for those that do commonly target sharks, species identification can be challenging, particularly for carcharhinids (Shiffman et al., 2017; Gibson et al., 2019). Additionally, we were unsure if depredation events would occur at depth with the shark out of sight or if anglers would see the shark committing the depredation. Despite this, 12 guides mentioned depredating shark species when describing shark behavior around their boats, with 50.0% implicating bull sharks in depredation. Additionally, the majority of respondents who had experienced depredation saw the shark committing the depredation, and more than half of respondents had previously engaged in recreational shark fishing. Avid anglers who have experienced depredation may be able to provide accurate data regarding shark species committing depredation that could aid in addressing shark-angler conflict, particularly as managers, like the Florida Fish and Wildlife Conservation Commission, discuss species-specific conflict and potential regulation changes.[2]

Since the perception of risk can often be higher than the realized risk in instances of human-wildlife conflict (Dickman, 2010), we suggest managers begin working directly with fishing guides to quantify depredation rates based on fishing effort in their fisheries. This information can be used to better understand the extent to which depredation is a threat to sustainable recreational fisheries. In addition, understanding when and how depredation occurs in a fishery can better inform mitigation strategies to improve fish survival and reduce shark-angler conflict (Tixier et al., 2020b). This could include limiting fish fight times, particularly in catch-and-release fisheries, or avoiding fishing in areas or conditions where depredation is known to occur frequently, for instance during certain points in the tidal cycle or at certain water temperatures, which can influence both fisheries effort

[2] Meeting of the Florida Fish and Wildlife Conservation Commission (May 12, 2021).

and catch rates.

4.5. Conclusions

Considering depredation frequency was directly tied to negative emotional response, which in turn influenced the likelihood of targeting and harvesting sharks, reducing shark-angler encounters should be a high priority for managers. The solutions to depredation and reduced shark-angler conflict will not be simple and will likely be highly variable among fisheries, but addressing this issue is essential to continued sustainability for both target species and sharks. Establishing open and collaborative partnerships based on mutual trust between fishers, managers, and researchers will be essential to successfully addressing this shark-angler conflict (Iwane et al., 2021). Managers and advocacy groups should work to ease angler perceptions related to sharks as a threat by quantifying depredation rates in specific target fisheries and testing solutions to mitigate depredation, while also valuing the issues that are important to anglers, particularly mortality of their target species.

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CRediT authorship contribution statement

Grace A. Casselberry: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Writing – original draft, Writing – review & editing. **Ezra M. Markowitz:** Conceptualization, Methodology, Writing – review & editing, Supervision. **Kelly Alves:** Investigation, Data curation, Writing – review & editing. **Joseph Dello-Russo:** Investigation, Data curation, Writing – review & editing. **Gregory B. Skomal:** Conceptualization, Methodology, Investigation, Writing – review & editing, Supervision. **Andy J. Danylchuk:** Conceptualization, Methodology, Investigation, Writing – review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

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