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A multifaceted citizen-science approach for characterizing shark depredation in Florida's recreational fisheries

Michael P. McCallister [1,*], **Lauran Brewster** [2], **Cheryl Dean** [3], **J. Marcus Drymon** [4,5], **Cliff Hutt** [6], **Thomas J. Ostendorf** [1], **Matthew J. Ajemian** [1]

[1]Harbor Branch Oceanographic Institute, Florida Atlantic University, Fort Pierce, FL 34946, United States
[2]School for Marine Science and Technology, University of Massachusetts Dartmouth, New Bedford, MA 02744, United States
[3]Cramer Fish Sciences-Genidaqs, West Sacramento, CA 95691, United States
[4]Coastal Research and Extension Center, Mississippi State University, Biloxi, MS 39532, United States
[5]Mississippi-Alabama Sea Grant Consortium, Ocean Springs, MS 39564, United States
[6]Atlantic Highly Migratory Species Management Division, Office of Sustainable Fisheries, National Marine Fisheries Service, Silver Spring, MD 20910, United States

*Corresponding author. Michael P.McCallister, Harbor Branch Oceanographic Institute, Florida Atlantic University, Fort Pierce, FL 34946, United States. E-mail: mmccallister@fau.edu

Abstract

Depredation (i.e. partial removal of target catch prior to retrieval) caused by sharks is a prevalent issue affecting several fisheries in the southeastern USA. While US fisheries managers have begun monitoring shark depredation in commercial fisheries, there have been few attempts to quantify these interactions in the recreational fishing sector. To address this knowledge gap, we initiated a citizen-science-based project to provide an in-depth characterization of shark depredation in Florida's recreational fisheries. This was done via multiple approaches, including social media content analysis, online angler surveys, and cooperative fishery-dependent charters. Across methodologies, snapper-grouper species were the most frequently depredated target species group, and bull and sandbar sharks were the most commonly identified depredating species. Forty-three percent of anglers experienced depredation, and the probability of experiencing depredation ranged from 10% to 60% and varied both regionally and seasonally. In addition, average depredation rates ranged from 31% to 47% and were within the range of reported rates from other recreational fisheries. These results will help build a comprehensive understanding of this human-wildlife conflict and could aid fishery managers in developing management measures to address this fisheries conflict. Furthermore, this study highlights the benefit of incorporating citizen science when addressing complex fisheries issues involving stakeholder conflict.

Keywords: human-shark conflict; human-wildlife conflict; fisheries management; depredation; sharks

Introduction

Rapid growth and expansion of human populations worldwide have increased competition for resources and space with wildlife populations, resulting in increased interactions between humans and wildlife (Woodroffe et al. 2005). Broadly defined as actions between humans and wildlife that have negative effects on the other, human-wildlife conflicts (HWC) are typically presented as real or perceived threats to human safety, property, economy, and recreation (Nyhus 2016). However, these conflicts also pose a threat to wildlife populations (deSouza et al. 2015, Torres et al. 2018), and more recently, HWCs have begun to be re-framed as a divergence of peoples' attitudes towards conservation (Redpath et al. 2013). While HWCs in terrestrial systems are well studied (see Woodroffe et al. 2005), particularly with respect to livestock depredation by large carnivores (Carter and Linnell 2016, van Eeden et al. 2018), within marine systems HWCs have not received the same level of attention. As global demand on fisheries has increased (Merino et al. 2012, Zeller and Pauly 2019), one HWC receiving increased attention is depredation in marine fisheries (Tixier et al. 2020b).

In fisheries, depredation is defined as the partial or complete removal of target species caught with fishing gear by a non-target species before it can be landed (Garrison 2007, Gilman et al. 2008). Typically attributed to larger marine predators (i.e. sharks, cetaceans, and large teleosts; MacNeil et al. 2009, Shideler et al. 2015, Söffker et al. 2015), depredation has become a significant fisheries issue. Depredation has been reported worldwide across all major fishing sectors and techniques, with 60%–80% of commercial, recreational, and artisanal fisheries reporting their first depredation experiences in the last 15–20 years (Tixier et al. 2020b). Effects of depredation on these fisheries include both socio-economic and ecological impacts, ranging from reduced catch and profits to increased fishing pressure and mortality of both the target and depredating species, and could pose a threat to the viability of these fisheries (Hamer et al. 2012, Tixier et al. 2020a, Clavareau et al. 2023).

While shark depredation in fisheries is not a new phenomenon (Drymon et al. 2024), research on shark depredation had been limited until the early 2000s (Mitchell et al. 2018a, 2023). Since then, the body of research on shark depredation has rapidly expanded, reflecting a growing awareness of this issue among scientists (see reviews by Gilman et al. 2008, Mitchell et al. 2018a, 2023) and fishery managers (DPIRD 2024, NOAA 2022). Much of this research has largely focused on characterizing and quantifying shark depredation in commercial fisheries (Gilman et al. 2008, Mandelman et al. 2008, MacNeil et al. 2009, Carmody et al. 2021); however, increasing reports of recreational anglers losing their catch to sharks over the last 10 years have led to a greater focus on shark depredation in recreational fisheries, particularly in the USA and Australia (see reviews by Mitchell et al. 2018a, 2023).

While studies on shark depredation in recreational fisheries from Australia have focused on quantifying rates and identifying factors that influence depredation (Mitchell et al. 2018b, Ryan et al. 2019, Coulson et al. 2022), as well as the potential behavioral effects of depredation (Mitchell et al. 2020), research in the USA has largely focused on anglers' perceptions of shark depredation. For instance, Casselberry et al. (2022) found that angler attitudes were largely driven by negative emotional responses towards shark depredation. Similar trends were observed among Florida anglers in a study by Klizentyte et al. (2023); however, this study examined depredation across all possible marine predators rather than depredation by sharks specifically. In addition, depredation also influenced opinions and support of shark conservation and management efforts among recreational anglers in both Florida (Drymon and Scyphers 2017) and the Gulf of Mexico (Prasky et al. 2023). While these studies provide valuable insight into anglers' attitudes towards shark depredation, they provide minimal quantitative data on the extent of shark depredation beyond reporting on the frequency with which anglers are experiencing depredation. More recently, studies by Holder et al. (2020), Griffin et al. (2022), and Casselberry et al. (2024) have examined shark depredation in recreational fisheries for permit (*Trachinotus falcatus*) and tarpon (*Megalops atlanticus*) in the Florida Keys, USA, identifying increased predator encounter rates and spatial overlap in core use areas with predators during specific times of the year for both species. However, detailed studies like these remain limited for other fisheries.

Recreational saltwater fishing is an important pastime in the USA (USDOI 2016, 2022), with much of the fishing effort concentrated in the southeastern US (NMFS 2024). Given the prevalence of saltwater fishing in these regions, it is not surprising that recent studies have identified these areas as shark depredation "hot spots." In a survey of recreational anglers and fishing guides, Casselberry et al. (2022) found ∼77% of respondents experienced shark depredation while fishing within the last 5 years, and was most frequently reported in the southeastern USA (i.e. Florida). More recently, a Florida-based survey by Klizentyte et al. (2023) found between 60% and 90% of respondents experienced depredation during the previous 12 months (though this included depredation by all marine predators, not just sharks). However, despite the apparent prevalence of shark depredation in recreational fisheries in the USA, efforts to quantify shark depredation rates and their underlying mechanisms in these fisheries remain limited. Given the significant economic importance of recreational fishing in Florida, as well as continued concern among stakeholders in the recreational fishing community that shark depredation is increasing, there is a pressing need to understand the extent of shark depredation in this fishery. Therefore, the goal of this project was to provide an in-depth characterization of the current state of shark depredation in Florida's recreational fisheries. From June 2020 to September 2023, we utilized a multifaceted citizen science approach that included content analysis, angler surveys, and cooperative fishery-dependent charters, in order to (1) identify species involved in shark depredation, (2) quantify shark depredation frequency (i.e. the percentage of anglers experiencing depredation) and rates (i.e. percentage of total catch lost to depredation), and (3) examine temporal and spatial trends in shark depredation. The data collected in this study will fill a critical knowledge gap in our understanding of shark depredation in US recreational fisheries and can be used by state and federal fishery managers to address this complex and contentious fisheries issue.

Methodology

Social media content analysis

A qualitative content analysis of the Facebook group "Sportsmen Fighting for Marine Balance" (SFMB; https://www.facebook.com/groups/291161112320504) was conducted to characterize shark depredation in Florida's recreational fisheries from the perspective of the most vocal anglers actively reporting shark depredation. The SFMB page was established in July 2020 by Florida anglers as a space to catalog and share their photographs and videos of shark depredation encounters, and although it is primarily focused on depredation encounters from Florida, there are reports from throughout the USA and other countries. At the outset of this study, the group consisted of ∼5700 members and grew to over 6500 members during the study period (July 2020–June 2022).

For the content analysis, posts were reviewed weekly and only original posts (i.e. primary posts, excluding comments) that reported shark depredation events were assessed. For each post, the following information was recorded: name of the person who made the post (to help ensure duplicate posts were not recorded), date (assumed to be the date of the post unless otherwise noted), location (determined based on information provided in the post), depredated fish species (recorded to the lowest possible taxonomic level), depredator species (if seen; identified to lowest possible taxonomic group based on text and/or photographs/videos), fishing method (e.g. hook and line, spear). Depredated species that were identifiable from photos were further classified into one of eight "species group" categories based on state and/or federal species management groups (see Supplemental Material 1 for details): snapper-grouper, dolphin-wahoo-blackfin tuna, coastal migratory pelagics, highly migratory species (HMS; excluding sharks), deep-water snapper-grouper, inshore sportfish (e.g. bonefish, permit, redfish, seatrout, snook, and tarpon), sharks, and "other" (any species that did not fit in one of the previous categories). Once data from all the posts were collected, the data were subset to include only those posts originating from Florida and summarized to characterize general depredation trends. Note, all common names of fish species used throughout this study are based on those listed in FishBase (Froese and Pauly 2024).

Florida angler surveys

Survey design and sample pool

An online survey was designed using Qualtrics XM software and distributed to current Florida saltwater fishing license holders to characterize the current state of shark depredation in Florida's recreational fisheries. In order to capture any temporal trends in depredation, the survey was distributed quarterly via email for 1 year, with each round comprising a 3-month season: summer (July–September 2021), fall (October–December 2021), winter (January–March 2022), and spring (April–June 2022). Surveys were sent out at the beginning of each month immediately following each season. In each round, 4000 license holders were selected from the Florida Fish and Wildlife Conservation Commission's saltwater license holder database using random sampling with replacement, with an even distribution of anglers from the following seven regions (determined by their home county): Western Panhandle, Big Bend, Southwest, Florida Keys, Southeast, Northeast, and out of state. These regions (excluding "out of state") were based on FWC's six regional management districts with modifications (Supplemental Material 2), and were also used as answer choices to the question, "In which region of Florida did you do most of your saltwater fishing in the last three months?" Due to our interest in angler fishing/depredation experiences within the three months preceding the distribution date, surveys were only sent to participants who had a valid license during that time frame. License holders could receive the survey during multiple rounds as their fishing activities and depredation experiences may vary monthly.

The online survey (Supplemental Material 3, Table S3.1) was divided into two parts: a quantitative and qualitative survey, and the number of questions presented to each participant was dictated by their responses. This paper focuses on results from the quantitative portion of the survey, which had a maximum of 36 questions and was split into two subsections. The first section was designed to determine angler experience, fishing habits (e.g. fishing region, fishing frequency, fishing years, target species), and how frequently anglers experience depredation. The second section focused on anglers' most recent depredation experience and was designed to determine which species are primarily being depredated, the species responsible for depredations, and calculate depredation rates. The survey was approved by the Florida Atlantic University Social, Behavioral, and Educational Research Institutional Review Board (Protocol #17907–1).

Survey data quality control

Prior to analysis all surveys were reviewed and only surveys with a completed quantitative section were included for subsequent analysis. Where respondents provided free-form text answers, responses were reviewed and manually categorized for consistency. For example, when asked to provide a species name (e.g. "Which species of fish did you most often target in saltwater in the last three months?"), the answers were modified to ensure each species was referred to by a single common name. In addition, all responses to the question "Which species of fish did you most often target in saltwater in the past three months?" were also classified into a "primary target species complex" using the same eight categories from the content analysis. Two additional categories were also added for shellfish (e.g. lobster and scallops) and "any species" (i.e. no specific target species listed). In cases where respondents listed more than one answer (e.g. listed multiple target species or multiple depredating species), the first species listed in the response was assumed to be the primary species.

Data analysis

General characterization

Responses from the survey's quantitative section were summarized to provide a general characterization of shark depredation in Florida. This included: (1) the percentage of anglers that experienced depredation in the previous three months, (2) the primary target species among anglers that experienced depredation, (3) the proportion of anglers experiencing depredation while targeting species groups, (4) species responsible for depredations, and (5) average depredation rates.

Depredation modeling

Two types of analyses were used to examine the effects of survey season and fishing region on shark depredation. First, binary logistic regression was used to assess whether season or fishing region affected the probability of experiencing depredation (i.e. depredation frequency; defined as the percentage of respondents who experienced depredation). The probability of experiencing depredation was modeled using anglers' responses to the question, "Have you experienced depredation during your fishing trips in the past three months?" for all respondents that also answered the question, "In which region of Florida did you do most of your saltwater fishing in the last three months?" ($n = 1170$). Depredation occurrence (i.e. "yes" or "no") was set as the binary response variable, and season, fishing region, and their interaction were set as categorical predictor variables. Analysis was conducted using the Fit Binary Logistic Model function in Minitab® Statistical Software (v. 20).

Following binary logistic regression, depredation rates were calculated for all respondents who answered "yes" to having experienced depredation. Respondents who experienced depredation were asked to provide additional details about their most recent fishing trip where they experienced depredation, including total number of fish caught and total number of fish depredated, and depredation rates were calculated as the percentage of the total trip catch that was depredated. Because only respondents that experienced depredation were asked about their most recent trip where they experienced depredation, calculated rates were always greater than 0%. Depredation rates that exceeded 100% ($n = 55$) indicated incorrect numbers were entered in the survey and were removed prior to analysis. Once calculated, a generalized linear model (GLM) was used to assess whether season or fishing region influenced depredation rates. A GLM with a beta distribution was built using the "glmmTMB" package (Brooks et al. 2017) in R (version 4.3.2), with depredation rate set as the response variable and season, fishing region, and their interaction as predictor variables. Data exploration was conducted prior to model building to avoid common statistical problems (Zuur et al. 2010), including checks for outliers, interactions, and collinearity. Collinearity of covariates was investigated using generalized variance-inflation factor (GVIF) scores. Any covariate with a score greater than three was removed and the GVIFs were recalculated (Zuur et al. 2010). Significance was set at $P = 0.05$ for all analyses.

Cooperative fishery-dependent charters

Depredation swabs and genetic analysis

Sample collection

To improve the identification of shark species responsible for depredating target catch, we partnered with local fishing charters (Supplemental Material 3, Table S3.2) to obtain genetic samples from depredated fish carcasses. Swab sampling methodology was modified from Drymon et al. (2019) and Fotedar et al. (2019), and charter captains and crew were trained by project personnel on the proper sampling technique. Briefly, upon retrieval of a depredated fish, the carcass was carefully brought aboard and placed on a sanitized area of the vessel, and the bite wounds of the depredated fish were gently swabbed with a sterile swab to collect transfer DNA (up to two replicates per fish). The swab was then placed into a storage vial with 100% ethanol. Each charter was provided with a DNA swab sampling kit that contained sampling bags and a spray bottle with 10% bleach solution to sterilize the sampling area. Each sampling bag contained two sterile swabs, two 2 ml cryo-vials with 100% ethanol, and a data card for recording depredation metadata. Depredation metadata included date, time, location (coordinates and/or description), water depth, water temperature, fishing depth (i.e. surface, mid-water, or bottom), species caught, length of species caught (total length or fork length; estimated or measured), depredation outcome, depredating species (if seen), and a QR code to submit photos of the depredated fish. Depredation outcome was recorded as minimal damage (i.e. teeth marks on fish), partial damage (i.e. fish partly consumed), full damage (i.e. only head left), or bite-off (i.e. fish and gear lost).

Charter operators reported that many depredation events often resulted in "bite-offs" (i.e. the complete loss of the fish and gear), and thus no carcass was available to swab for DNA. To address this, monofilament samples were collected from the bite-offs to test the feasibility of using monofilament as an alternative method of obtaining DNA to identify the depredating species. To collect the monofilament samples, captains were provided with a pair of scissors and bleach wipes (to sterilize scissors before and after collection) and instructed to cut two ~2.5 cm sections of monofilament from the end of the bite-off and store the monofilament in the sample vials as they would do for a swab. Negative field controls (i.e. swabs from non-depredated catch) were haphazardly collected by project personnel during ride-along charters. In addition, the ethanol supply used to fill the sample storage vials was tested as another negative control.

Genetic analysis

Genetic identification of depredating shark species was conducted by direct comparison of DNA sequences identified from swab or monofilament samples with DNA sequences obtained from local shark species and was based on genetic techniques previously described by Drymon et al. (2019), Fotedar et al. (2019), Vardon et al. (2021), and Webb et al. (2022). All genetic analyses were performed by Genidaqs (Cramer Fish Sciences, West Sacramento, CA). Full laboratory methods are available in Supplemental Material 4.

Cooperative charter surveys

Periodic cooperative surveys (i.e. ride-alongs) were conducted aboard our local, homeport charter fishing partner (Shockleader Charters) between June 2022 and August 2023 to collect data on depredation rates and potential drivers of depredation, including environmental conditions and various fishing variables (i.e. fishing effort, fishing style, bait type). For each ride-along, fishing effort and environmental data were collected at each fishing location. Fishing effort data included: time spent fishing, number of rods being fished, species caught and the outcome (i.e. whether the fish was kept or released), and the number of depredations (including bite-offs). Environmental data included location, water depth, time of day, and a vertical profile of conductivity and water temperature using a CastAway CTD (SonTek/Xylem Inc.). Ride-alongs also served as quality control checkpoints for the genetic sampling.

Results

Social media analysis

Content analysis of the Facebook group SFMB was conducted from July 2020–June 2022 and identified 616 primary posts that reported an incidence of shark depredation. Overall, 502 posts (81.5%) were from the USA, of which 442 (71.8%) were from Florida. The remainder of the posts were from The Bahamas ($n = 14$), Australia ($n = 5$), the Caribbean ($n = 5$), Mexico ($n = 1$), Thailand ($n = 1$), or did not report a location ($n = 88$). All subsequent results are based on posts from Florida.

In 364 (82.4%) of the posts, the depredator was not seen. In posts where the depredator was seen ($n = 78$; 17.6%), 12 species were positively identified, and sharks (10 species) were the most frequently reported depredator (96.2% of posts; Table 1). Non-shark depredators were only reported in three of the posts (barracuda, $n = 2$; goliath grouper, $n = 1$). Bull sharks (*Carcharhinus leucas*) were the most frequently reported depredating shark species (38.5%, $n = 30$) and depredated 17 species of fish. Forty-eight fish species were reported as being depredated (Table 1), with greater amberjack (*Seriola dumerili*, 10.4%), mutton snapper (*Lutjanus analis*, 10.2%), king mackerel (*Scomberomorus cavalla*, 9.5%), gag grouper (*Mycteroperca microlepis*, 7.9%), and Atlantic sailfish (*Istiophorus albicans*, 7.9%) comprising the five most frequently reported depredated species. No single species comprised greater than 10.5% of the reports. Overall, 74.5% of the depredations occurred on species in the snapper-grouper (48.9%), HMS (12.8%), and coastal migratory pelagics (12.8%) species management complexes. The remainder of depredations occurred on inshore sportfish (10.8%), dolphin-wahoo-blackfin tuna (8.9%), other species (3.2%), deepwater snapper-grouper species (1.6%), and sharks (0.9%). Depredation reports throughout the year were multimodal, with the highest peak in reports observed in July ($n = 19$, 24.4%), after which reports decreased through the fall and winter months. A second, albeit lower, peak in reports was observed in April ($n = 7$, 9.0%) followed by the lowest number of reports in June ($n = 1$, 1.3%) (Fig. 1a).

Florida angler surveys

From October 2021–July 2022, a total of 2259 Florida recreational saltwater fishing license holders responded to the online survey for an overall response rate of 14.1%, of which 2213 (98%) agreed to participate. Of those anglers who agreed to participate, 1688 (76.3%) completed the quantitative section. Overall, responses were distributed relatively evenly across the study regions within each round, except for the Florida Keys region, which saw consistently higher response rates across all rounds compared to the remaining regions (Supplemental Material 3; Table S3.3, Fig. S3.1).

Table 1. Species interaction list for content analysis.

	Depredator															
	Shark											Fish				
Depredated species	Cleu	Shrk	Cplu	Smok	Cobs	Gcuv	Ioxy	Nbre	Gcir	Cfal	Clim	Sbar	Eita	UNK	TOT	% DEP
Greater amberjack	2	3	2	1						1				37	46	10.4
Mutton snapper			1											44	45	10.2
King mackerel	2		1											39	42	9.5
Gag					1									34	35	7.9
Atlantic sailfish	8	4			1									22	35	7.9
Red snapper		1	1	1								1		30	34	7.7
Common snook	3													17	20	4.5
Black grouper						1		1						15	17	3.8
Blackfin tuna	1		1											15	17	3.8
Wahoo	1	3	1	1								1		8	15	3.4
Yellowfin tuna					1									13	14	3.2
Cobia	1												1	10	12	2.7
Tarpon	1	1		2										6	10	2.3
Dolphin	1													6	7	1.6
Gray snapper									1					6	7	1.6
Unidentified fish		4	1											1	6	1.4
Permit	1							1						4	6	1.4
Red grouper														6	6	1.4
Little tunny														5	5	1.1
Spotted seatrout	2										1			2	5	1.1
Golden tilefish														4	4	0.9
Crevalle jack	2													2	4	0.9
Red drum	1													3	4	0.9
Swordfish							2							2	4	0.9
Great barracuda	1													2	3	0.7
Cubera snapper														3	3	0.7
Goliath grouper	1					1								1	3	0.7
Gray triggerfish														3	3	0.7
Porgy sp.														3	3	0.7
Yellowtail snapper									1					2	3	0.7
Almaco jack														2	2	0.5
Bonefish														2	2	0.5
Grouper sp.														2	2	0.5
Mackerel sp.														2	2	0.5
Scalloped hammerhead							1							1	2	0.5
Tuna sp.	1													1	2	0.5
Blacktip shark		1													1	0.2
Bonnethead	1														1	0.2
Jack sp.						1									1	0.2
Nassau grouper														1	1	0.2

Table 1. Continued

Depredated species	Depredator															
	Shark											Fish				
	Cleu	Shrk	Cplu	Smok	Cobs	Gcuv	Ioxy	Nbre	Gcir	Cfal	Clim	Sbar	Eita	UNK	TOT	% DEP
Queen snapper														1	1	0.2
Red porgy														1	1	0.2
Skipjack tuna														1	1	0.2
Snowy grouper														1	1	0.2
Vermilion snapper														1	1	0.2
White margate														1	1	0.2
Yellowjack														1	1	0.2
Yellowmouth grouper														1	1	0.2
TOT	30	17	8	5	3	3	3	2	2	1	1	2	1	364	442	100.0
# SD	17	7	7	4	3	3	2	2	2	1	1	2	1	45		
% DEP	38.5	4.1	1.0	0.6	0.4	0.4	0.4	0.2	0.2	0.1	0.1	0.2	0.1	82.4		

Depredators are listed by four-letter species codes comprised of the first letter of genus name and the first three letters of species name: Clue = *Carcharhinus leucas*, Shrk = unidentified shark, Cplu = C. *plumbeus*, Smok = *Sphyrna mokarran*, Cobs = *C. obscurus*, Gcuv = *Galeocerdo cuvier*, Ioxy = *Isurus oxyrinchus*, Nbre = *Negaprion brevirostris*, Gcir = *Ginglymostoma cirratum*, Cfal = *C. falciformis*, Clim = C. *limbatus*, Eita = *Epinephelus itajara*, Sbar = *Sphyraena barracuda*, UNK = unknown depredator. TOT = total. % DEP = percentage of total depredations. SD = species.

General characterization

Across all completed surveys, 42.8% of respondents (n = 1179) experienced depredation while saltwater fishing during the previous three months. A total of 344 respondents said they saw the depredator during their most recent depredation experience. Of those respondents, 88.4% (n = 304) answered "Yes" when asked if they could reliably identify the depredating species, with a total of 20 species identified as depredators (Table 2). Sharks (16 species; 86.6%) were the most frequently identified depredator, with bull sharks (33.8%) the most commonly identified shark species followed by unidentified sharks (21.3%), lemon sharks (*Negaprion brevirostris*; 7.2%), and sandbar sharks (6.2%); all other identified shark depredators each accounted for <5% of the total. Only 13.4% (n = 41) of respondents who identified the depredator during their most recent depredation experience reported a non-shark species as the depredator, including dolphin (6.6%), barracuda (5.3%), goliath grouper (1.3%), and American alligator (0.3%). Overall, given the large percentage of respondents that identified sharks as the depredator in their last depredation experience, depredation trends in subsequent analyses were associated with anglers' experiences with shark depredation.

Among those anglers that experienced depredation and listed a primary target species (n = 503), snapper-grouper were the most frequently targeted species group (54.5%), followed by inshore sportfish (18.3%) and dolphin-wahoo-blackfin tuna (16.1%); all other target species groups each comprised less than 5% (Fig. 2a). Regional differences were observed in the three most frequently reported primary target species among anglers that experienced depredation (Fig. 2b). While snapper-grouper were the most frequently targeted species complex in all regions except the Northeast, there were differences in the second most frequently targeted species group. Dolphin-wahoo-blackfin tuna was the second most frequently targeted group when experiencing depredation in the Southeast (29.7%) and Florida Keys (26.8%) regions, whereas inshore sportfish were the second most targeted species group in the Western Panhandle (13.3%), Big Bend (38%), and Southwest (31.1%) regions. In the Northeast, inshore sportfish (38.5%) were the most frequently targeted species group when experiencing depredation and snapper-grouper (28.2%) were the second most frequently targeted group.

Although snapper-grouper, dolphin-wahoo-blackfin tuna, and inshore sportfish were the most frequently targeted species among anglers that experienced depredation, the proportion of respondents targeting those species groups that reported experiencing depredation was 59.1%, 57%, and 23.6%, respectively. In contrast, 100% of respondents who targeted deepwater snapper-grouper species (n = 2) and 82.1% of respondents who targeted highly migratory pelagic species (i.e. tunas, billfish; n = 23) reported experiencing depredation while targeting those species (Fig. 3).

Depredation modeling

Regional and seasonal variation was observed in the percentage of respondents experiencing depredation (Fig. 4). Results from the binary logistic regression (χ^2 = 93.62, df = 23, P < 0.0001, adj. R^2 = 0.0533; Table 3) indicated that both season (χ^2 = 17.76, df = 3, P = 0.000) and fishing region (χ^2 = 31.97, df = 5, P < 0.0001) were significant factors,

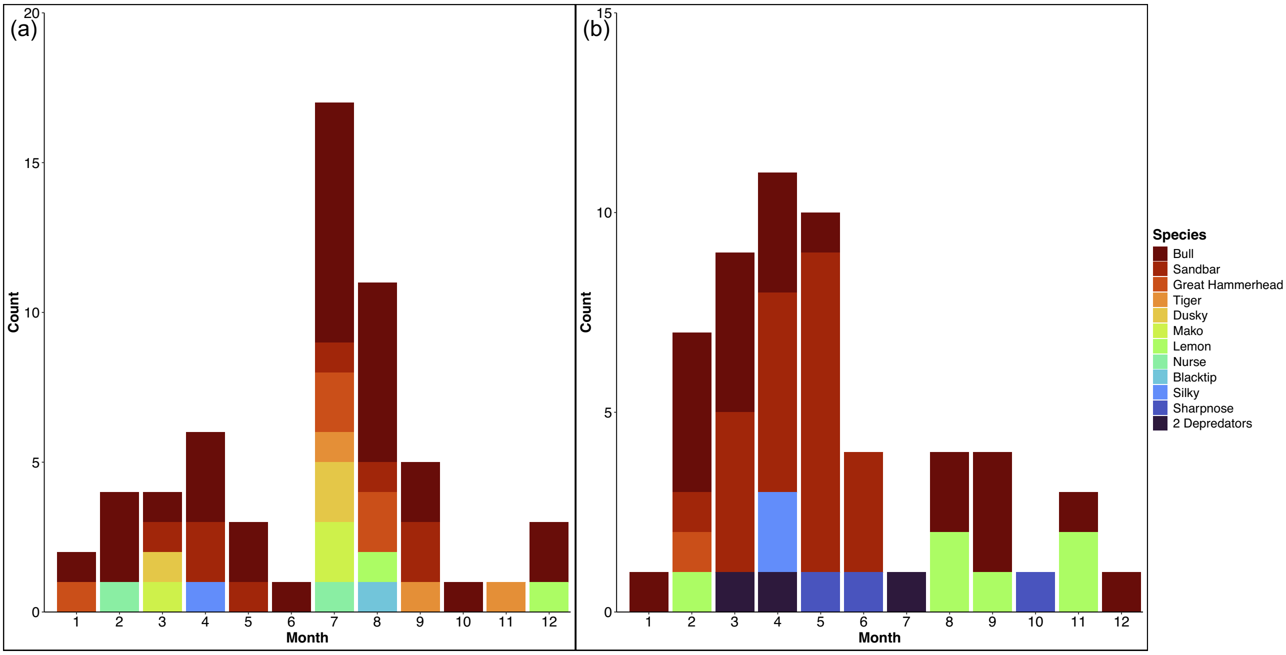

Figure 1. Number of depredations per month by depredating species (a) reported in posts from the SFMB Facebook page (not shown: unidentified sharks ($n = 17$), barracuda ($n = 1$), and goliath grouper ($n = 1$); excludes depredations where the depredator was not seen) and (b) identified from genetic analysis of swab and monofilament samples (2 depredators include bull and finetooth ($n = 1$), bull and sharpnose ($n = 1$), and lemon and sharpnose ($n = 1$).

Table 2. List of suspected depredator species as identified by respondents that answered "Yes" to the question "Could you reliably identify the depredator?" when answering questions related to their most recent depredation experience.

Depredator species	*n*	%
Bull shark	103	33.8%
Unidentified shark	65	21.4%
Lemon shark	22	7.2%
Dolphin	20	6.6%
Sandbar shark	19	6.2%
Barracuda	16	5.2%
Blacktip shark	15	4.9%
Reef shark	9	3.0%
Tiger shark	7	2.3%
Dusky shark	5	1.6%
Hammerhead shark (unidentified)	5	1.6%
Goliath grouper	4	1.4%
Nurse shark	4	1.4%
Spinner shark	4	1.4%
American alligator	1	0.3%
Bonnethead shark	1	0.3%
Great hammerhead shark	1	0.3%
Mako shark	1	0.3%
Smalltooth sawfish	1	0.3%
Silky shark	1	0.3%
White shark	1	0.3%
Total	305	100%

but not their interaction ($\chi^2 = 22.94$, df = 15, $P = 0.085$). The probability of experiencing depredation was highest in spring (48.7%; Fig. 5a) and the odds of experiencing depredation were between 1.3 and 1.5 times greater than all other seasons (Table 4). The Florida Keys (57.4%), Western Panhandle (48.5%), and Southeast (47.1%) regions had the highest probabilities of experiencing depredation, compared to the Northeast (32.5%), Big Bend (31.3%), and Southwest (24.2%) regions, which had the lowest probabilities of experiencing depredation (Fig. 5b, Table 4). Although the interaction effect was not significant, there did appear to be some seasonal variation in depredation probability among the fishing regions (Fig. 5c). Notably, the probability of depredation was consistently high across all seasons in the Florida Keys, whereas in the Southeast it was higher during summer and winter, and lower during fall and spring. In the Big Bend region, depredation probability decreased steadily from summer to winter, but then showed a substantial increase during spring to a probability similar to that for the Florida Keys and Western Panhandle.

A total of 493 respondents provided answers to questions relating to their most recent depredation experience, allowing for the calculation of trip-specific depredation rates. These rates represent the percentage of catch that was lost on reported trips that experienced depredation and are not adjusted to account for trips that did not involve depredation. The percentage of the total depredated catch reported by anglers ranged from 1% to 100% (based on answers only from respondents who experienced depredation), with an overall average depredation rate of 41.3% ± 0.01% (mean ± SE; Fig. 6a). Average seasonal depredation rates ranged from 37.3% ± 0.04% (fall) to 47.1% ± 0.03% (winter); spring and summer both had average depredation rates of 40.0% ± 0.02% (Fig. 6b). Average regional depredation rates ranged from 31% ± 0.04% (Southwest region) to 45.8% ± 0.04% (Southeast region; Fig. 6c). However, results from the GLM ($\chi^2 = 1.39$, df = 1, $P = 0.24$) showed no significant effect of season ($\chi^2 = 2.25$, df = 3, $P = 0.52$), fishing region ($\chi^2 = 7.95$, df = 5, $P = 0.16$), or their interaction ($\chi^2 = 18.83$, df = 15, $P = 0.22$) on depredation rates.

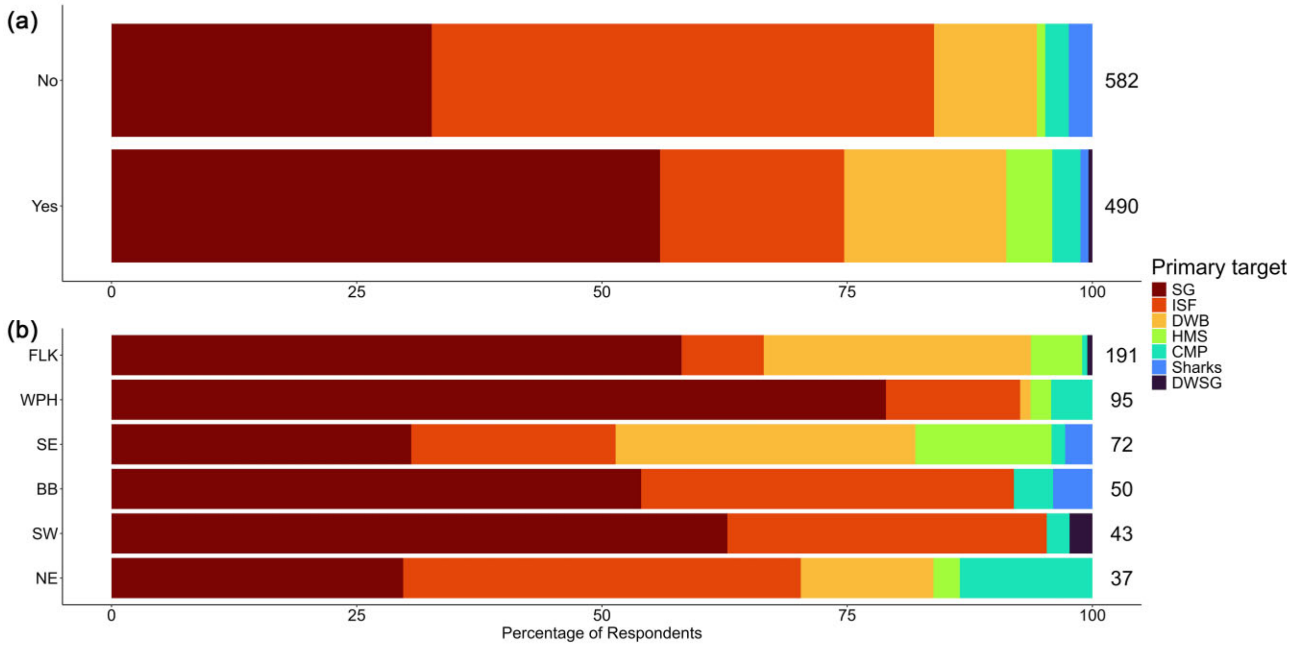

Figure 2. Primary target species complex (a) for anglers that had been saltwater fishing in the past 3 months ($n = 1130$) based on depredation experience, and (b) by region among respondents that experienced depredation ($n = 500$). Note: the generic groups—any species (yes, $n = 7$; no, $n = 24$) and other (yes, $n = 6$; no, $n = 21$)—are not shown in the figure. Region abbreviations are FLK = Florida Keys, WPH = Western Panhandle, SE = Southeast, BB = Big Bend, SW = Southwest, and NE = Northeast. Primary target abbreviations are: SG = Snapper-Grouper, ISF = Inshore Sportfish, DWB = Dolphin-Wahoo-Blackfin tuna, HMS = HMS-Pelagics, CMP = Coastal Migratory Pelagics, DWSG = DeepWater Snapper-Grouper.

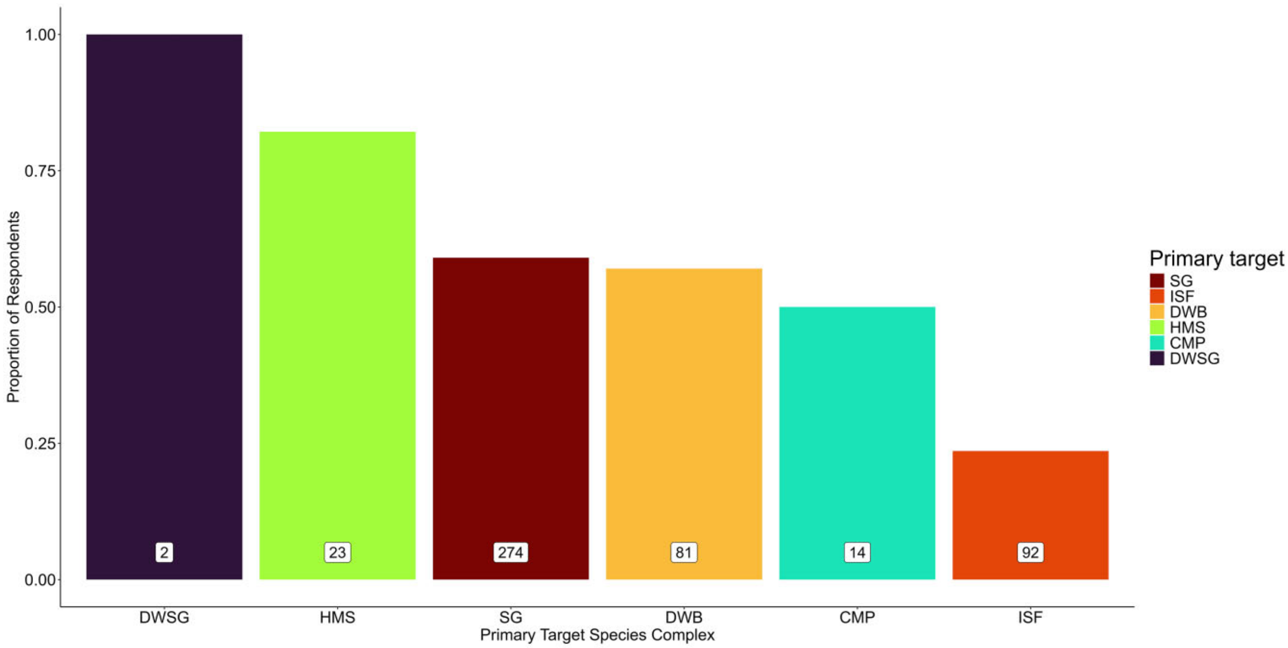

Figure 3. Proportion of respondents experiencing depredation based on the primary target species complex. Numbers at the bottom of the bars indicate the number of respondents targeting a given species complex that experienced depredation. Proportions are based on the total number of respondents targeting a given species complex: DWSG = DeepWater Snapper-Grouper ($n = 2$), HMS = HMS-pelagics ($n = 28$), SG = snapper-grouper ($n = 464$), DWB = dolphin-wahoo-blackfin tuna ($n = 142$), CMP = coastal migratory pelagics ($n = 28$), and ISF = inshore sportfish ($n = 390$). Note: this excludes the generic groups: other, any species, shellfish, and sharks.

Cooperative fishery-dependent charters

Depredation swabs and genetic analysis

Genetic samples were collected from 18 species of fish across 85 depredation events between October 2021–September 2023 and included samples from both depredated fish carcasses ($n = 57$) and monofilament bite-offs ($n = 28$; Supplemental Material 3, Table S3.4). Samples were collected during every month of the study period and in depths ranging

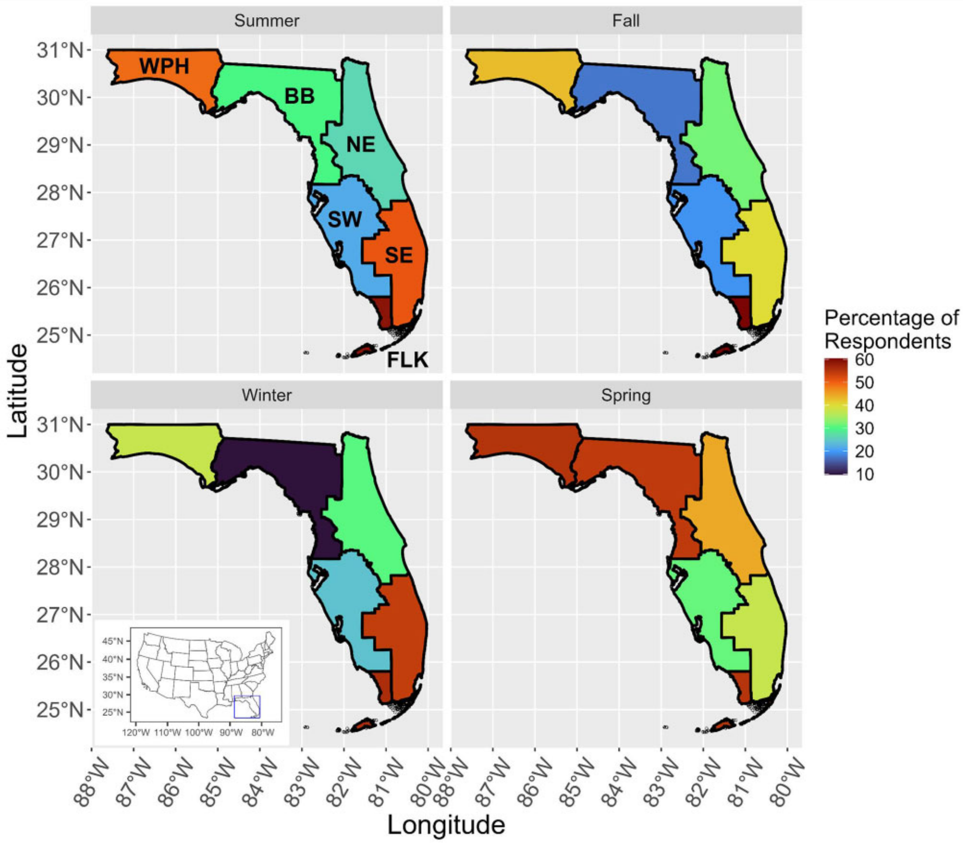

Figure 4. Seasonal and regional variation in the percentage of respondents that experienced depredation while saltwater fishing in the past three months. Region labels are shown in the upper left panel for Summer and are consistent across all seasons: WPH = Western Panhandle, BB = Big Bend, NE = Northeast, SW = Southwest, SE = Southeast, and FLK = Florida Keys. Individual samples sizes per region/season can be found in Supplemental Material 3, Table S3.3.

Table 3. Results of the binary logistic regression ($\chi^2 = 93.62$, df = 23, $P = 0.000$, adj. $R^2 = 0.0533$) assessing the effect of season (survey round), fishing region, and their interaction on the probability of experiencing depredation.

Term	Coefficient	Coefficient SE	z-value	*P*-value
Constant	−0.847	0.282	−3.01	0.003
Season: $\chi^2 = 17.76$, df = 3, P = 0.000				
Fall	−0.711	0.618	−1.15	0.250
Winter	**−1.386**	**0.670**	**−2.07**	**0.038**
Spring	**1.022**	**0.409**	**2.50**	**0.012**
Region: $\chi^2 = 31.97$, df = 5, P = 0.000				
Florida keys	**1.208**	**0.341**	**3.54**	**<0.0001**
Northeast	−0.182	0.464	−0.39	0.694
Southeast	**0.880**	**0.381**	**2.31**	**0.021**
Southwest	−0.438	0.421	−1.04	0.299
Western panhandle	**0.816**	**0.378**	**2.16**	**0.031**
Round ∗ Region: $\chi^2 = 22.94$, df = 15, P = 0.085				

Levels for significant factors are shown, with significant levels within each factor shown in bold.

from 9.8 to 121.9 m (Supplemental Material 3, Table S3.5). Most samples (41.2%) were collected in April ($n = 18$) and May ($n = 17$) and from depths between 20 and 30 m ($n = 54$, 63.5%). Seventy-one samples (83.5%) were collected while bottom fishing and 14 samples (16.5%) were collected while pelagic fishing/trolling.

The depredating species was successfully identified in 65.9% of the samples, with successful DNA amplification and depredator identification from both swabbed carcasses (75.4%) and monofilament samples (46.4%). Seven shark species were positively identified as depredators and depredated 13 species of fish (Table 5). The percentage of depredation events with a confirmed depredator for each fishing charter ranged between 35.7% and 85.7%, and the number of depredating species encountered by the charters ranged from one to five. Sandbar sharks (*Carcharhinus plumbeus*, 37.5%) and bull sharks (35.7%) were the most frequently identified depredating species, and snappers were the most frequently depredated species group (43.5%) with a positively identified depredator. Depredations by sandbar sharks were highest in May, whereas depredations by bull sharks were highest in February and March (Fig. 1b). Three samples identified sharpnose sharks (genus *Rhizoprionodon*) as the depredator; however, it was not possible to distinguish between Atlantic sharpnose (*R. terraenovae*) and Caribbean sharpnose (*R. porosus*), even with voucher specimens from both species. In addition, there were also three instances where two depredators were positively identified from the same depredation event (Supplemental Material 3, Table S3.4): (1) bull and finetooth sharks were identified from a single swab from a depredated mutton snapper (sample 13); (2) bull and sharpnose sharks were identified on separate swabs from a gray triggerfish carcass (sample 19); (3) and lemon and sharpnose sharks were identified on separate swabs taken from a mutton snapper carcass (sample 34).

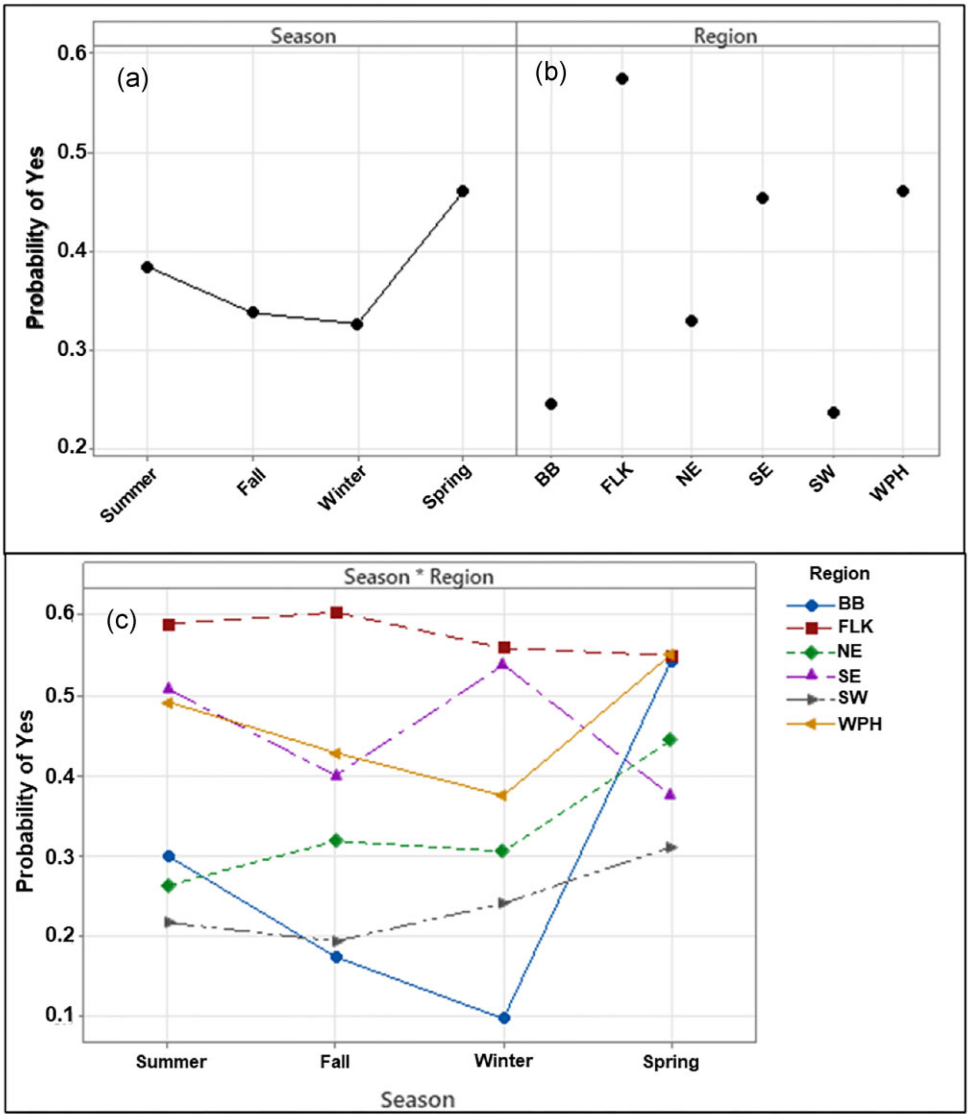

Figure 5. Main effects plots showing the probability of experiencing depredation ("yes" response) (a) per season, (b) by fishing region, and (c) per season in each fishing region.

Cooperative charter surveys

A total of 12 ride-alongs were conducted with our industry fishing partner Shock Leader Charters, LLC between June 2022 and August 2023 (Table 6). The number of sites fished per trip ranged from 3 to 6 (mode = 5), with an average fishing time per site of 0.67 ± 0.05 hours. A total of 597 fish were hooked during these trips, of which 562 fish (45 species; Supplemental Material 3, Table S3.6) were landed and 40 were depredated (6.7%; includes 35 bite-offs). Most of the catch was comprised of snapper-grouper species (77.6%), with mutton snapper (15.5%), gray snapper (*Lutjanus griseus*, 13.7%), tomtates (*Heamulon aurolineatum*, 12.8%), and lane snapper (*Lutjanus synagris*, 11.2%) accounting for 53.2% of the total catch. Depredations occurred on 83.3% of the trips ($n = 10$) and the average per trip depredation rate was 9.4% ± 3.4% (mean ± SE, range = 0–41.7%). Across all trips, the average depredation rate per fishing location was 8.9% ± 2.7% (mean ± SE, range 0%–100%). The five depredations that were not bite-offs included two mutton snapper, one red snapper (*Lutjanus campechanus*), one cobia (*Rachycentron canadum*), and one tomtate.

Discussion

Shark depredation in Florida's recreational fisheries continues to be a substantial concern. Utilizing a multifaceted citizen science approach, this study provides an in-depth characterization of shark depredation in Florida's recreational fisheries. Collectively, this approach identified depredating species, depredation frequencies, and rates across all components of the study and highlights the benefits of incorporating citizen science when addressing this important fisheries issue.

Identifying species responsible for depredations

Identification of the depredating shark species remains a major gap in shark depredation research (Mitchell et al. 2018a, Mitchell et al. 2023). This is largely because most depredation events occur at depth and are rarely observed, making it difficult to accurately identify the species involved, and even when the depredator is seen, it can be difficult to distinguish between similar species (Fotedar et al. 2019). This is

Table 4. Pairwise odds ratios for categorical predictors and 95% confidence intervals (CI).

Level A	Level B	Odds ratio	95% CI
Season			
Fall	Summer	0.8531	0.5855–1.2429
Winter	**Summer**	**0.8512**	**0.6186–1.1713**
Spring	**Summer**	**1.2801**	**0.9378–1.7474**
Winter	**Fall**	**0.9979**	**0.6708–1.4844**
Spring	**Fall**	**1.5006**	**1.0132–2.2225**
Spring	**Winter**	**1.5038**	**1.0727–2.1083**
Region			
Florida keys	**Big bend**	**3.0682**	**2.0559–4.5789**
Northeast	Big bend	1.1023	0.6641–1.8294
Southeast	**Big bend**	**2.0339**	**1.2833–3.2235**
Southwest	Big Bend	0.723	0.4505–1.1603
Western panhandle	**Big bend**	**2.0206**	**1.3072–3.1234**
Northeast	**Florida keys**	**0.3593**	**0.2323–0.5555**
Southeast	**Florida keys**	**0.6629**	**0.4525–0.9711**
Southwest	**Florida keys**	**0.2356**	**0.1584–0.3505**
Western panhandle	**Florida keys**	**0.6586**	**0.4620–0.9388**
Southeast	**Northeast**	**1.8452**	**1.1279–3.0186**
Southwest	Northeast	0.6559	0.3963–1.0857
Western panhandle	**Northeast**	**1.8332**	**1.1445–2.9362**
Southwest	**Southeast**	**0.3555**	**0.2248–0.5621**
Western panhandle	**Southeast**	**0.9935**	**0.6516–1.5149**
Western panhandle	**Southwest**	**2.7948**	**1.8101–4.3153**

Pairwise odds ratios with significant predictors identified in the binary logistic regression are highlighted in bold. Odds ratios are for level A relative to level B.

particularly true for untrained anglers and could partly explain why previous studies by Casselberry et al. (2022) and Klizentyte et al. (2023) did not ask anglers to identify the shark species involved in the depredation. In an effort to address this knowledge gap, we used established genetic techniques (Drymon et al. 2019, Fotedar et al. 2019, Vardon et al. 2021, Webb et al. 2022) to facilitate identification of the depredating shark species in 66% of the depredation events sampled by charter fishing partners. While previous studies have either had high success rates (>60%) and small sample sizes (n < 30; Drymon et al. 2019, Fotedar et al. 2019, and Webb et al. 2022) or a large sample size (n = 52) and low success rate (<20%; Vardon et al. 2021), this study had both a large sample size and high success rate (n = 89, 66%), particularly for samples obtained from swabbed carcasses (n = 57, 75%). In addition, we were also able to validate the use of monofilament samples to identify the depredating species from depredations that resulted in a bite-off (i.e. no fish carcass retrieved), though it should be noted that these bite-offs could have also been the result of the shark taking the bait directly (i.e. not a depredation event). Still, this is the first time that this technique has been attempted, and its moderate success (∼46%) shows promise for improving our ability to accurately identify shark species responsible for depredations in both recreational and commercial fisheries.

Results from the depredation swab and monofilament analysis identified bull sharks and sandbar sharks as common depredator species in Florida. Although these results are from a limited geographic region (i.e. east-central Florida), they support the findings from both the content analysis and online survey (which encompassed the entire state of Florida) that also identified bull sharks and sandbar sharks as the two species most frequently reported as responsible for depredation. These results are also consistent with other studies from the Gulf of Mexico (Drymon et al. 2019) and Australia (Fotedar et al. 2019, Vardon et al. 2021) that also identified bull sharks and sandbar sharks as common depredating species, as well as other carcharhinid sharks. Identifying these two species as the most common depredators should aid fishery managers as they develop ways to address shark depredation and could have significant implications for managing both species. For instance, sandbar sharks have been historically overfished but have been protected from overfishing since the mid-1990s when their retention became prohibited outside of the shark research fishery (SEDAR 2017c). Since then, there has been evidence that the population has begun to recover (Peterson et al. 2017, SEDAR 2017c), although the stock remains overfished. Conversely, bull sharks have not had a species-specific stock assessment, and their population status is unknown. Given the differences and uncertainty among the stock statuses for these two species, it is likely that different management approaches may be needed to address depredation by each species.

Although this study focused on shark depredation in recreational fisheries, it should be noted that other species of marine predators (i.e. dolphins, large teleosts, seabirds) can also be responsible for depredations. For instance, Mitchell et al. (2019) observed multiple attempts by large teleosts to depredate hooked fish while studying shark depredation in a Western Australia recreational fishery. In the USA, Casselberry et al. (2022) found that 68.5% of North American saltwater anglers had experienced depredation by species other than sharks. Similarly, 85% of Florida anglers reported depredations by more than one predator species (Klizentyte et al. 2023). Indeed, sharks were the most frequently identified depredator in the current study; however, non-shark species, including dolphins, barracuda, and goliath grouper were also identified as depredators, which is consistent with findings by Klizentyte et al. (2023). While it is important to acknowledge non-shark species as potential depredators, given the relatively low number of reports from this study, we are confident that the depredation trends observed throughout this study accurately reflect shark depredation trends in Florida's recreational fisheries.

Identifying frequently depredated species

Snapper-grouper species were the most frequently depredated target species group reported across all study methodologies. Mutton snapper, red snapper, and greater amberjack were three of the five most frequently depredated species in both the content analysis and depredation swab sampling and are all part of the snapper-grouper species complex, which was the most reported target species group from online survey respondents that had experienced depredation. This is consistent with recent findings by Klizentyte et al. (2023), who also found that most Florida anglers experienced depredation while targeting reef fish, as many of the species in the snapper-grouper complex are demersal/semi-demersal and typically associated with both natural and artificial reef habitats. Similar trends have also been reported in Western Australia, where depredation was generally higher for demersal species than for pelagic species (Mitchell et al. 2018b, Coulson et al. 2022). Considering recent stock assessments have shown that some reef fish species are overfished and/or experiencing overfishing in the South Atlantic (e.g. red snapper, SEDAR 2017a; red grouper, SEDAR 2017b) and Gulf of Mexico (e.g. greater

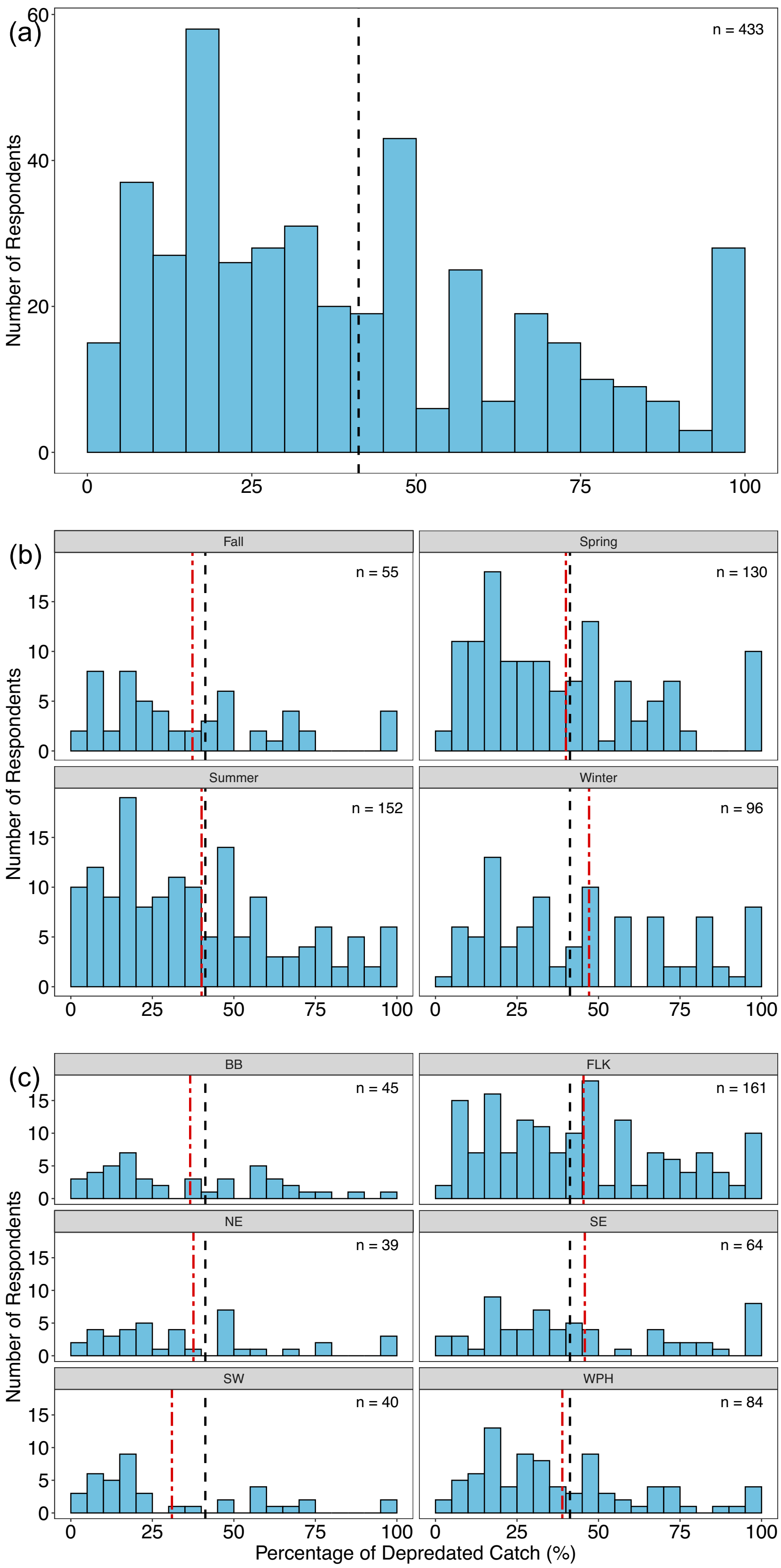

Figure 6. Percentage of depredated catch reported by respondents who provided details about their most recent trip where they had experienced depredation ($n = 493$): (a) overall, (b) per season, and (c) per fishing region. Dashed lines (black) represents the overall mean proportion of depredated catch across all fishing types (41.3%). Dot-dashed lines (red) represent the mean proportion of depredated catch in each fishing region. Fishing region abbreviations: BB = Big Bend, FLK = Florida Keys, NE = Northeast, SW = Southwest, WPH = Western Panhandle, and SE = Southeast.

Table 5. Species interaction list for swab/mono samples with a positively identified depredator.

	Depredator species											
Depredated species	Cplu	Cleu	Nbre	Rhsp[a]	Cfal	Smok	Cleu and Ciso	Cleu and Rhsp	Nbre and Rhsp	Total	# DS	% DEP
Mutton snapper	1	6	4				1		1	13	6	23.2
Unknown	3	5		1		1				10	5	17.9
Red snapper	7		1		1					9	4	16.1
Gray snapper	4	2	1							7	4	12.5
Greater amberjack	2	1								3	3	5.4
Vermillion snapper		2		1						3	3	5.4
Cobia		2								2	2	3.6
Gag	1				1					2	3	3.6
Gray triggerfish	1							1		2	3	3.6
Great barracuda	1									1	2	1.8
Blackfin tuna		1								1	2	1.8
King mackerel	1									1	2	1.8
Mackerel (unidentified)		1								1	2	1.8
Red grouper				1						1	2	1.8
TOT	21	20	6	3	2	1	1	1	1	56	7	100.0
# SD	9	8	3	3	2	1	1	1	1	13[b]		
% DEP	37.5	35.7	10.7	5.4	3.6	1.8	1.8	1.8	1.8	100.0		

[a]Unable to distinguish between *Rhizoprionodon terraenovae* and *R. porosus*.
[b]Excludes unknown depredated species.
DS = depredator species, SD = species depredated. % DEP = percentage of total depredations. Depredators are listed by four-letter species codes comprised of the first letter of genus name and first three letters of species name: Clue = *Carcharhinus leucas*, Cplu = C. plumbeus, Nbre = *Negaprion brevirostris*, Rhsp = *Rhizoprionodon* sp., Cfal = *C. falciformis*, Smok = *Sphyrna mokarran*, Ciso = *C. isodon*.

amberjack, SEDAR 2020; gag grouper, SEDAR 2021), high levels of mortality from shark depredation could have significant implications for the recovery and management of these species.

In addition to identifying the most frequently depredated species/target species groups, results from the online survey revealed an interesting trend related to the proportion of anglers that target certain species groups and experience depredation. Specifically, 100% of anglers targeting deepwater snapper-grouper (DWSG) and 82% of anglers targeting highly migratory pelagics (HMS) reported experiencing depredation, which is markedly higher than the nearly 24% of anglers that experience depredation when targeting inshore sportfish and the roughly 50% of anglers that experience depredation while targeting snapper-grouper, dolphin-wahoo-blackfin tuna, or coastal migratory pelagics. Overall, this suggests that there may be an association between the time spent retrieving a fish and the likelihood of experiencing depredation, as both DWSG and HMS typically have longer fight times due to the depths at which they are caught and/or their large size and extended fight times when hooked compared to other the other target species groups. This trend is consistent with recent findings by Casselberry et al. (2024), which show that longer fight times lead to decreased survival of Atlantic tarpon due to depredation by Great Hammerhead sharks (*S. mokarran*). Although the sample sizes for both DWSG and HMS were low ($n = 2$ and $n = 23$, respectively), this trend suggests that encouraging anglers to employ fishing techniques that can reduce fight times could help to minimize their chances of experiencing depredation.

Depredation frequency

Results from the Florida angler survey and data from the cooperative charter surveys indicated a high frequency of shark depredation. In the Florida angler survey, ~43% of respondents reported experiencing depredation while fishing in the past three months, while depredation was observed on ~82% of cooperative charter survey trips. These frequencies are consistent with depredation frequencies reported in other studies. For instance, the 43% of surveyed anglers experiencing depredation in the previous 3 months in the Florida angler survey is within the range of the 38%–56% of surveyed anglers in Western Australia that reported experiencing depredation at least once in the last year (Mitchell et al. 2018b, Ryan et al. 2019, Coulson et al. 2022). Conversely, the 83% frequency of shark depredation on ride-along charters is consistent with the 60%–90% of anglers that reported experiencing depredation in the US (Casselberry et al. 2022), Florida (Drymon and Scyphers 2017, Klitzentyte et al. 2023), and Gulf of Mexico (Prasky et al. 2023). Overall, our results provide further evidence of the persistence and prevalence of shark depredation in recreational fisheries, but that certain user groups are being disproportionately affected.

Depredation frequency also showed seasonal and regional variability, with the highest depredation frequencies occurring during the spring, and in the Florida Keys, southeast, and southwest regions. Although this study was the first to examine seasonal variations in depredation frequency in the USA, the regional trends in this study are generally consistent with results from Klizentyte et al. (2023), who also highlighted these same regions of the state. One possible explanation for these trends is that this variation corresponds with seasonal and regional variability in angler fishing behavior. For instance, sea state in Florida is generally more favorable for fishing offshore during the summer, providing more opportunities for anglers to get on the water. In addition, the South Atlantic recreational grouper season opens in May, and the Gulf of Mexico and South Atlantic recreational red snapper seasons typically open in July, which previous studies have shown results in a marked increase in fishing pressure (Powers and Anson 2016, Sauls et al. 2017). This could explain the higher

Table 6. Summary of cooperative charter surveys conducted with Shock Leader, LLC, a fishing charter based out of Fort Pierce, FL, USA.

Charter date	Hours fished	# of fish		# of depredations	# of bite-offs	Depredation rate (%)	
		Hooked	Landed			Per site	Per trip
6/9/2022							5.6
Site 1	1.43	38	36	3	2	7.9	
Site 2	1.45	26	25	1	1	3.8	
Site 3	0.62	8	8	0	0	0.0	
6/28/2022							15.2
Site 1	1.02	16	10	6	6	37.5	
Site 2	0.57	11	10	1	1	9.1	
Site 3	1.00	19	19	0	0	0.0	
7/25/2022							18.9
Site 1	0.42	7	7	0	0	0.0	
Site 2	1.33	12	9	4	3	33.3	
Site 3	0.78	10	9	1	1	10.0	
Site 4	0.53	4	4	0	0	0.0	
Site 5	0.42	3	1	2	2	66.7	
Site 6	0.25	1	1	0	0	0.0	
7/29/2022							2.9
Site 1	1.22	13	13	0	0	0.0	
Site 2	0.63	1	1	0	0	0.0	
Site 3	0.33	1	1	0	0	0.0	
Site 4	0.50	0	0	0	0	0.0	
Site 5	0.77	19	18	1	1	5.3	
8/30/2022							10.2
Site 1	0.63	14	14	0	0	0.0	
Site 2	0.77	13	8	5	5	38.5	
Site 3	0.33	1	1	0	0	0.0	
Site 4	0.62	15	15	0	0	0.0	
Site 5	0.60	6	6	0	0	0.0	
9/19/2022							0.0
Site 1	1.10	18	18	0	0	0.0	
Site 2	0.38	0	0	0	0	0.0	
Site 3	0.78	11	11	0	0	0.0	
Site 4	1.33	18	18	0	0	0.0	
10/14/2022							0.0
Site 1	0.57	17	17	0	0	0.0	
Site 2	1.08	16	16	0	0	0.0	
Site 3	0.32	3	3	0	0	0.0	
Site 4	0.57	6	6	0	0	0.0	
Site 5	1.08	27	27	0	0	0.0	
3/28/2023							5.4
Site 1	0.67	16	16	0	0	0.0	
Site 2	0.37	15	15	0	0	0.0	
Site 3	0.35	12	12	0	0	0.0	
Site 4	1.52	11	11	0	0	0.0	
Site 5	0.48	10	10	0	0	0.0	
Site 6	0.82	29	25	5	4	17.2	
4/27/2023							4.3
Site 1	0.50	7	6	1	1	14.3	
Site 2	0.35	3	3	0	0	0.0	
Site 3	0.38	3	3	0	0	0.0	
Site 4	0.27	0	0	0	0	0.0	
Site 5	0.85	10	10	0	0	0.0	
5/25/2023							5.0
Site 1	1.25	25	23	2	2	8.0	
Site 2	1.23	23	23	0	0	0.0	
Site 3	0.18	2	1	1	1	50.0	
Site 4	0.08	10	10	0	0	0.0	
8/17/2023							41.7
Site 1	0.50	5	3	3	2	60.0	
Site 2	0.53	6	5	1	1	16.7	
Site 3	0.25	1	1	1	0	100.0	

odds of experiencing depredation during Spring (i.e. April–June) in the online survey and the greater number of depredation posts identified via content analysis during July, respectively. We should also note that variation in angler behavior may have contributed to response bias that could have influenced overall response rates in the online survey. For instance, the lower number of responses during the winter season could be related to anglers spending less time fishing due to the

Table 6. Continued

Charter date	Hours fished	# of fish		# of depredations	# of bite-offs	Depredation rate (%)	
		Hooked	Landed			Per site	Per trip
9/26/2023							3.6
Site 1	0.88	16	15	1	1	6.3	
Site 2	0.48	11	11	0	0	0.0	
Site 3	0.78	17	16	1	1	5.9	
Site 4	0.33	7	7	0	0	0.0	
Site 5	0.22	4	4	0	0	0.0	
Site 6	0.28	0	0	0	0	0.0	
Total	–	597	562	40	35	–	–
Mean	0.67	–	–	–	–	8.9	9.4
(± SE)	(± 0.05)					(± 2.7)	(± 3.4)

winter holidays and/or less favorable weather conditions (i.e. cold fronts). Similarly, more favorable weather conditions throughout the year in the southern portion of the state, could explain the consistently higher response rates across seasons in the Florida Keys.

Another possible explanation for the seasonal variation in depredation frequency could be shark behavior. In particular, the large number of depredation samples collected in April and May by our charter fishing partners could correspond to seasonal increases in shark abundance during these months when adult sharks for many of the species identified as depredators in this study are known to give birth and mate (Castro 1993, McCandless et al. 2007) and have been shown to exhibit natal or regional philopatry to parturition and mating areas (Chapman et al. 2015). This is particularly true for bull sharks, which have well-documented nursery habitats in the estuaries throughout Florida (Heupel and Simpfendorfer 2011, Strickland et al. 2020, Edwards et al. 2022) and were frequently identified as a depredator in this study. These characteristics of shark reproductive ecology could lead to higher local or regional abundances of sharks during this time, particularly in nearshore/coastal waters where recreational fishing pressure might be higher, thus increasing the likelihood of experiencing shark depredation. As such, our findings have implications for managing and mitigating shark depredation, as there is often a desire to protect these same areas to help facilitate shark conservation (Speed et al. 2010).

Depredation rates

While many previous studies have broadly quantified the frequency of shark depredation in recreational fisheries, this study quantified per trip shark depredation rates in recreational fisheries. Labinjoh (2014) reported an average depredation rate of 8.4% for a charter fishery in South Africa, and in Western Australia depredation rates ranged from 3.7% to 7.2% depending on fishing style and target species (Mitchell et al. 2018b). In this study, average per trip depredation rates from the cooperative surveys were consistent with those reported by Mitchell et al. (2018b) and Labinjoh (2014), ranging from 0% to 26.2% with an average of 9.4%. On the other hand, depredation rates reported from the Florida angler survey were more variable, with the proportion of depredated catch (among anglers who reported experiencing depredation on their last trip) ranging from 1% to 100%, and the average proportion of depredated catch (41.3%) was markedly higher than the depredation rates recorded during the cooperative fishing charters and those reported in earlier studies. It is possible, however, that this value is an overestimate of the average depredation rate. First, there were multiple surveys with calculated depredations rates greater than 100% that were excluded from analysis. This suggests that some respondents entered incorrect values when completing the survey, and thus it is possible that values reported in the included surveys may have also been over-estimated due to recall bias (Tarrant et al. 1993). For instance, anglers may have been more likely to remember fish they lost to depredation (e.g. snapper or grouper), but not all the fish that were caught and discarded (e.g. smaller, less charismatic species such as grunts). Conversely, anglers may be less likely to remember or report depredations on smaller, less charismatic species because they are not targeting them, thus leading to an underestimate of depredation rates. Second, because depredation rates were only calculated for respondents that had experienced depredation, all rates were greater than 0%. If surveys from those respondents that did not experience depredation had been included when calculating depredation rates (using a value of 0), the average depredation rate would have been considerably lower than 43.1%. Furthermore, although survey recipients were randomly selected and overall response rates were relatively high, it is also possible that anglers who have had more recent and/or frequent experiences with shark depredation may have been more willing to respond to the survey than those that did not. Collectively, these caveats illustrate some of the challenges associated with establishing depredation rates in this sector.

Studies examining factors that influence shark depredation in recreational fisheries are notably limited, possibly due to the limited quantitative data available on depredation rates. In this study, despite having a significant effect on depredation frequency, neither season nor fishing region had a significant effect on depredation rates. The difference in the significance of these factors between depredation metrics (i.e. frequency vs. rates) suggests that depredation rates may be influenced by other factors (e.g. water depth, habitat, fishing pressure, fishing location, fishing style) that vary across smaller scales within broader factors such as season and region. For instance, Mitchell et al. (2018b) found that shark depredation rates at Ningaloo Marine Park in Western Australia varied spatially, and fishing pressure, depth, and latitude were all significant factors influencing depredation rates. In particular, they found higher depredation rates in areas with higher levels of fishing pressure (Mitchell et al. 2018b). Casselberry et al. (2024) identified fishing fight time and current as significant factors having an effect on shark depredation risk at a tarpon fishing hot spot in the Florida Keys. In an effort to examine the effects of other variables on depredation rates in this study, survey respondents who provided detailed catch data for their most recent trip where they experienced depredation were also asked to provide additional details about the environmental conditions (e.g. water temperature, depth, habitat) and their fishing behavior (e.g. time fishing, fishing style, bait type). Our initial goal was to incorporate these variables into a predictive model to assess what conditions might influence depredation rates. Unfortunately, due to a combination of limited and inconsistent responses (possibly due to memory recall) and a wide range of values among the responses we did receive, it was not possible to develop this model. Thus, future work to quantify the factors influencing shark depredation rates in Florida's recreational fishery should explore these and other potential predictors.

Conclusions

Shark depredation is a complex and polarizing human-wildlife conflict that represents a significant issue facing recreational fisheries. The results from this study are crucial for building a comprehensive understanding of shark depredation in a recreational fishing hotspot. Our integrative approach using citizen science (content analysis, angler surveys, cooperative charters, and genetic sampling) helped provide a holistic view of this issue. These techniques helped us achieve a consensus on the depredator species involved (primarily bull and sandbar sharks) and the recreational target species being affected (primarily snapper-grouper species). We hope these findings will facilitate discussions between stakeholders and both state and federal fishery managers as they work to develop actionable management measures to address this conflict.

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Author contributions

Michael P. McCallister: data curation, formal analysis, investigation, methodology, project administration, resources, validation, visualization, writing—original draft, writing—review & editing. Lauran Brewster: conceptualization, data curation, formal analysis, investigation, methodology, software, validation, visualization, writing—original draft, writing—review & editing. Cheryl Dean: data curation, formal analysis, investigation, validation, writing—review & editing. These roles were fulfilled with respect to the genetic component of this project. J. Marcus Drymon: conceptualization, funding acquisition, methodology, project administration, resources, visualization, writing—review & editing. Cliff Hutt: methodology, writing—review & editing. Thomas J. Ostendorf: data curation, investigation, project administration, resources, visualization, writing—review & editing. Matthew J. Ajemian: conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, project administration, resources, supervision, validation, visualization, writing—original draft, writing—review & editing

Supplementary data

Supplementary data is available at *ICES Journal of Marine Science* online.

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Data availability

The data underlying this article are available upon reasonable written request to the corresponding author.

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