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Co-Producing a Shared Characterization of Depredation in the Gulf of Mexico Reef Fish Fishery: Comprehensive Report

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MISSISSIPPI STATE UNIVERSITY EXTENSION

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Executive Summary

Depredation, defined as the partial or complete removal of a hooked fish by a non-target species, is a cryptic form of mortality that can affect the accuracy of stock assessments and species management efforts. Accounting for depredation is crucial to minimize uncertainty in stock assessment models and to obtain accurate and reliable fisheries catch data. If these interactions are frequent, failure to properly quantify this form of mortality can lead to the underestimation of reef fish population removals, inappropriate harvest recommendations, and stakeholder unrest.

In recent years, depredation has escalated in the Gulf of Mexico (GoM) reef fish fishery. Although GoM reef fish fishery stakeholders (fishermen) have actively pushed for resource managers to implement solutions to address these increasingly pervasive interactions, a comprehensive characterization of this issue is lacking, and trends surrounding GoM reef fish depredation – as well as factors that impact depredation – have not been adequately described or evaluated. ***Therefore, the objective of this project was to co-produce a shared characterization of the impacts of depredation in the GoM reef fish fishery.***

To accomplish this, we employed a three-phased approach consisting of synthesis (phase 1), survey (phase 2), and feedback (phase 3). During phase 1, we synthesized data from the NOAA Fisheries Southeast Fisheries Science Center (SEFSC) GoM Reef Fish Observer Program, the largest and longest depredation-related dataset available. Marked increases in depredation were shown starting in 2017 for both bottom longline and vertical longline, particularly in the Eastern GoM. To complement the analysis of the commercial sector from phase 1, we designed and implemented an electronic survey of private recreational anglers in phase 2. Survey results demonstrate that anglers across the GoM routinely experience depredation and have identified a variety of influential factors such as geographic location and depth. Surprisingly, depredation has not affected fishing behavior for the majority of those surveyed. Findings from the commercial fishery (phase 1) and private recreational fishery (phase 2) were then presented to a representative group of (predominantly) charter-for-hire fishermen during an in-person, collaborative participatory modeling workshop (phase 3). These stakeholders provided unique insights, suggesting that factors like the length of the red snapper fishing season, recreational angler high-grading, and a diminished GoM shrimp trawl fleet, have led to increases in depredation. Perhaps more importantly, these stakeholders noted a growing disconnect between their on-the-water observations (i.e., increased depredation), and what they perceived as an increasing desire from NOAA Fisheries and the general public to protect all sharks. Notably, these sentiments resulted in a lack of trust with respect to shark science, stock assessments, and resource management.

Ultimately, this planning project led to a deeper understanding of shark depredation in the GoM commercial, private recreational, and charter-for-hire fisheries. Project findings formed the basis of a comprehensive Research and Development Plan and an Application Plan. In addition, data and insights from this planning project contributed to a peer-reviewed depredation review (Mitchell et al. 2022), a stock assessment report (Drymon et al. 2022), a manuscript in prep (Duffin et al.), five conference presentations, and three outreach products.

The specific natural resource management decision to be made in the future is: how can depredation in the GoM reef fish fishery be quantified to reduce uncertainty when setting catch targets and limits?

1. Background

Stock assessments provide critical information used to set sustainable catch targets and limits. Accurate and reliable fisheries catch data are the cornerstone of a statistical stock assessment model because removals from the population are the principal data source from which the total population size is then reconstructed. However, uncertainty in removals can occur for a variety of reasons (e.g., misreporting catch or ignoring biological removals), which can result in bias in the assessment model outputs (Hanselman et al. 2018). Depredation, defined as the partial or complete removal of captured fishes by non-target species (Gilman et al. 2008), is a cryptic form of mortality that can lead to underestimation of population removals and inappropriate harvest recommendations. Yet, accounting for depredation in a stock assessment is impossible without first effectively characterizing the problem, which can then inform research needs for developing estimates of the magnitude of depredation (Mitchell et al. 2022).

Depredation has become a topic of significant concern worldwide, including the GoM. In particular, the GoM red snapper (*Lutjanus campechanus*) fishery is plagued by an escalating occurrence of depredation. Common depredators in the GoM red snapper fishery include sandbar shark (*Carcharhinus plumbeus*, Drymon et al. 2019), greater amberjack (*Seriola dumerili*, Streich et al. 2018), goliath grouper (*Epinephelus itajara*, Shideler et al. 2015), and bottlenose dolphin (*Tursiops truncatus*, Powell et al. 2011). In addition to introducing uncertainty into the GoM red snapper stock assessment, depredation in this fishery has led to significant frustration among stakeholders (i.e., fishermen). Furthermore, during the data workshop for the most recent stock assessment for GoM red snapper (SEDAR 74), it was requested that “any known evidence regarding ecosystem, climate, species interactions (e.g., predation studies), … that would reasonably be expected to affect red snapper population dynamics” be included in the stock assessment process (SEDAR 2020). Subsequent interviews with the charter-for-hire fleet revealed that depredation was the most common environmental issue in the red snapper fishery (Gervasi et al. 2022). However, the effects of depredation have not yet been incorporated into GoM stock assessments.

In response to stakeholder outcry, the U.S. Congressional Joint Explanatory Statement accompanying the Consolidated Appropriations Act of 2021 directed NOAA Fisheries to undertake a review “…to assess and better understand the occurrence of conflicts between dolphins and sharks and commercial, charter-for-hire, and recreational fishing vessels in the Gulf of Mexico and South Atlantic” (Consolidated Appropriations Act 2021). The report notes that dolphin and shark interactions with fisheries are complex and challenging, and appear to be increasing across the GoM and South Atlantic. These interactions pose injury or mortality risks (e.g., becoming entangled in gear, ingesting hooks) to the depredating species (i.e., dolphin or shark), reduce salable catch in commercial fisheries, and degrade the fishing experience in recreational fisheries. The report concludes by summarizing current research efforts to characterize depredation and suggesting immediate research priorities, including “new data collection methods focused on shark depredation in tandem with cooperation and communication between stakeholders” (Coit and Spinrad 2022).

Therefore, our objective was to co-produce a shared characterization of depredation in the GoM reef fish fishery. We accomplished this objective through the following three phases. First, we gathered, analyzed, and interpreted existing GoM depredation-related datasets. Second, we designed and implemented a depredation-related electronic survey of fishermen across the GoM. Finally, we presented these findings to stakeholders at a collaborative mental modeling workshop.

2. Methods

2.1 Data synthesis

Co-producing a shared characterization of depredation in the GoM was the result of three phases. During the first phase, we gathered, analyzed, and interpreted existing depredation-related dataset from the GoM. Specifically, Benjamin Duffin, a fisheries statistician with NOAA Fisheries Highly Migratory Species Division, performed an exploratory analysis of data collected by the NOAA Fisheries SEFSC GoM Reef Fish Observer Program. This program deploys observers on commercial fishing vessels targeting GoM groupers and snappers. Information related to depredation is collected at the set level, and includes the following predator conditions: *not present*, *observed but not feeding*, *observed feeding on hooked captures* (i.e., depredation), *observed but unable to determine if feeding*, and *feeding on discarded captures*. The Duffin analysis focuses only on sets indicating that sharks were *feeding on hooked captures*, and includes data from the beginning of mandatory observer coverage (3-5%) in the GoM in 2006 through 2019. Sets where shark depredation was indicated were compared to sets where no depredation occurred to examine if shark depredation varied as a function of time (i.e., year to year), season (winter, spring, summer, fall), gear type (bottom longline, vertical longline), statistical zone (21-1, west to east), region (West Texas, East Texas/West Louisiana, East Louisiana/Mississippi/Alabama, North Florida, South Florida), depth (0-1000 meters), time of day (hours 1-24), habitat (13 categorical bottom type codes), and interactions of the above factors. These methods are summarized in a manuscript (in prep) by Duffin et al.

2.2 Electronic survey

After compiling existing information on GoM reef fish depredation, we designed and implemented a comprehensive depredation-focused electronic survey to target ~1,000 GoM fishermen. To achieve our target sample, we used Qualtrics survey software. Qualtrics has been described as a quick and inexpensive way to target subpopulations within an area of interest (Zack et al. 2019) and has gained popularity over the last decade as a robust approach to online surveys (Harlan et al. 2019; Boas et al. 2020; Miller et al. 2020).

All recipients received the same survey, and no randomization was done. Questions were asked from the following categories: 1) consent and screeners, 2) general fishing characteristics, 3) depredation screeners and identification, 4) quantifying depredation and mitigation, 5) depredation attitudes, and 6) demographics. A self-classifying question from Needham et al. (2009) was used to determine angler avidity. Specifically, we asked, “Which of the following best describes you?” and allowed anglers to select one of three responses:

> Type I: *“Fishing is an enjoyable, but infrequent activity that is incidental to other travel and outdoor interests. I am not highly skilled in fishing, rarely read fishing articles, and do not own much fishing equipment beyond the basic necessities.”*
>
> Type II: *“Fishing is an important, but not exclusive outdoor activity. I occasionally read fishing articles and purchase additional equipment to aid in fishing, my participation in fishing is inconsistent, and I am moderately skilled in fishing.”*

Type III: *"Fishing is my primary outdoor activity. I purchase ever-increasing amounts of equipment to aid in fishing, go fishing every chance that I get, consider myself to be highly skilled in fishing, and frequently read fishing articles."*

Key concepts from the survey are shown in **Table 1.** After informed consent was obtained, a self-affirming question that required participants to select whether or not they would "provide their best answers" was asked (Scyphers et al. 2021); if a participant did not select "yes," the participant was exited from the survey. Qualtrics included a question in the middle and at the end of the survey to ensure the survey was being taken by a human. Additionally, Qualtrics has established processes to identify if respondents are "speed-running" (finishing the survey faster than 50% of the mean completion time) or "straight-lining" (repeatedly selecting the same answer). If either of these conditions were identified, those responses were eliminated. Eliminated responses were replaced by Qualtrics with new responses that were subjected to this same review process until a minimum of 1,000 satisfactory responses were received.

This survey was approved by Northeastern University's Institutional Review Board (Approval #13-07-16) and ran from 25 February 2022 through 31 March 2022. Answers to free response questions were binned to identify concepts that may have not been addressed through other, non-free response survey questions. All concepts were analyzed and compiled to create individual fuzzy-logic cognitive maps (mental models) that were subsequently combined to create community models that capture group beliefs on the social and ecological impacts of GoM reef fish depredation.

Data from Qualtrics were imported into R studio (version 4.1.2) for analysis (R Core Team 2022). A Fisher exact test was used for nominal responses with two options, while a chi-square test was used for nominal responses with more than two choices. Questions containing numerical data were examined with a Kruskal-Wallis test.

2.3 Stakeholder workshop

Data syntheses from phase 1 and community models from phase 2 laid the groundwork for the development of a collaborative mental modeling workshop (**Appendices A-D**). This workshop, which was convened on April 4, 2022 in Gulf Shores, Alabama, served to: 1) allow stakeholders to develop, assess, discuss, and refine regional GoM reef fish depredation community models; 2) facilitate in-person discussion and reciprocal learning among researchers, resource managers, and stakeholders about GoM reef fish depredation; and 3) identify knowledge gaps concerning GoM reef fish depredation. Informed consent was acquired from all stakeholders.

First, the reef fish depredation data syntheses were presented to workshop stakeholders. Most stakeholders represented the GoM charter-for-hire industry, a sector where temporal and spatial trends in depredation are particularly lacking. Stakeholders were divided into three breakout groups (Western GoM, Central GoM, and Eastern GoM) to develop regional depredation community models. Four core model concepts (depredation, angler satisfaction, reef fish populations, and fisheries management effectiveness) identified from the survey were presented to stakeholders during these breakout groups. Twenty additional concepts (also identified from the survey) were also presented in a word bank to encourage further discussion and to identify which components were most important to characterizing GoM reef fish depredation (**Figure 1**). Stakeholders were able to select components presented in the word bank and/or suggest components of their own to incorporate into regional community models. Stakeholders were also asked to assign categorical weights to the causal links drawn between components presented, which were assigned as follows: strong negative (-1), moderate negative (-0.50), moderate positive (0.50), and strong positive (1). Community models were then created and finalized through moderated group discussion.

Although attempts were made to divide stakeholders by region, clear differences at the state level resulted in the creation of five breakout groups (Texas, Louisiana, Mississippi, Alabama, Florida) to accurately capture more fine-scale differences in depredation components and interactions within community models. Levels of agreement and confidence among all components and relationships within community models were identified and displayed in *Mental Modeler*, a cognitive mapping software designed to allow researchers, resource managers, and stakeholders to construct semi-quantitative concept maps and illustrate hypothesized or known relationships (Gray et al. 2013). Relationships between concepts are connected via directional arrows that indicate the influence (positive/negative) one component has on another. For each community model, variables were categorized as driver, receiver, or ordinary to assess each variable's role within the model. Depredation drivers are listed for each community model and are defined as having positive outdegrees and zero indegrees within the *Mental Modeler* software. Scenario analysis was also completed within *Mental Modeler* to determine how increases or decreases in components within the models altered the remainder of the system. Specifically, scenario analyses are simulations that produce the relative change of each component within the model in response to changes in one or more of the system's other components (Gray et al. 2012).

Additionally, stakeholder breakout groups contributed to participatory mapping exercises to determine temporal and spatial depredation trends. This process resulted in tangible products that incorporated stakeholder knowledge and perceptions of GoM depredation that could be used to accurately capture changes and preferred states within a dynamic social-ecological system.

Lastly, exit surveys were distributed to all stakeholders at the conclusion of the workshop to enable us to elicit feedback on workshop effectiveness and design and to determine future research directions.

3. Results

3.1 Data synthesis

Examination of the Reef Fish Observer Program data indicated that depredation has increased over time in both bottom longline (**Figure 2**) and vertical longline (**Figure 3**) fisheries, with a notable increase beginning in 2017. From 2017-2019, depredation was slightly higher during the months of March-June (**Figure 4**) but occurred year-round. In general, depredation was higher at night and in the early morning (8pm-6am, **Figure 5**), although this may reflect the preferred setting times for the fishery.

A closer examination of these data demonstrates spatial variation in depredation rates. The most significant increase in depredation was seen in the Eastern GoM bottom longline fishery. Trends in the Western GoM were much less clear (**Figure 6**). A regional examination of these trends shows that the highest rates of depredation are occurring on bottom longline in the North-central GoM (East Louisiana, Mississippi, Alabama, **Figure 7**). Within this region, bottom longline depredation is higher in shallower water (~ 300 m) relative to deeper water (~ 700 m) (**Figure 8**). When examined as a function of habitat type, depredation was again highest in the

North-central GoM bottom longline fishery, specifically on mud and rock substrates (**Figure 9**). These results are presented in a manuscript (in prep) by Duffin et al.

3.2 Electronic survey

After data scrubbing and QA/QC, a total of 1,038 GoM fishermen were surveyed. Respondents were predominantly white with a postsecondary education (**Table 2**). The vast majority of respondents (n = 740) identified as recreational fishermen; thus, subsequent analyses focused solely on this stakeholder sector. In response to the angler avidity question, anglers were relatively evenly distributed between groups; 39.1% Type I, 30.3% Type II, and 30.7% Type III. There was no significant variation between states (p = 0.132) (**Figure 10**).

When asked how often they experienced depredation in 2021 (described in the survey as "the number of fish bitten off for every 100 fish you hook"), anglers' responses showed no state-level variation (Kruskal-Wallis test, p = 0.21). Median and mean depredation rates were 30% and 32%, respectively (**Figure 11**). Interestingly, reported depredation rates varied as a function of angler avidity. Type II anglers (i.e., those with a moderate avidity) experienced depredation less than Type I (i.e., infrequent anglers) or Type III (i.e., avid anglers) (**Figure 12**).

Surprisingly, reported increases in depredation did not result in changes to angler behavior. Approximately half of respondents (45.7%) indicated that depredation has not impacted their fishing, while approximately one quarter (26%) indicated the depredation has impacted their fishing in the last year (**Figure 13**). When asked to rank the factors that most strongly influenced depredation, all factors presented to respondents were identified. Factors thought to "strongly influence" depredation included geographic location and depth. "Returning to fishing locations" was considered the least influential factor influencing depredation (**Figure 14**).

In general, anglers expressed support for maintaining shark populations at current levels (45.4% of respondents) or reducing shark populations (34.9% of respondents). Little support was expressed for eliminating or increasing shark populations (**Figure 15**).

3.3 Stakeholder workshop

3.3.1 Depredation trends

The first goal of the stakeholder workshop was to share findings from the data synthesis and electronic survey. Most stakeholders agreed that reef fish depredation in the GoM started increasing significantly in 2017, which agrees with the data from the GoM Reef Fish Observer Program (**Figures 2 and 3**). Stakeholders presented a number of potential contributing factors for this increase that ranged from changes in fisheries management and socio-economic dynamics to environmental and ecological alterations. Specifically, some stakeholders attributed the large increase in depredation to the GoM states' ability to set and manage their own fishing seasons, claiming that this approach has resulted in increased private recreational fishing activity for each individual GoM state. In addition, restricted harvest regulations lead to more anglers competing to harvest the same species, thus resulting in increasing instances of depredation for the individual fishermen. Stakeholders also acknowledged that climate change may be exacerbating depredation interactions. For example, areas with low dissolved oxygen (e.g., the "Dead Zone") seem to be expanding in recent years, and these areas result in shifting fish stocks as well as shifting predator populations. Stakeholders noted that sharks can become concentrated in areas with higher dissolved oxygen along the coast, increasing their proximity to coastal fishermen and potentially increasing shark-human interactions. Freshwater runoff, increasing sea surface temperature, and water clarity were also identified as potential predictors of depredation. Both freshwater runoff and increasing sea surface temperature contribute to expanding areas of low dissolved oxygen; murky waters tend to have more instances of shark depredation, whereas clear waters have more instances of bottlenose dolphin (hereafter dolphin(s)) depredation.

3.3.2 Scenario analysis

While the majority of stakeholders agreed that instances of depredation are increasing, there was division among stakeholders on whether GoM shark populations have significantly increased or decreased in recent years, and whether fisheries management efforts are responsible for the rise in depredation interactions. Because these two concepts were identified to be of high importance among breakout group discussions compared to other system components, they were selected for use in scenario analyses to determine how each regional community model would be altered by changes in shark populations and fisheries management effectiveness. Changes in these two concepts resulted in a range of different outcomes for each region (**Figures 16-20**).

Some stakeholders agreed with current shark population assessments, which do not show significant increases in shark populations. They insisted that increases in shark depredation are instead the result of more anglers on the water, fewer commercial shrimp boats on the water, and smaller fish populations than in the past. Stakeholders explained that sharks are drawn to shrimp boats due to their extensive bycatch, and a decrease in the number of shrimp boats has resulted in higher concentrations of sharks around other fishing vessels, which causes increases in depredation. Additionally, these stakeholders stated that the GoM does not have the same fish populations (food source) as it did 50 years ago, so it cannot support the same shark populations as it did historically. Other stakeholders attributed the rise in depredation to fisheries management efforts and regulatory changes for protecting sharks that have resulted in the recovery of many shark populations. Specifically, increased shark populations – along with an increased number of anglers and fewer prey items – results in more frequent depredation interactions. While division existed regarding the current status of shark populations and the role of fisheries management in increased depredation, other stakeholders simply stated that shark population status simply does not matter; the central problem is shark-human interactions are becoming more frequent and more problematic, and personal and economic costs are increasing at a faster rate than increases in depredation.

3.3.3 Species responsible

Although some stakeholders attributed the rise in depredation interactions to increased shark populations, there was no consensus on which shark species are predominantly responsible. Ridgeback shark species, specifically sandbar sharks, silky sharks (*Carcharhinus falciformis*) and dusky sharks (*Carcharhinus obscurus*), as well as bull sharks *(Carcharhinus leucas*) were frequently mentioned as primary depredators, along with dolphins. Goliath grouper and greater amberjack were also mentioned as depredator species, although these species were not discussed in detail. Spatial trends in the species responsible for depredation were examined through a participatory mapping exercise (**Figures 21-24**).

3.3.4 Depredation solutions

Potential solutions to increased reef fish depredation in the GoM were numerous and mirrored stakeholder opinion on shark population status. If stakeholders felt that shark populations have increased and recovered, they felt that the implementation of a directed and expanded shark fishery was a viable solution to decrease the negative impacts of depredation. These stakeholders noted that historically, there was a thriving directed shark fishery and depredation was not as pervasive as it is today; thus, a shark harvest would theoretically decrease shark populations and alleviate shark-human interactions.

However, many stakeholders recognized that the development of an effective shark fishery would necessitate addressing two primary challenges. The first of these involved changing the negative public opinion on shark harvest. Recent efforts to protect shark populations have likely resulted in the preliminary recovery of some shark populations; however, a mandate to sustainably harvest shark populations could be at odds with the desire for a complete harvest moratorium on all shark species. Specifically, stakeholders noted that management efforts communicating messages about conserving shark populations have resulted in a perspective that, even if some shark populations are healthy, there continues to be a need for stringent shark conservation. This message – and the public opinion that upholds this perspective – was a pervasive issue raised by stakeholders, both from a safety perspective and as an immediate threat to their livelihood. This message actively prevents stakeholders (particularly commercial fishermen) from using resources already established for a managed shark harvest to their advantage as well as mobilizing efforts to try to address solutions for shark depredation. Thus, some stakeholders felt that a significant culture shift is necessary to both implement and sustain a shark fishery.

The second primary challenge stakeholders identified was incorporating effective fisheries management throughout the implementation process. Additionally, fisheries management efforts must address current regulations that effectively prevent the establishment of a long-term shark product market; for example, Florida currently has a ban on shark fins, Texas has a commercial shark harvest ban, and current federal regulations prevent Mississippi fishermen from reaching the blacktip shark (*Carcharhinus limbatus*) quota. Many of these stakeholders recognized the need to harvest responsibly and sustainably and were in favor of conducting stock assessments for “problematic” shark species like bull shark. Some felt that their observations and experiences do not align with current assessments and emphasized that research must be cooperative in scope to involve fishermen in the process, whether through current reporting applications or future collaborative research projects.

While some stakeholders identified an expanded shark harvest as a possible solution to alleviate depredation in the GoM, others felt a multifaceted approach would be more appropriate and effective. Many stakeholders recognized that changing public perception and depending on consumers to support a shark market may simply not be feasible. Even if stock assessments were to support sustainable shark harvest, public opinion may not change to the degree needed to implement market changes. Deterrents seemed to have moderate support among these stakeholders, with the use of the Zeppelin (manufactured by SharkBanz) and shark necromones mentioned specifically. While some stakeholders have not heard of or used the Zeppelin, other stakeholders have found it to be only moderately effective. Some stakeholders who have used deterrents seemed to agree that although deterrents may be effective initially, their effectiveness declines over time. Despite this, stakeholders maintained interest in using shark necromones as a possible deterrent and showed support for more collaborative research on their effectiveness in minimizing depredation interactions. Some felt that the development of an effective and reliable shark deterrent would take time to design, but the implementation of both a shark harvest and deterrents could result in decreased depredation. Stakeholders also mentioned the SeaQualizer as an option to explore, presumably to limit depredation following the discarding of undersized or illegally caught fishes.

3.3.5 Regional dynamics
Significant effort was made to ensure comprehensive workshop representation by selecting stakeholders from each GoM state. In total, four stakeholders were from Texas, two were from Louisiana, four were from Mississippi, four were from Alabama, and eight were from Florida. Most stakeholders (72%) represented the charter-for-hire sector, although a few represented either the commercial sector or both the charter-for-hire and commercial sectors. A GoM-wide community model of reef fish depredation was not developed due to distinct differences at the state level. Regional dynamics of reef fish depredation in the GoM are discussed below; major and minor concepts captured from breakout discussions were documented based on the frequency each component was mentioned (**Figure 25**).

All stakeholders were encouraged to estimate the percentage of their catch lost to shark and dolphin depredation and to create time-series plots of depredation trends. For percentage of catch lost, 15 responses were collected for dolphin depredation and 20 responses were collected for shark depredation. Average percent catch lost to shark depredation was 9.65% +/- 4.57 SE (range = 1-60%) and average percent catch lost to dolphin depredation was 16% +/- 2.40 SE (range = 1-50%, **Figure 26**). Interestingly, individual time-series plots converged on a general trend indicating a marked increase in depredation beginning around 2017 (**Figure 27**), in general agreement with the trends identified through analysis of the Reef Fish Observer Program data (**Figures 2 and 3**).

3.3.5.1 Texas. – Breakout group discussion among Texas stakeholders illuminated clear differences in viewpoints between the commercial and charter-for-hire sectors with respect to reef fish depredation (**Figure 28**). Although depredation interactions decrease safety and satisfaction while increasing economic loss for both sectors, stakeholders agreed that economic loss due to depredation is significantly greater for the commercial sector. Impacts to the charter-for-hire sector are more complex and mostly characterized by satisfaction. Clients in the charter-for-hire sector enjoy catching sharks, which increases customer satisfaction. However, clients' satisfaction decreases if sharks are the only species that can be caught, and/or if sharks are severely limiting their harvest of preferable and more readily consumed species. With respect to economic impact in the charter-for-hire sector, media content obtained through fishing and catching sharks has been used to promote future trips, resulting in an economic gain for the charter-for-hire sector.

Texas stakeholders identified that the composition of depredation interactions influences satisfaction and economic loss (**Figure 28**). Depredation interactions as a result of many small sharks generally decrease angler satisfaction, whereas depredation interactions as a result of one large shark tend to increase angler satisfaction (i.e., anglers prefer seeing/catching one large shark rather than several small sharks). Both depredation interactions result in economic loss, although economic loss is greater from large sharks since they tend to cause more extensive damage to gear. Texas stakeholders were divided on whether there was a learned behavior component to shark depredation. If sharks have the ability to develop learned behaviors, depredation would increase instances of learned behavior, which would then result in increased depredation interactions (i.e., positive feedback loop), increased economic loss, and increased or decreased satisfaction based on the sector. There also was no consensus on whether learned behavior differed based on the size of the shark.

Although Texas stakeholders did not report effects of depredation on reef fish populations, they did emphasize that reef fish populations have strong correlations with angler satisfaction. Increases in reef fish populations increase angler satisfaction in both sectors and decrease economic loss in both sectors, but also increase depredation interactions. Effective fisheries management (resulting in increased reef fish populations) would also increase commercial and recreational satisfaction. Other factors identified that influence depredation rates include the number of shrimp boats, environmental changes, and fisheries management effectiveness (**Figure 28**). Increases in the number of shrimp boats decrease rates of depredation; sharks and dolphins concentrate around these vessels and do not target charter-for-hire or recreational boats if more shrimp boats are on the water. Additionally, climate change (fewer forage fishes, low dissolved oxygen) has resulted in shark aggregations, which strongly impacts depredation interactions. Although shark populations may not be increasing, shark aggregations are increasing, and current regulations do not accurately reflect these ecological dynamics. Texas stakeholders also identified significant differences between state and federal shark fisheries, and mentioned that the state shark fishery strongly impacts the federal fishery. Texas state waters have very few depredation interactions but very high levels of shark harvest, whereas federal waters have very high levels of depredation and low levels of shark harvest. Strong regulations for shark harvest in federal waters are in response to the high level of shark harvest in state waters.

3.3.5.2 Louisiana. – Breakout group discussion among Louisiana stakeholders identified that frequency of depredation and species responsible for depredation depend upon location. Depredation appears to be more common offshore than inshore, and more common on natural bottom areas compared to artificial reefs. Louisiana stakeholders tend to concentrate their fishing effort on natural bottom areas. Additionally, Atlantic sharpnose shark (*Rhizoprionodon terraenovae*) and blacktip shark depredation are common in inshore areas, blacktip shark depredation is common in nearshore areas, and silky shark and sandbar shark depredation are common in offshore areas. Several components influence depredation rates, including reef fish fishery seasons, prey populations, and barotrauma (**Figure 29**). Louisiana stakeholders specifically mentioned red snapper season length as a predictor for depredation interactions; as season length (charter-for-hire and recreational) increases, there is increased exposure to depredation since it takes anglers a longer time to catch red snapper after this species has been heavily targeted. Because depredation interactions are closely linked to the red snapper season, Louisiana stakeholders found it difficult to compare reef fish and shark populations to current depredation rates and trends. Barotrauma and depletion of other prey populations (e.g., Gulf menhaden, *Brevoortia patronus*) also are thought to cause increases in depredation. Overall, charter-for-hire clients are most interested in catching quality fish species, so depredation interactions (regardless of species) decrease angler satisfaction. Lastly, stakeholders emphasized a strong desire to see fisheries management regulations mirror their observations; many stakeholders' experiences do not align with current stock assessments, and there is a desire for fisheries management to evaluate these differences and implement regulations based on updated information. Effective fisheries management would increase angler satisfaction and decrease depredation, but ineffective fisheries management would decrease angler satisfaction and increase depredation (**Figure 29**). It is important to note that Louisiana and Mississippi stakeholders were originally part of the same breakout group (Central GoM); however, clear differences by state resulted in the creation of separate community models. A combination of a limited number of Louisiana stakeholders as well as limited time after the Central GoM breakout group was divided may have resulted in an incomplete community model for this region.

3.3.5.3 Mississippi. – Similar to Louisiana, Mississippi stakeholders determined that primary depredator species differed by location. Blacktip sharks are primary depredators in inshore areas, whereas bull sharks, blacktip sharks, and spinner sharks (*Carcharhinus brevipinna*) are common depredators in nearshore areas, with bull sharks being the most common. In offshore areas, the most common depredators are bull sharks, tiger sharks (*Galeocerdo cuvier*), and hammerhead sharks (*Sphyrna* spp.). Stakeholders identified depredation interactions in this region to be closely linked to the red snapper fishery, angler skill level, and dolphin learned behavior (**Figure 30**).

Most Mississippi stakeholders target red snapper, and most agreed that red snapper season length influences the frequency of depredation interactions (**Figure 30**); however, red snapper season length has different effects on depredation between the recreational and commercial sectors. For example, depredation interactions are more common towards the end of red snapper season because charter-for-hire fishermen must fish longer to catch the same amount of fish (i.e., there is a greater chance of experiencing shark-human interactions). While charter-for-hire fishermen reported fewer depredation interactions earlier in the red snapper season and more frequent depredation interactions at the end of the red snapper season, the commercial sector reported increasingly frequent shark depredation interactions earlier in the year (primarily in April, May, and June, but in some instances as early as February and March). Stakeholders from both sectors acknowledged that several components (such as changes in climate, water temperatures, red snapper biology and behavior, and fisheries management and regulations) or a combination of these components may also contribute to the frequency of shark depredation in relation to the red snapper season.

Because Mississippi stakeholders attributed depredation interactions to be closely correlated with the red snapper season, identifying the time scale and seasonal fluctuation of depredation could not be completed. Changes in red snapper regulations throughout the past couple decades made it difficult to determine exactly when depredation became a significant issue in this region, and because the majority of Mississippi fishing effort is concentrated in the summer months, depredation rates in winter months are largely unknown.

In addition to the red snapper season, the number of shrimp boats, angler skill level, and dolphin learned behavior were also identified by stakeholders to influence reef fish depredation rates (**Figure 30**). An increased number of shrimp boats in an area increases the number of predators (dolphins and sharks), which increases depredation rates. Low angler skill levels are typically associated with increased fight time of hooked fishes and therefore more sharks being attracted to the movement of a struggling fish, which increases depredation rates. Dolphin learned behavior also strongly increases depredation rates. Stakeholders felt that dolphins in this region are able to both recognize and follow specific boats, and share this information among pod members. This learned behavior may be further magnified by fisheries management regulations and angler behavior. For example, regulations prevent anglers from catching and keeping an unlimited number of fishes, so inevitably anglers must throw hooked fishes back. Recreational anglers also only want to keep the best fishes they catch, so they will throw a fish back if they catch another that is more desirable. This angler behavior results in increased dolphin learned behavior and, by extension, increased rates of depredation. Conversely, Mississippi stakeholders do not think depredation is influenced by shark learned behavior. Fishing effort for this region is largely concentrated on artificial reefs, and sharks are found on artificial reefs since this is where their prey items are located.

Very few Mississippi stakeholders take advantage of the current blacktip shark harvest due to complex regulations and difficulty identifying shark species. Smaller sharks are better to harvest and promote because their meat contains lower mercury levels, and fishermen can keep more of them on the boat. However, Mississippi fishermen have difficulty finding and catching blacktip sharks at legal sizes. Furthermore, most Mississippi fishermen do not have a need to fish far offshore; unlike in other GoM states, the presence of the inshore artificial reef complex means many fishermen do not have a Highly Migratory Species (HMS) permit. Difficulty with shark species identification also worsens the potential for a large shark harvest; it is easier for stakeholders to not target sharks instead of learning the different size limits for different species and how to identify those species with an adequate degree of certainty. Regulations in other GoM states (e.g., Texas fin ban) effectively shut down the market for selling shark products and eliminated profit potential for stakeholders in this region.

3.3.5.4 Alabama. – Breakout group discussion among Alabama stakeholders highlighted that depredation has a significant impact on satisfaction, but there are differences between client satisfaction and captain satisfaction. Depredation interactions with either sharks or dolphins can increase the satisfaction of some clients, particularly those who are novice anglers and tourists. However, depredation interactions tend to decrease captain satisfaction; many captains do not want to devote trips to only catching sharks, and catching and handling sharks tends to increase captain stress. Additionally, captain satisfaction is also influenced by their own past experience: they have their own standards for fishing trips, and catching an undersized or depredated fish or a shark may in some instances increase angler satisfaction, but overall decreases captain satisfaction. In some cases, angler satisfaction is also partially determined by captain satisfaction in that clients can sense when and if a captain is stressed or dissatisfied (**Figure 31**).

Although Alabama stakeholders do not feel depredation is significantly impacting reef fish populations, most agree that shark populations have been increasing every year and depredation is becoming worse of a problem in their region. Stakeholders identified several components that may be impacting depredation. Water quality – specifically water clarity and salinity – and location seem to affect the rate of depredation interactions (**Figure 31**). More shark interactions occur in waters with less clarity. For example, stakeholders have observed increased depredation interactions on the West side of Mobile Bay when there is significant runoff (reduced water clarity and salinity). Time of day may also influence depredation rates; however, stakeholders acknowledged that this statement is complicated by varying lengths of charter-for-hire trips (half versus full days). Some have observed increased instances of depredation in the afternoon, whereas others have not seen these mid-day interactions because they are not fishing at this time. However, there was a consensus that the longer stakeholders fish a spot, the higher the chance of experiencing depredation interactions (**Figure 31**). Typically, if depredation interactions begin, stakeholders must leave the area and try to fish another spot. Many stakeholders are discouraged by losing time and resources when they must leave areas where there are both fishes and high instances of depredation. Most interactions seem to occur in the summer months, although depredation can also be influenced by angler behavior, predator learned behavior, red snapper seasons, and fisheries management. There are significantly more boats on the water today than in the past, and anglers could be contributing to the depredation problem by having long reel times and discarding undersized fishes (**Figure 31**). Longer reel times increase depredation interactions (predators can detect the movement from a hooked fish), and discarding undersized fishes and depredated fishes may create and amplify learned behavior among both sharks and dolphins. Shark depredation may also be correlated with the red snapper fishery. Some stakeholders felt that the red snapper fishery is currently experiencing a generalized depletion; thus, half-day charters are going further offshore to access areas with more red snapper, and shark interactions are more frequent in these areas (**Figure 31**). Additionally, high-grading – where anglers selectively harvest fishes so only the best quality or largest fishes are brought ashore – remains a common practice because only a limited number of fishes are permitted to be harvested based on current fisheries regulations. Some stakeholders felt that sharks only target large, hooked fishes. Other stakeholders felt that most fishes caught are small (16” or less). As a result, many of these fishes are thrown back and become easy prey, leading to increases in depredation interactions.

Stakeholders also agreed that shark depredation is uncommon when artificial reefs have high numbers of reef fish. Some question the accuracy of data collection and fisheries management given the GoM states' ability to set their own red snapper seasons, which some stakeholders felt exacerbated localized red snapper depletions.

3.3.5.5 Florida. – Breakout group discussion among Florida stakeholders illustrated that the outcome of both dolphin and shark depredation is the same. Overall, depredation decreases angler satisfaction in commercial and charter-for-hire sectors and depredation represents a strong economic loss for the commercial sector. Both the commercial and charter-for-hire sectors consider safety (of both clients and staff) to be a significant concern when trying to land a shark alive (**Figure 32**).

Many shark species were identified as common depredators; large sharks (including silky sharks, lemon sharks, *Negaprion brevirostris*, sandbar sharks, and bull sharks) are frequently responsible for depredation, while Atlantic sharpnose sharks are primarily responsible for depredation interactions in coastal areas and cause extensive gear damage. However, there may also be regional differences in primary depredators and depredation frequency within Florida waters. Blacktip and spinner sharks do not depredate as frequently in the Florida Panhandle, whereas bull sharks are found in the Middle Grounds in the summer. Many large shark species live in areas with natural bottom year-round, so depredation typically does not vary by season. However, stakeholders mentioned that sea surface temperature may influence rates of shark depredation since sharks in the Northern GoM are not as problematic during the months of November-February. Furthermore, depredation interactions were reported to be more common on the Atlantic coast of Florida; fishermen from this region regularly travel to fish on the West coast of Florida to avoid the frequent depredation interactions of the Atlantic coast.

Florida stakeholders believe sharks do not intentionally target large, hooked fishes; however, large, hooked fishes struggle more, and this struggle is easier for sharks to track. Thus, Florida stakeholders determined that there is a strong correlation between hooked fish size and its likelihood of being depredated (**Figure 32**). Average anglers struggle to land a large fish, and the fight time is longer, so there is a higher probability a predator will take it prior to the angler landing it.

Florida stakeholders contended that dolphin depredation is significantly more detrimental than shark depredation and is also more challenging to address. Strong dolphin-learned behavior significantly increases depredation interactions (**Figure 32**); dolphins recognize the sound of engines and may follow or wait for boats. Additionally, not all captured fishes are eaten in dolphin depredation interactions – there were several accounts where dolphins simply "played" with a captured fish. The creation of effective dolphin deterrents is hindered by marine mammal protections, cost, and long-term effectiveness. In many cases, deterrents lose effectiveness over time (e.g., acoustic deterrents), and there is some fear that using deterrents may inadvertently train dolphins to know where easy food sources are located. Overall, dolphins are more difficult to deter than sharks since sharks do not possess a learned behavior. Shark depredation interactions tend to be inconsistent, and stakeholders can simply move to another area to fish. Dolphins, however, will readily follow boats to another location. As a result, stakeholders must bring copious amounts of tackle to combat dolphin depredation and adjust trip prices to account for the excessive gear loss to dolphin depredation.

Additionally, there was a strong disconnect between fishery managers and Florida stakeholders regarding shark conservation and regulation (**Figure 32**). Stakeholders felt that fishery managers have been taking regulations for one shark species that may need protection and applying these protections to all shark species, thereby creating significant imbalances in the GoM ecosystem. For example, ridgeback sharks continue to require protection, but stakeholders have observed a significant increase in their population numbers. Many emphasized a desire to see ecosystem-based management with a focus on specific species, and blame NOAA and HMS for continuing shark protections to satisfy non-governmental organizations' (NGO) conservation agendas, thereby limiting management efficiency and effectiveness and significantly decreasing angler satisfaction (**Figure 32**).

3.3.6 Workshop effectiveness

At the conclusion of the workshop, stakeholders were given a short survey to complete to evaluate the utility and effectiveness of the workshop. Overall, stakeholders rated the workshop highly, with 100% of stakeholders agreeing or strongly agreeing that the workshop purpose was clear, the workshop achieved its objectives, the workshop was a valuable use of time, and the workshop fostered active participant involvement and interaction (**Table 3**).

4. Tables

Table 1: Key concepts and associated questions from the electronic survey.

Concept	Question	Response Format/Choices
Angler perceptions of causes of depredation	What do you think causes depredation?	Free response
Angler perceptions of impacts of depredation	What do you think are outcomes or impacts of depredation?	Free response
Angler perceptions of possible solutions to depredation	What do you see as potential ways to reduce depredation?	Free response
Satisfaction with fisheries management	How would you describe your overall level of satisfaction with current fisheries management?	Very dissatisfied to very satisfied
Identification of the most common forms of depredation in the GoM	What form of depredation do you think is the most common?	Shark depredation, dolphin depredation, other fish depredation, not sure

Table 2: Summary of sociodemographic variables of survey respondents by state. *N* = the number of respondents.

	Alabama (N=141)	Florida (N=155)	Louisiana (N=152)	Mississippi (N=141)	Texas (N=151)	Overall (N=740)
Age (years)						
Mean (SD)	41.6 (13.0)	39.0 (11.6)	39.5 (11.7)	46.3 (83.7)	42.3 (13.4)	41.7 (38.0)
Median [Min, Max]	38.0 [19.0, 78.0]	38.0 [19.0, 72.0]	39.0 [19.0, 91.0]	37.0 [19.0, 1010]	38.0 [19.0, 80.0]	38.0 [19.0, 1010]
Missing	2 (1.4%)	5 (3.2%)	4 (2.6%)	4 (2.8%)	0 (0%)	15 (2.0%)
Sex						
Missing	1 (0.7%)	13 (8.4%)	4 (2.6%)	2 (1.4%)	9 (6.0%)	29 (3.9%)
Female	67 (47.5%)	47 (30.3%)	70 (46.1%)	66 (46.8%)	69 (45.7%)	319 (43.1%)
Male	73 (51.8%)	93 (60.0%)	78 (51.3%)	72 (51.1%)	72 (47.7%)	388 (52.4%)
Prefer not to answer	0 (0%)	2 (1.3%)	0 (0%)	1 (0.7%)	0 (0%)	3 (0.4%)
Other	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (0.7%)	1 (0.1%)
Race						
White	116 (82.3%)	119 (76.8%)	124 (81.6%)	116 (82.3%)	104 (68.9%)	579 (78.2%)
Black or African American	20 (14.2%)	16 (10.3%)	20 (13.2%)	20 (14.2%)	14 (9.3%)	90 (12.2%)
American Indian or Alaska Native	2 (1.4%)	1 (0.6%)	0 (0%)	2 (1.4%)	6 (4.0%)	11 (1.5%)
Asian	3 (2.1%)	3 (1.9%)	2 (1.3%)	5 (3.5%)	5 (3.3%)	18 (2.4%)
Native Hawaiian or other Pacific Islander	1 (0.7%)	2 (1.3%)	1 (0.7%)	2 (1.4%)	0 (0%)	6 (0.8%)
Hispanic or Latino	5 (3.5%)	15 (9.7%)	10 (6.6%)	6 (4.3%)	25 (16.6%)	61 (8.2%)
Prefer not to answer	0 (0%)	1 (0.6%)	0 (0%)	1 (0.7%)	0 (0%)	2 (0.3%)
Highest Education Level						
Missing	1 (0.7%)	13 (8.4%)	4 (2.6%)	2 (1.4%)	9 (6.0%)	29 (3.9%)
Bachelor's degree	43 (30.5%)	39 (25.2%)	26 (17.1%)	48 (34.0%)	36 (23.8%)	192 (25.9%)
Doctorate (PhD)	6 (4.3%)	9 (5.8%)	4 (2.6%)	4 (2.8%)	5 (3.3%)	28 (3.8%)
High school diploma or GED	17 (12.1%)	20 (12.9%)	37 (24.3%)	26 (18.4%)	22 (14.6%)	122 (16.5%)
Law or MD	2 (1.4%)	4 (2.6%)	2 (1.3%)	0 (0%)	1 (0.7%)	9 (1.2%)
Less than high school	6 (4.3%)	1 (0.6%)	1 (0.7%)	0 (0%)	2 (1.3%)	10 (1.4%)
Master's degree	22 (15.6%)	38 (24.5%)	20 (13.2%)	21 (14.9%)	26 (17.2%)	127 (17.2%)
Some college or 2 year degree	44 (31.2%)	30 (19.4%)	58 (38.2%)	39 (27.7%)	48 (31.8%)	219 (29.6%)
Prefer not to answer	0 (0%)	1 (0.6%)	0 (0%)	1 (0.7%)	2 (1.3%)	4 (0.5%)
Household Income						
Missing	1 (0.7%)	13 (8.4%)	4 (2.6%)	2 (1.4%)	9 (6.0%)	29 (3.9%)
$100,001 to $150k	24 (17.0%)	26 (16.8%)	24 (15.8%)	26 (18.4%)	29 (19.2%)	129 (17.4%)
$150,000 to $250k	11 (7.8%)	20 (12.9%)	9 (5.9%)	11 (7.8%)	13 (8.6%)	64 (8.6%)
$25,001 to $35k	17 (12.1%)	11 (7.1%)	18 (11.8%)	12 (8.5%)	14 (9.3%)	72 (9.7%)
$25k or less	25 (17.7%)	13 (8.4%)	28 (18.4%)	19 (13.5%)	17 (11.3%)	102 (13.8%)
$35,001 to $50k	16 (11.3%)	14 (9.0%)	15 (9.9%)	20 (14.2%)	19 (12.6%)	84 (11.4%)
$50,001 to $75k	30 (21.3%)	24 (15.5%)	34 (22.4%)	21 (14.9%)	31 (20.5%)	140 (18.9%)
$75,001 to $100k	10 (7.1%)	21 (13.5%)	17 (11.2%)	26 (18.4%)	12 (7.9%)	86 (11.6%)
More than $250k	6 (4.3%)	9 (5.8%)	2 (1.3%)	3 (2.1%)	5 (3.3%)	25 (3.4%)
Prefer not to answer	1 (0.7%)	4 (2.6%)	1 (0.7%)	1 (0.7%)	2 (1.3%)	9 (1.2%)

Table 3: Effectiveness of workshop organization and delivery.

	Percentage of Respondents				
Rating Categories	**Strongly Disagree**	**Disagree**	**Not Sure**	**Agree**	**Strongly Agree**
The workshop purpose was clear.				26.09	73.91
The workshop achieved the stated objectives.				47.83	52.17
The workshop was a valuable use of time.				56.52	43.48
The workshop fostered active participant involvement and interactions.				30.43	69.57
I feel my contributions to the workshop influenced the final decisions.			13.04	47.83	39.13
The workshop provided opportunities to learn about and discuss Gulf of Mexico reef fish depredation.				26.09	73.91
The mental models generated from the workshop accurately portray reef fish depredation in the Gulf of Mexico.		4.35	4.35	39.13	52.17
Knowledge gaps concerning Gulf of Mexico reef fish depredation were adequately described and documented.			8.70	30.43	60.87
Information about Gulf of Mexico reef fish depredation identified during this workshop will be used in future research and management initiatives.			13.04	39.13	47.83

5. Figures

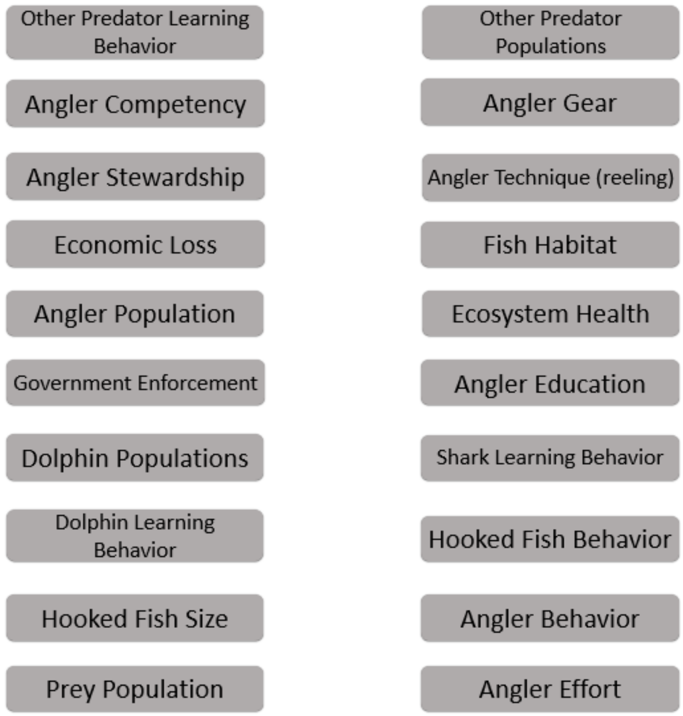


Figure 1: Concept word bank presented to all breakout groups during the stakeholder workshop.

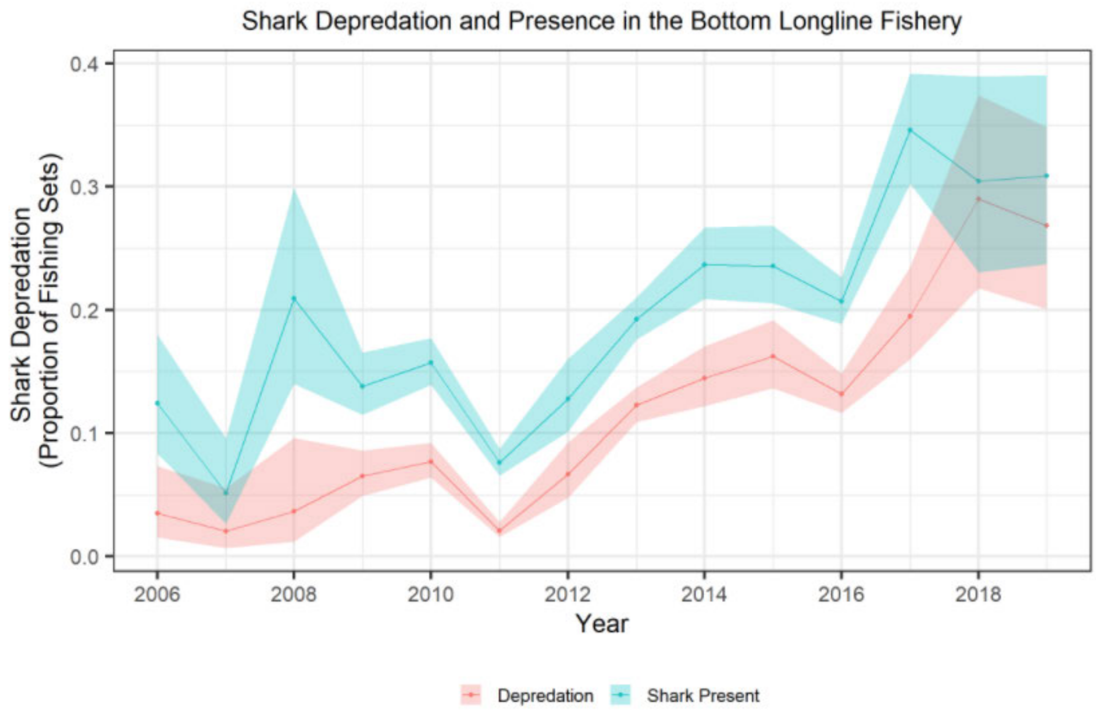


Figure 2: Temporal trends of shark presence and depredation in the GoM bottom longline reef fish fishery from 2006-2020. From Duffin et al. unpublished data.

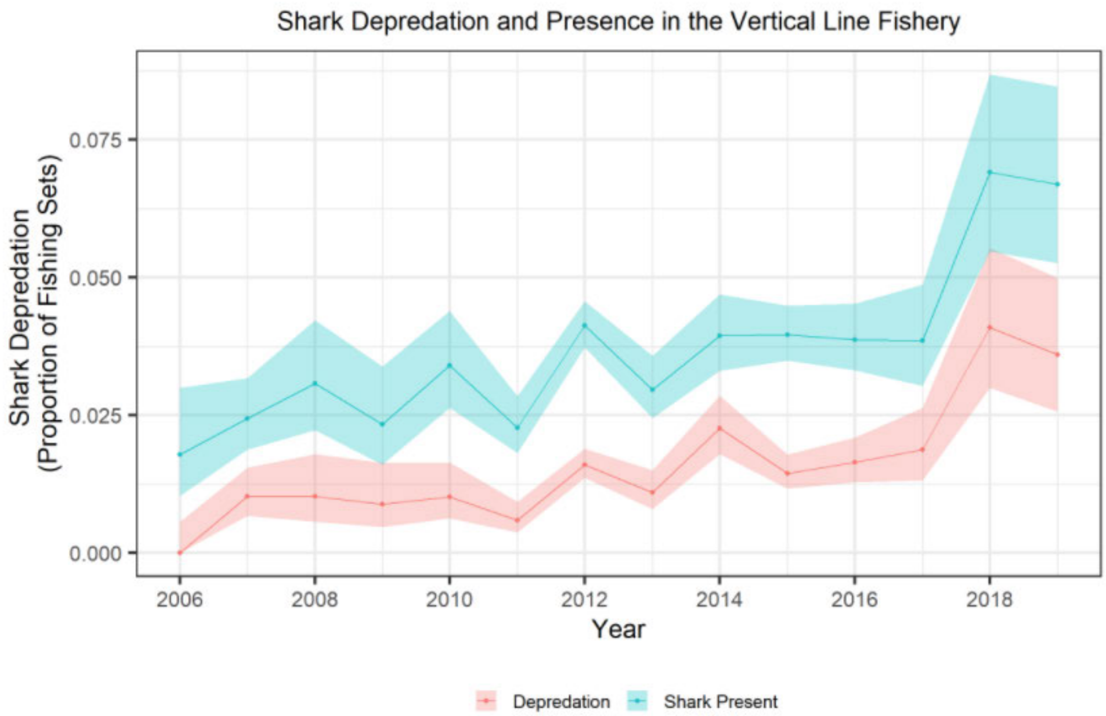


Figure 3: Temporal trends of shark presence and depredation in the GoM vertical longline reef fish fishery from 2006-2020. From Duffin et al. unpublished data.

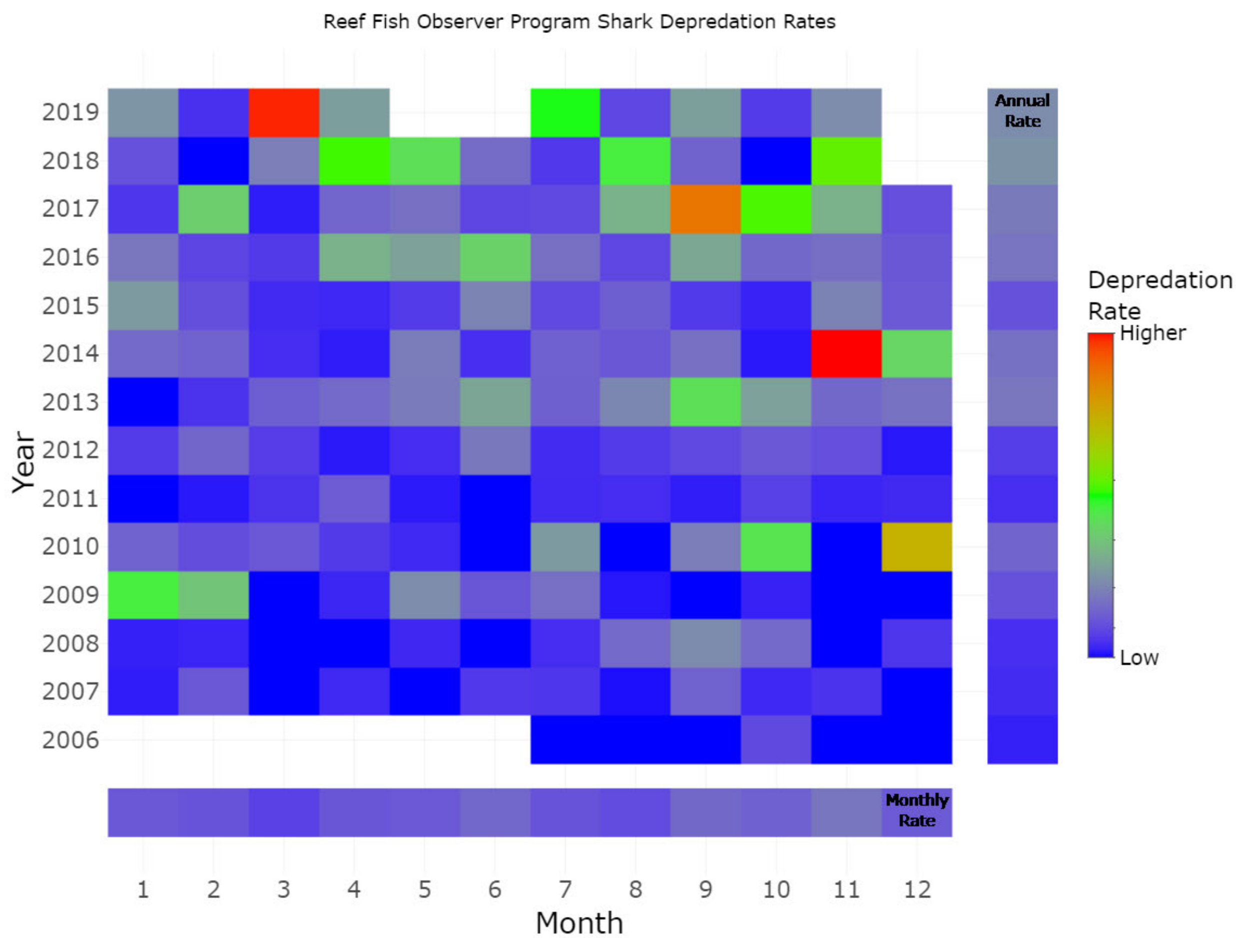


Figure 4: Shark depredation documented by the Reef Fish Observer Program at a monthly time scale from 2006-2019, where warmer colors indicate a higher proportion of depredated sets for each time period. The annual and monthly proportions of sets with depredation are plotted along the y- and x-axis, respectively. From Duffin et al. unpublished data.

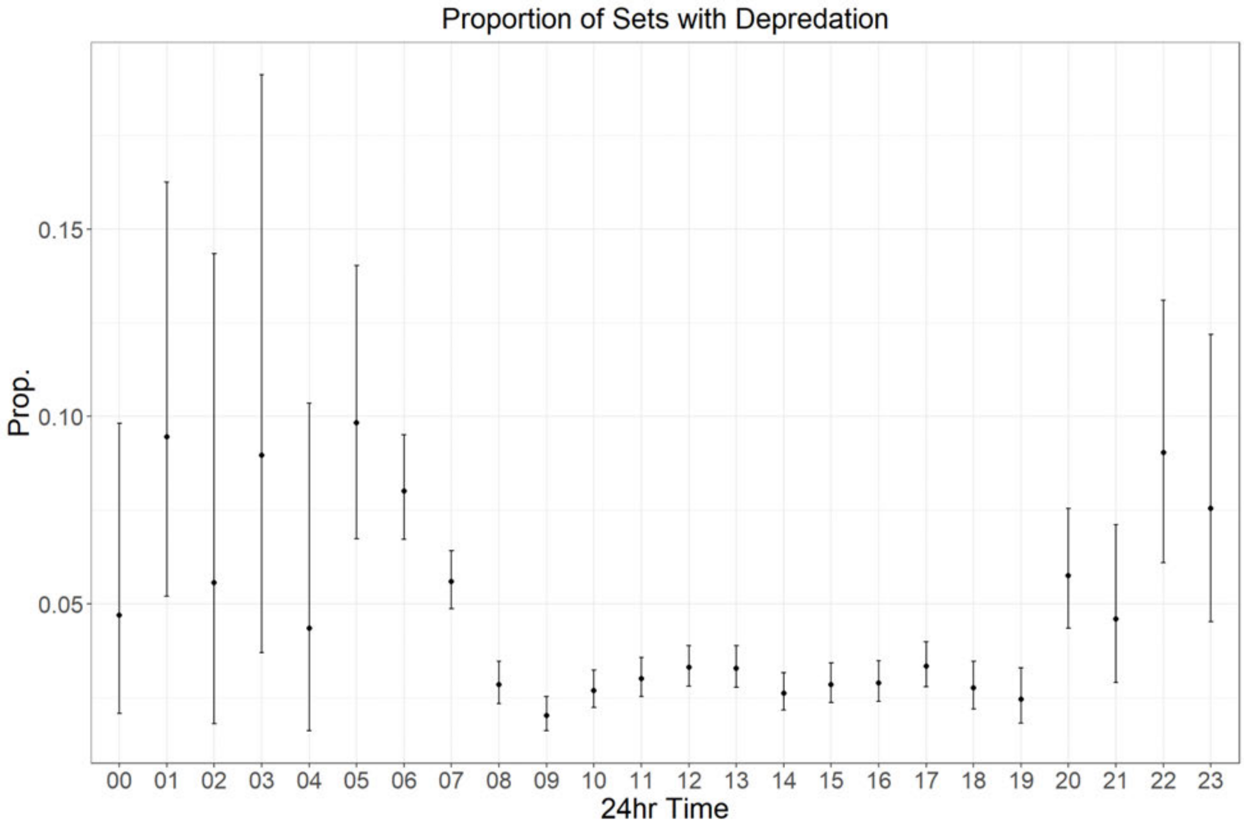


Figure 5: Observed depredation by hour of day, as documented by the Reef Fish Observer Program. From Duffin et al. unpublished data.

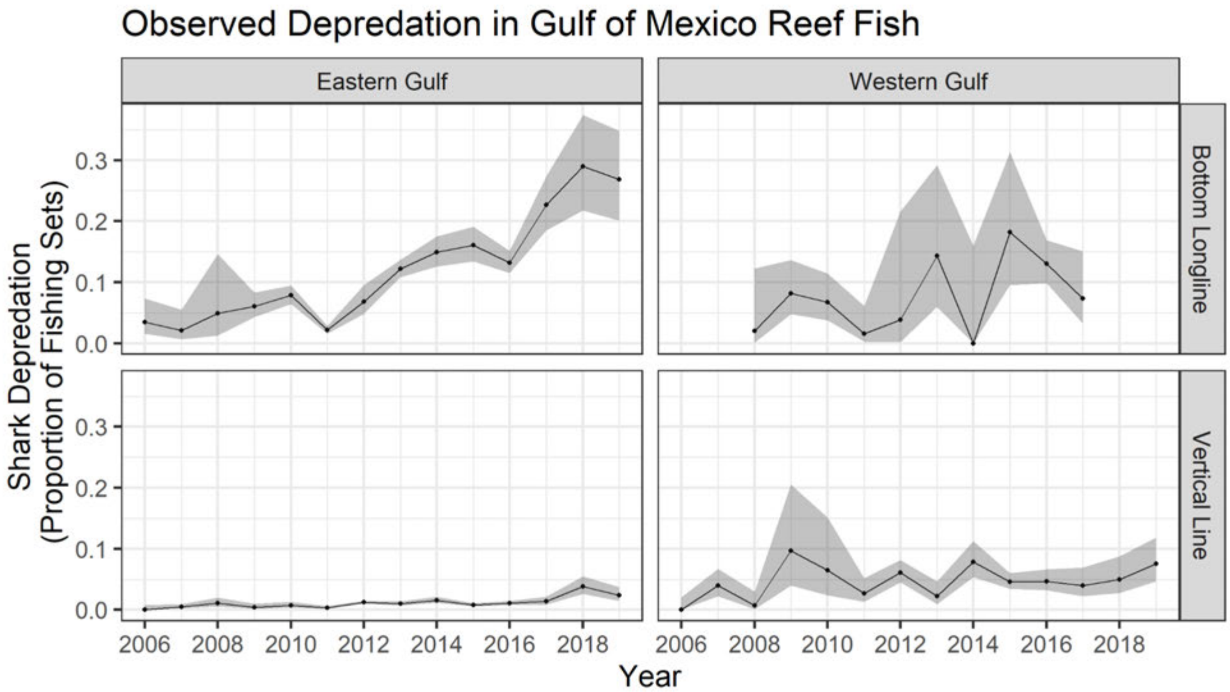


Figure 6: Shark depredation rates (as the proportion of sets with depredation) in the Eastern GoM and Western GoM over time on bottom longline and vertical line gear, as documented by the Reef Fish Observer Program. From Duffin et al. unpublished data.

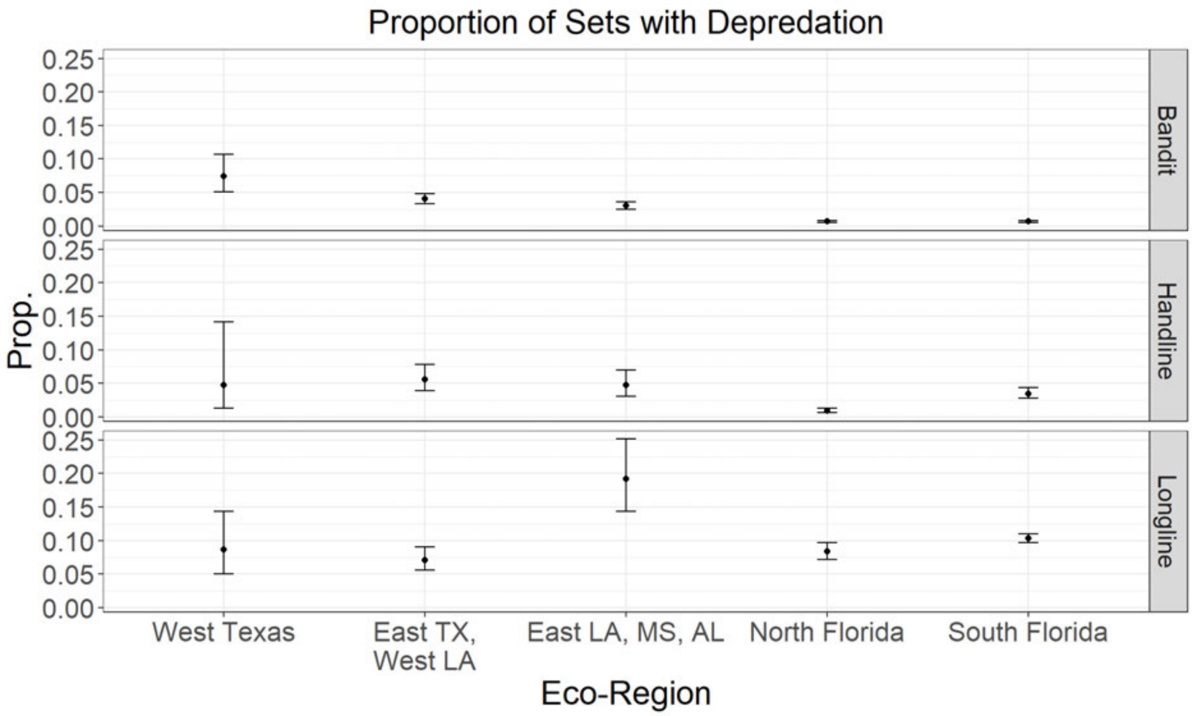


Figure 7: Depredation rate (as the proportion of sets with depredation) for each GoM eco-region on bandit, handline, and longline gear, as documented by the Reef Fish Observer Program. From Duffin et al. unpublished data.

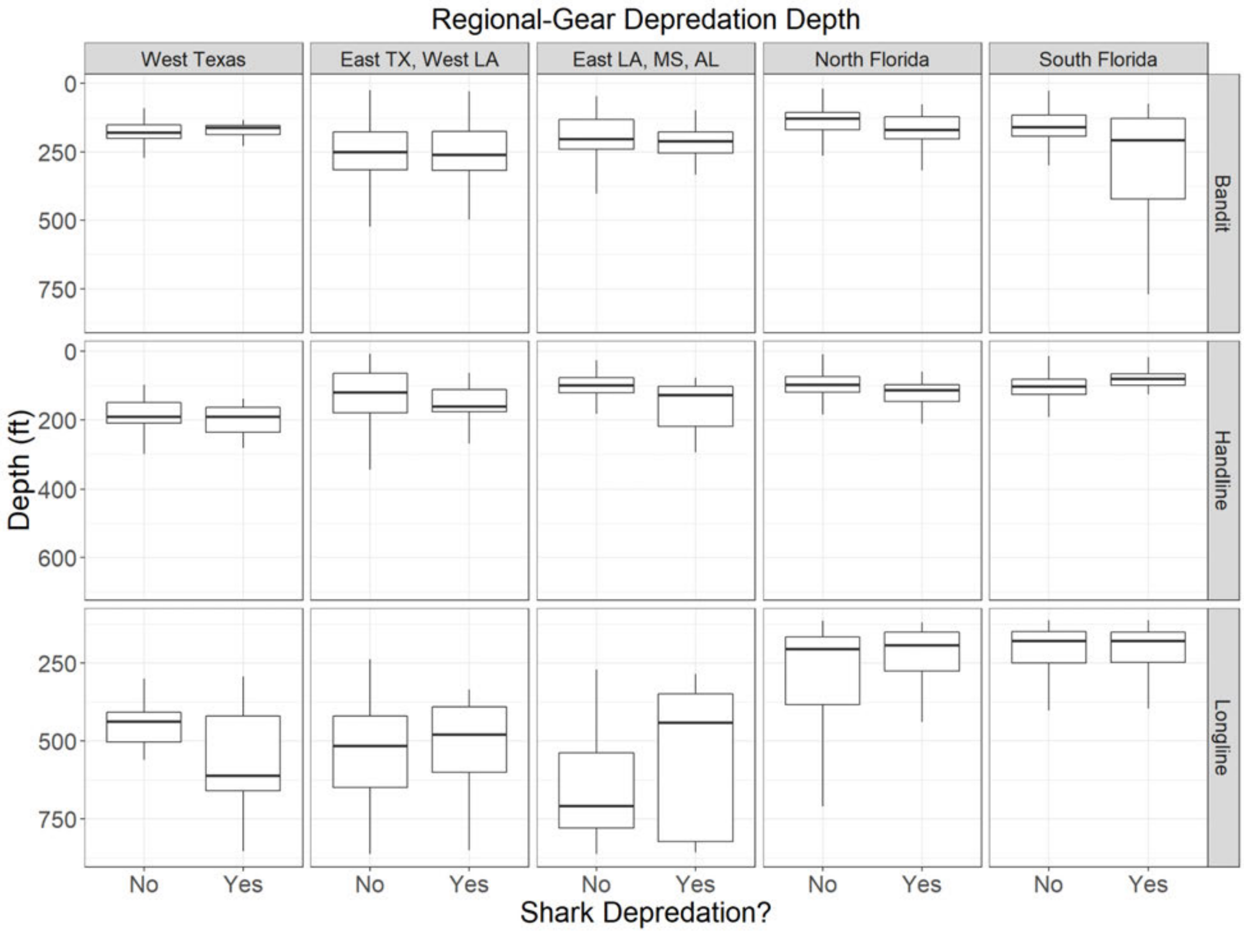


Figure 8: Observed shark depredation by depth across eco-region on bandit, handline, and longline gear, as documented by the Reef Fish Observer Program. From Duffin et al. unpublished data.

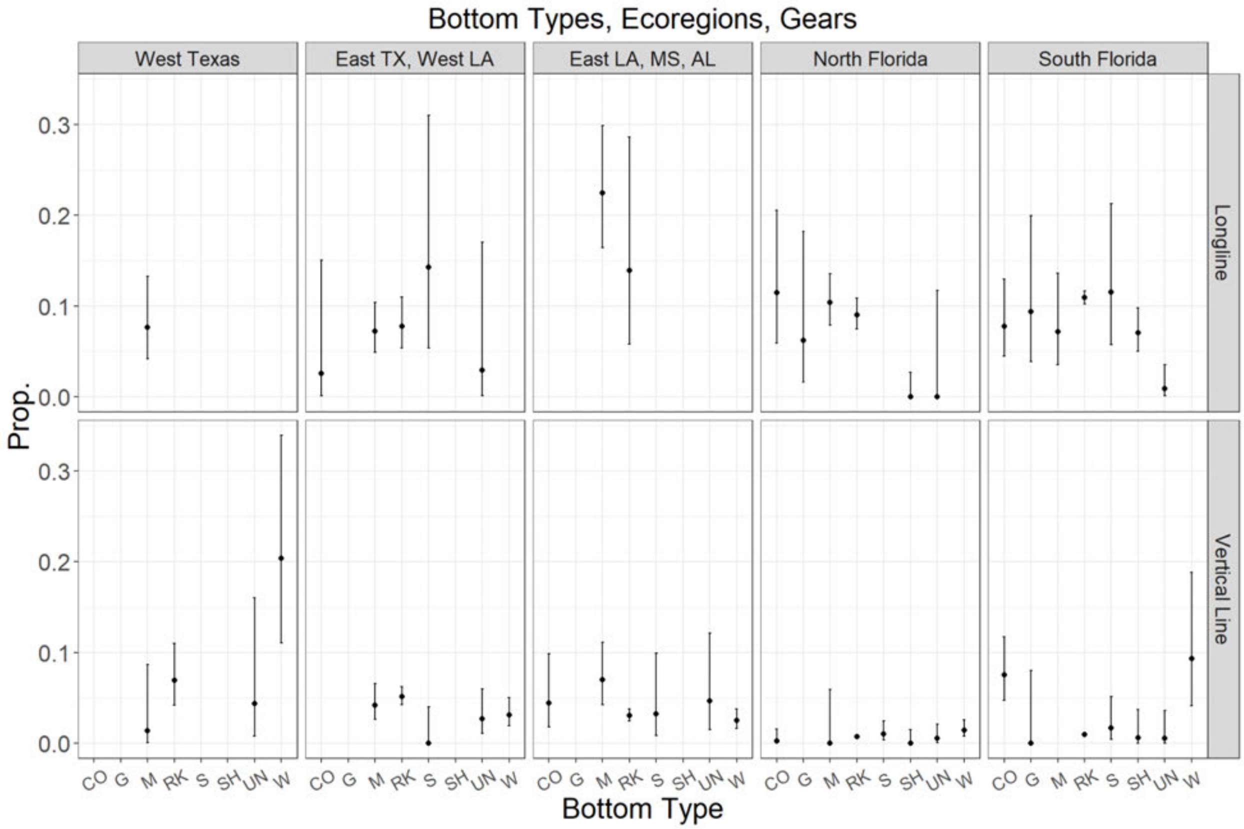


Figure 9: Observed depredation by bottom type across eco-region on longline and vertical line gear, as documented by the Reef Fish Observer Program. Only the most common bottom types are shown; abbreviations are as follows: CO = coral, G = gravel, M = mud, RK = rock, S = sand, SH = shell, UN = undetermined, W = wreck. From Duffin et al. unpublished data.

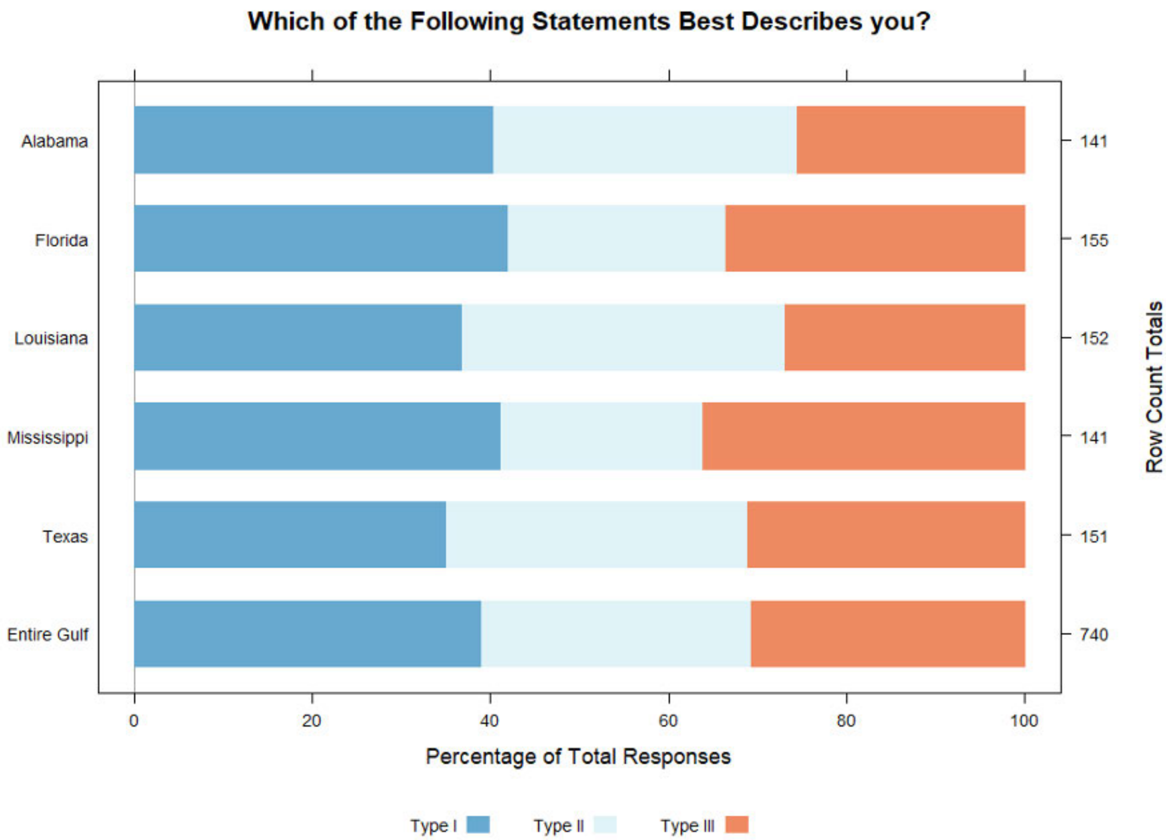


Figure 10: Response to the question, "Which of the following statements best describes you?"

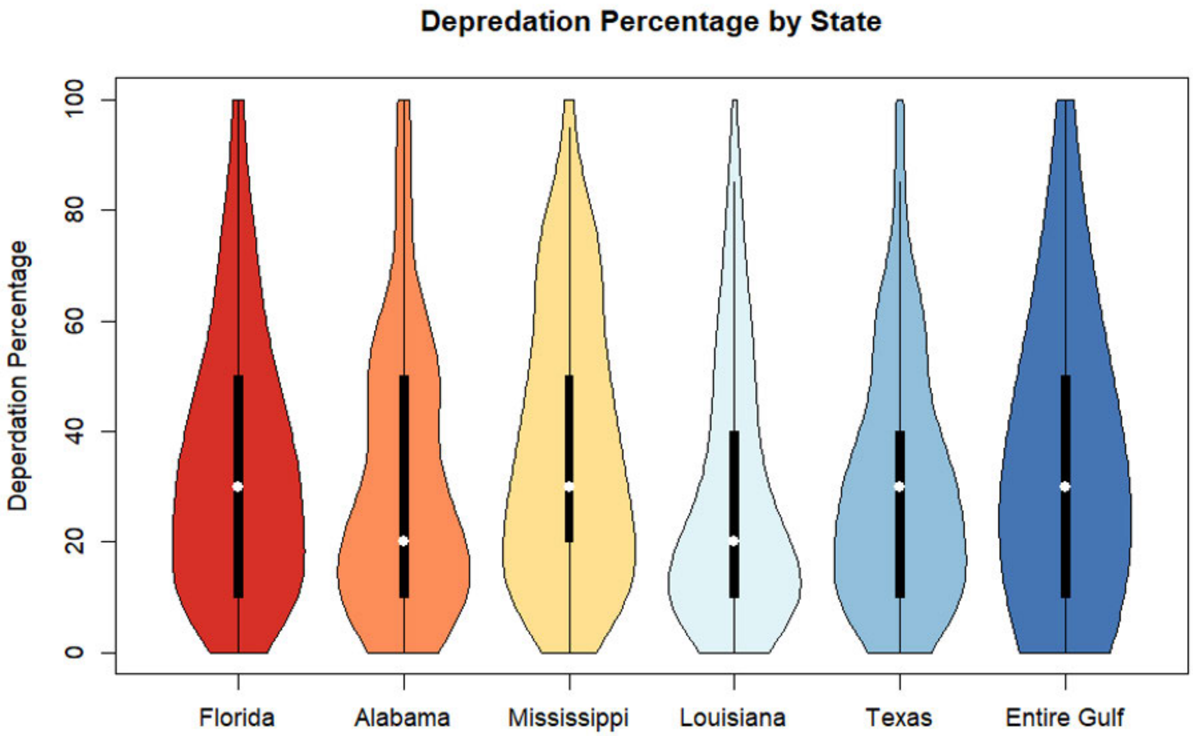


Figure 11: Violin plots of reported depredation percentage. The thick black bar represents the interquartile range, the thin black bar represents the distribution, and the white dot represents the median reported depredation percentage. If the thin black line did not extend the length of the colored shaded region, the distribution beyond that was considered an outlier.

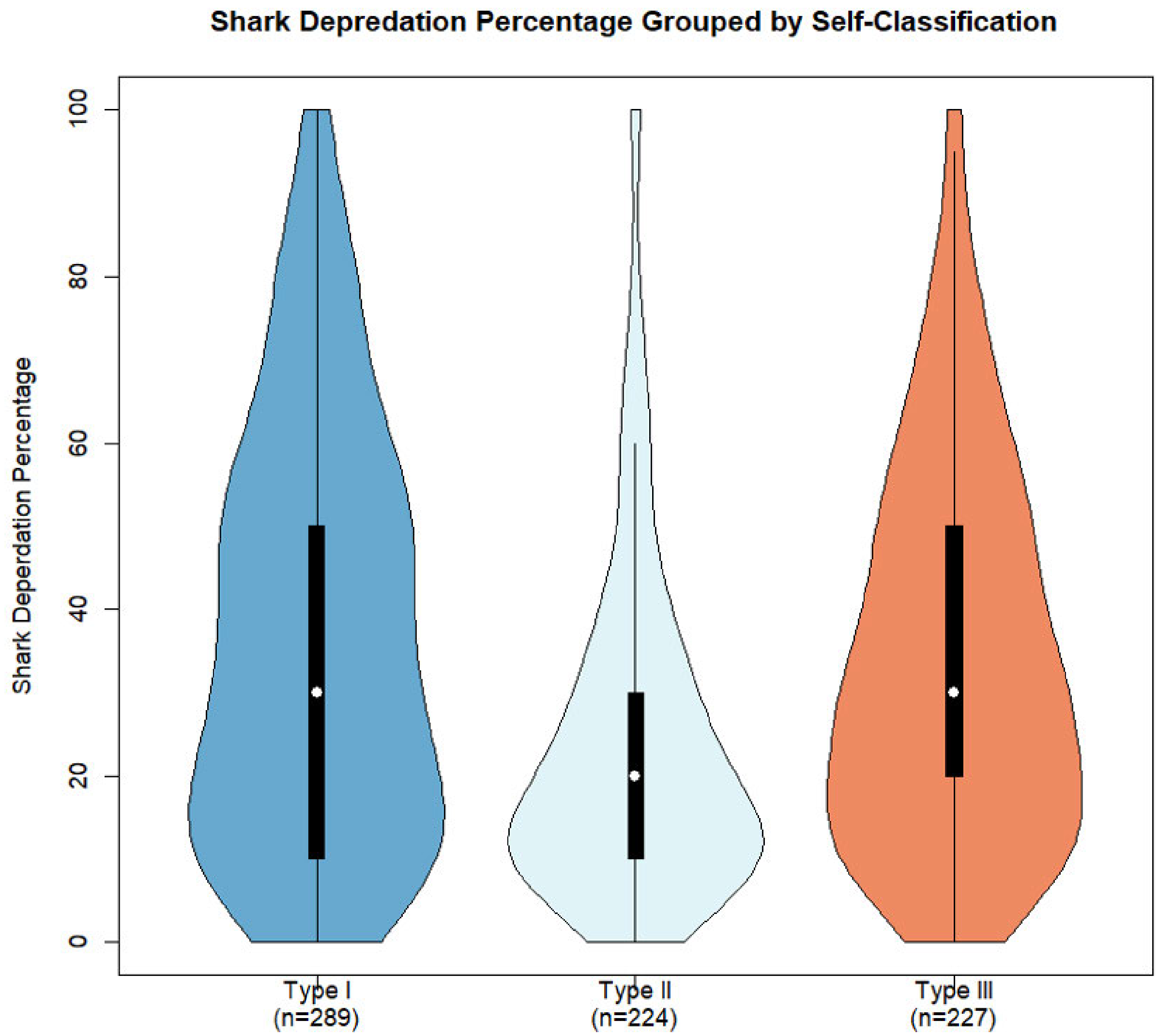


Figure 12: Shark depredation percentage grouped by angler self-classification.

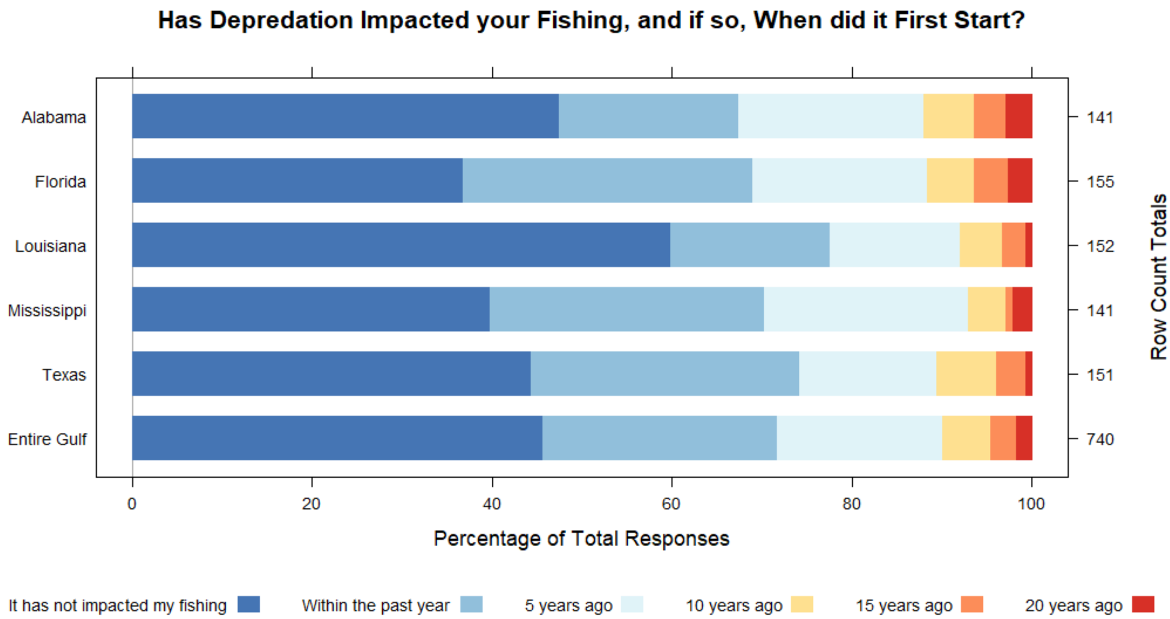


Figure 13: Response to the question, “Has depredation impacted your fishing, and if so, when did it start?”

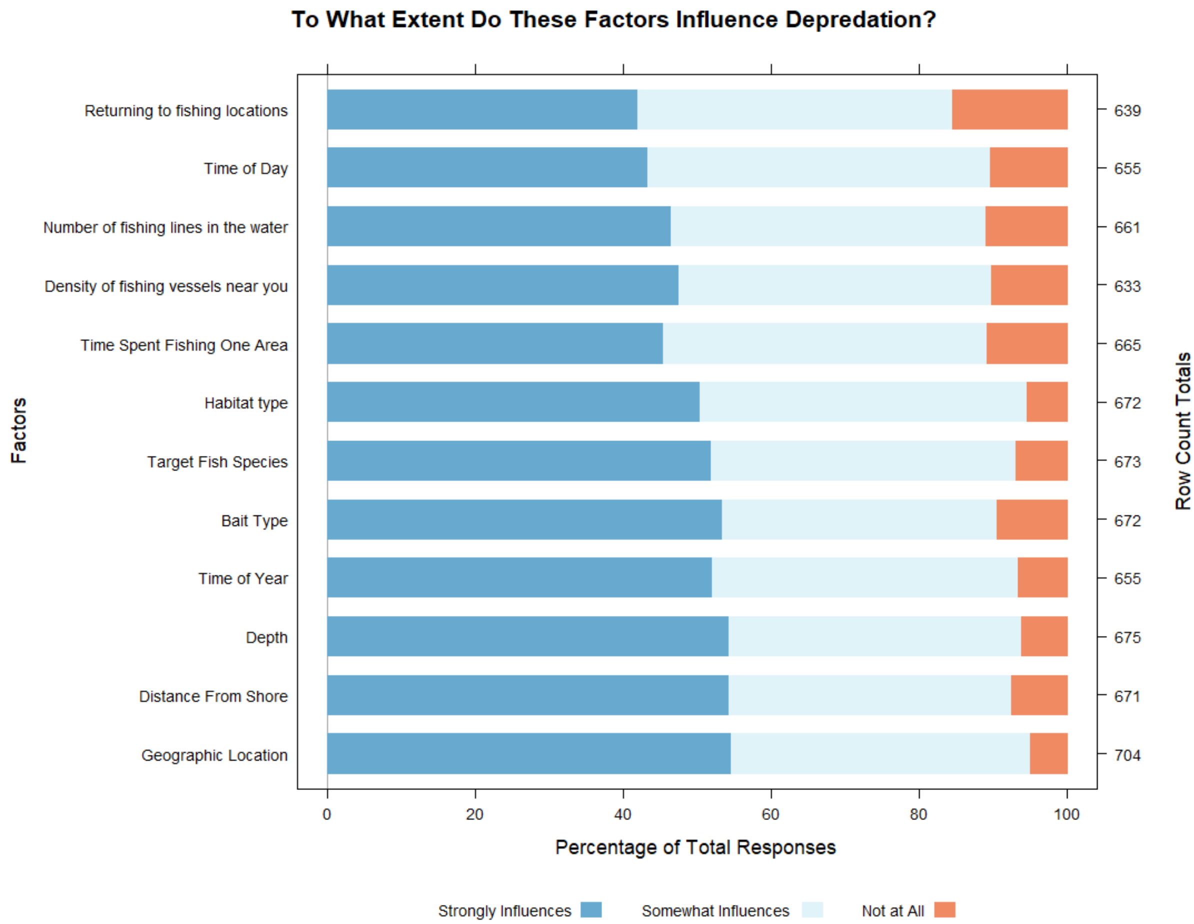


Figure 14: Response to the question, "To what extent do these factors influence depredation?". Dark blue represents "strongly influences," light blue represents "somewhat influences," and orange represents "not at all."

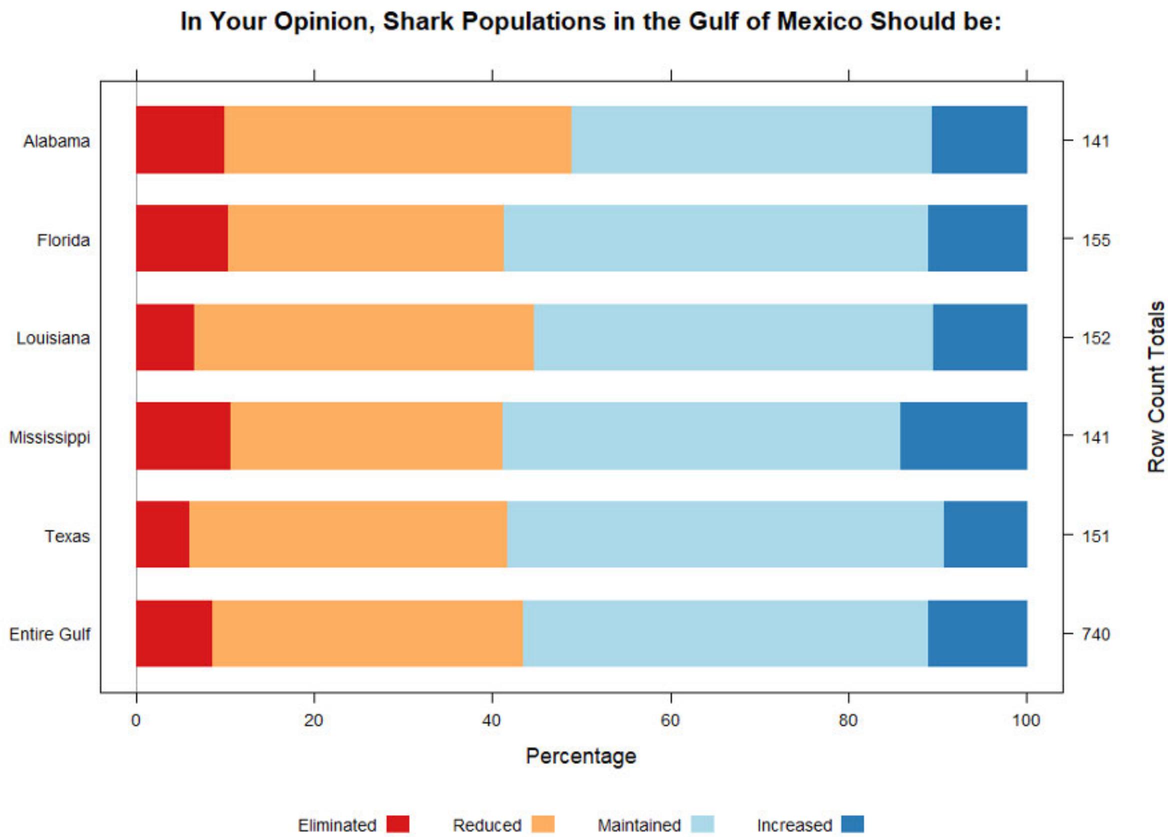


Figure 15: Response to the question, "In your opinion, shark populations in the GoM should be:" by state and the entire GoM. Red represents "eliminated," orange represents "reduced," light blue represents "maintained at current levels," and dark blue represents "increased."

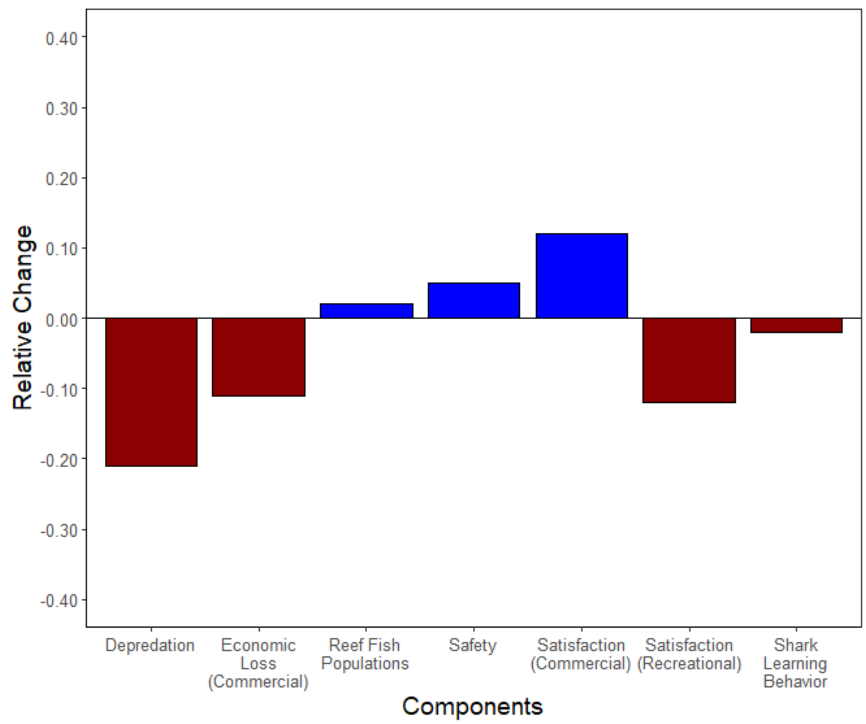


Figure 16: Reef fish populations, safety, and satisfaction (commercial) increased relative to decreases in shark populations and increases in fisheries management based on the Texas community model, while decreases were seen in depredation, economic loss (commercial), satisfaction (recreational), and shark learning behavior.

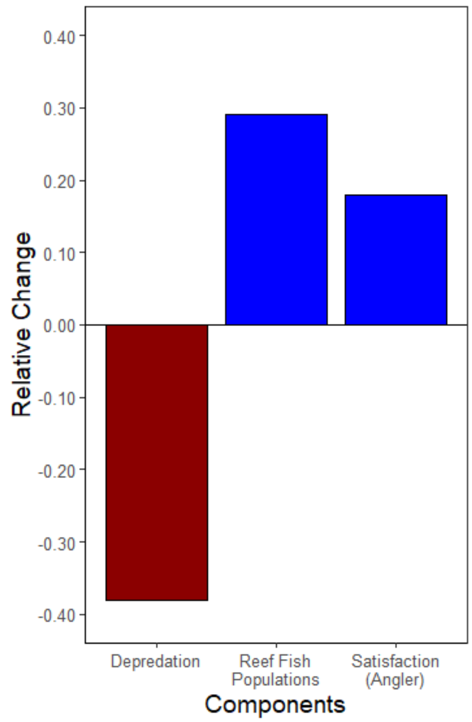


Figure 17: Reef fish populations and satisfaction (angler) increased and depredation decreased relative to decreases in shark populations and increases in fisheries management effectiveness based on the Louisiana community model.

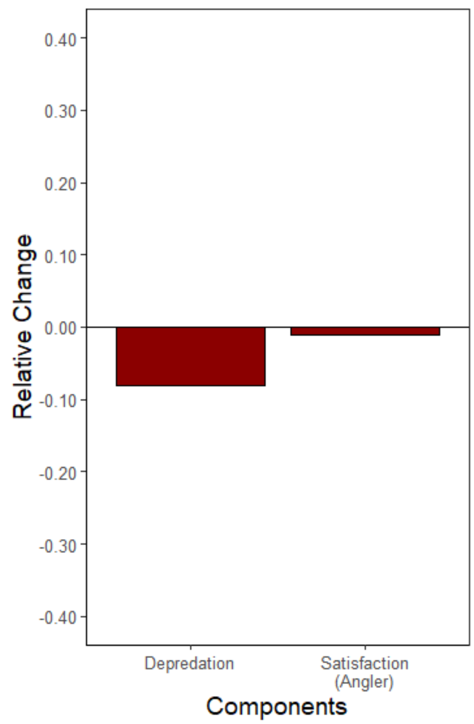


Figure 18: Depredation and satisfaction (angler) both decreased relative to decreases in shark populations and increases in fisheries management effectiveness based on the Mississippi community model.

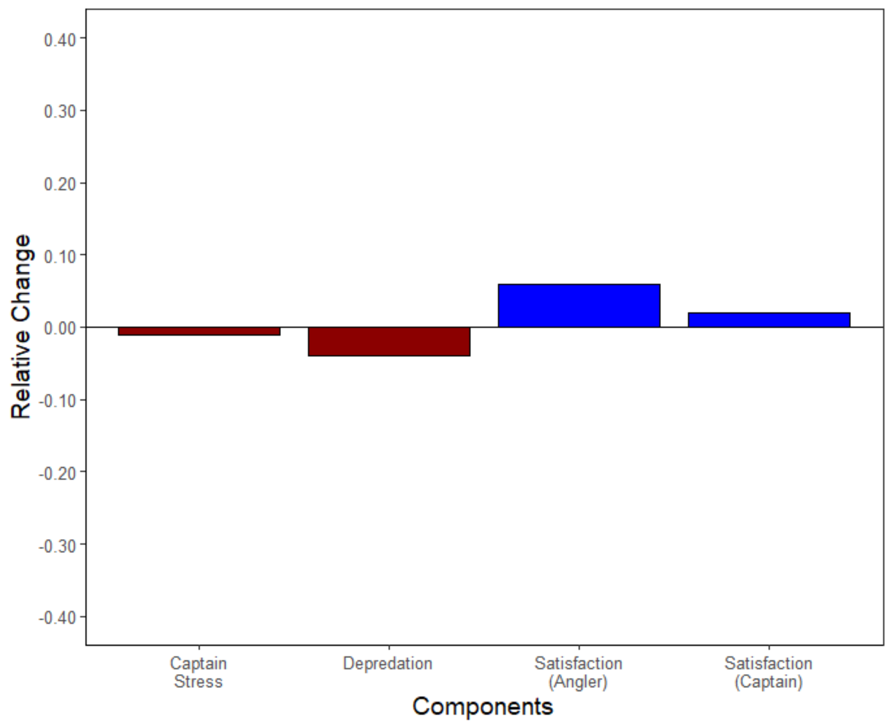


Figure 19: Depredation and captain stress both decreased relative to decreases in shark populations and increases in fisheries management effectiveness based on the Alabama community model, while satisfaction for both anglers and captains increased.

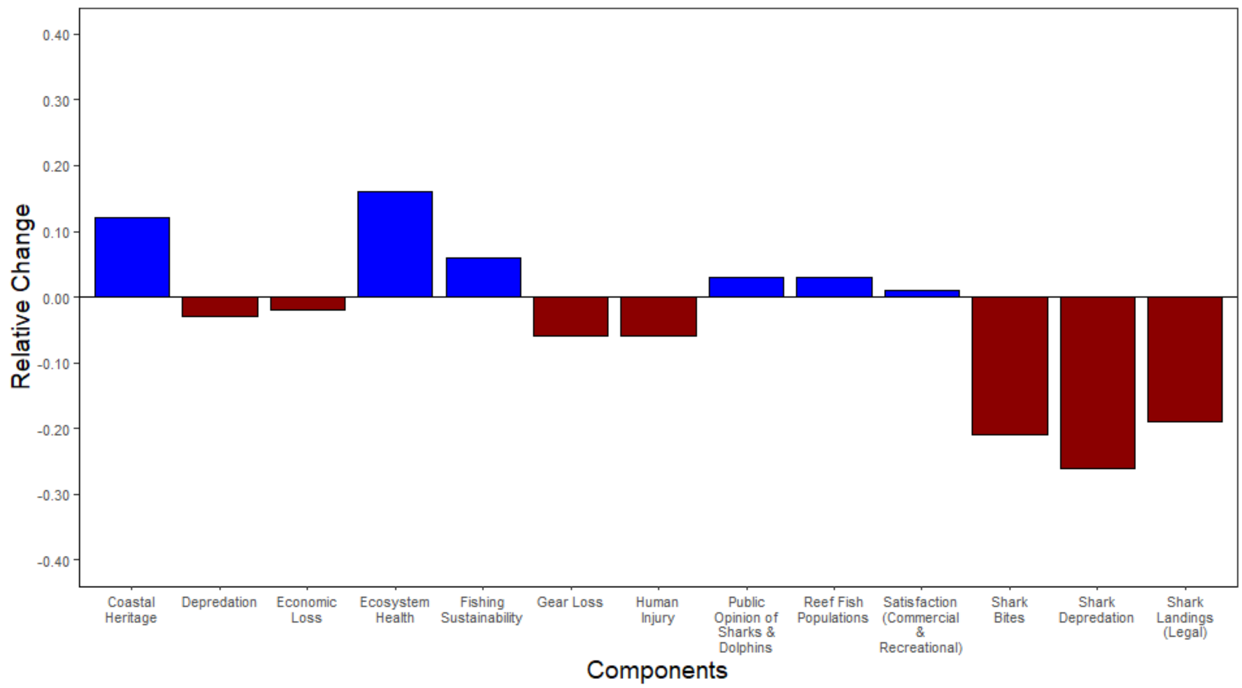


Figure 20: Shark depredation, shark bites, shark landings (legal), gear loss, human injury, depredation, and economic loss all decreased relative to decreases in shark populations and increases in fisheries management effectiveness based on the Florida community model, while ecosystem health, coastal heritage, fishing sustainability, public opinion of sharks and dolphins, reef fish populations, and satisfaction (commercial and recreational) all increased.

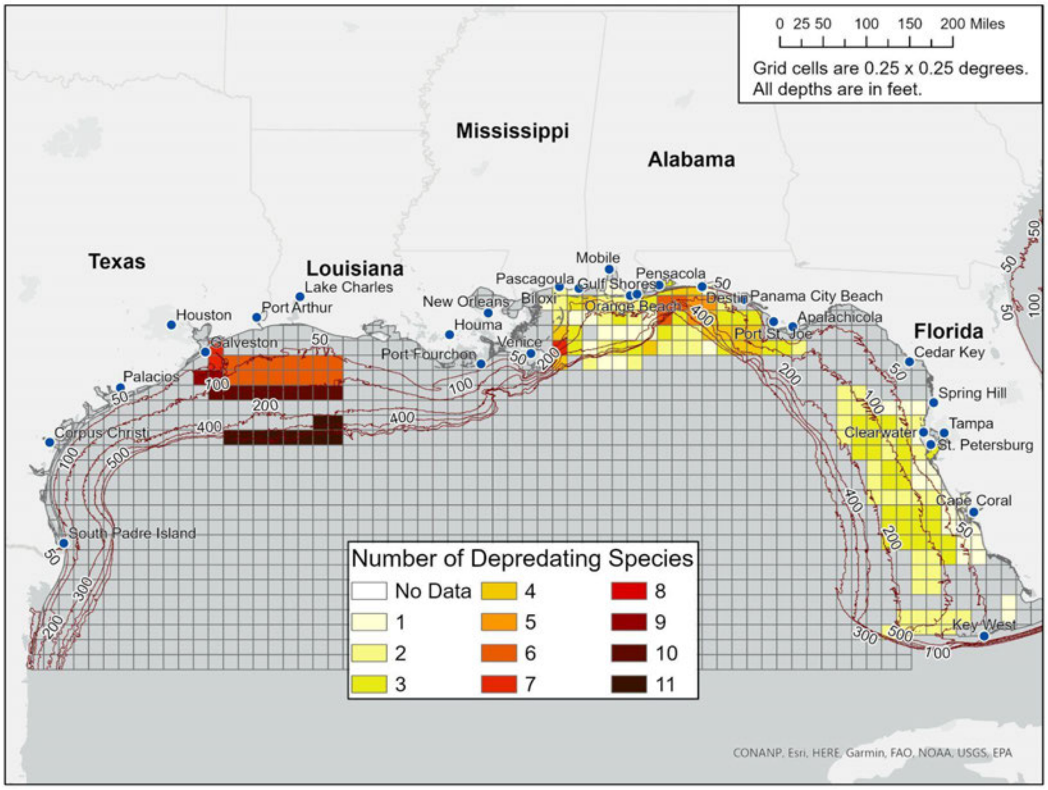


Figure 21: Reef fish depredation hot-spots throughout the GoM.

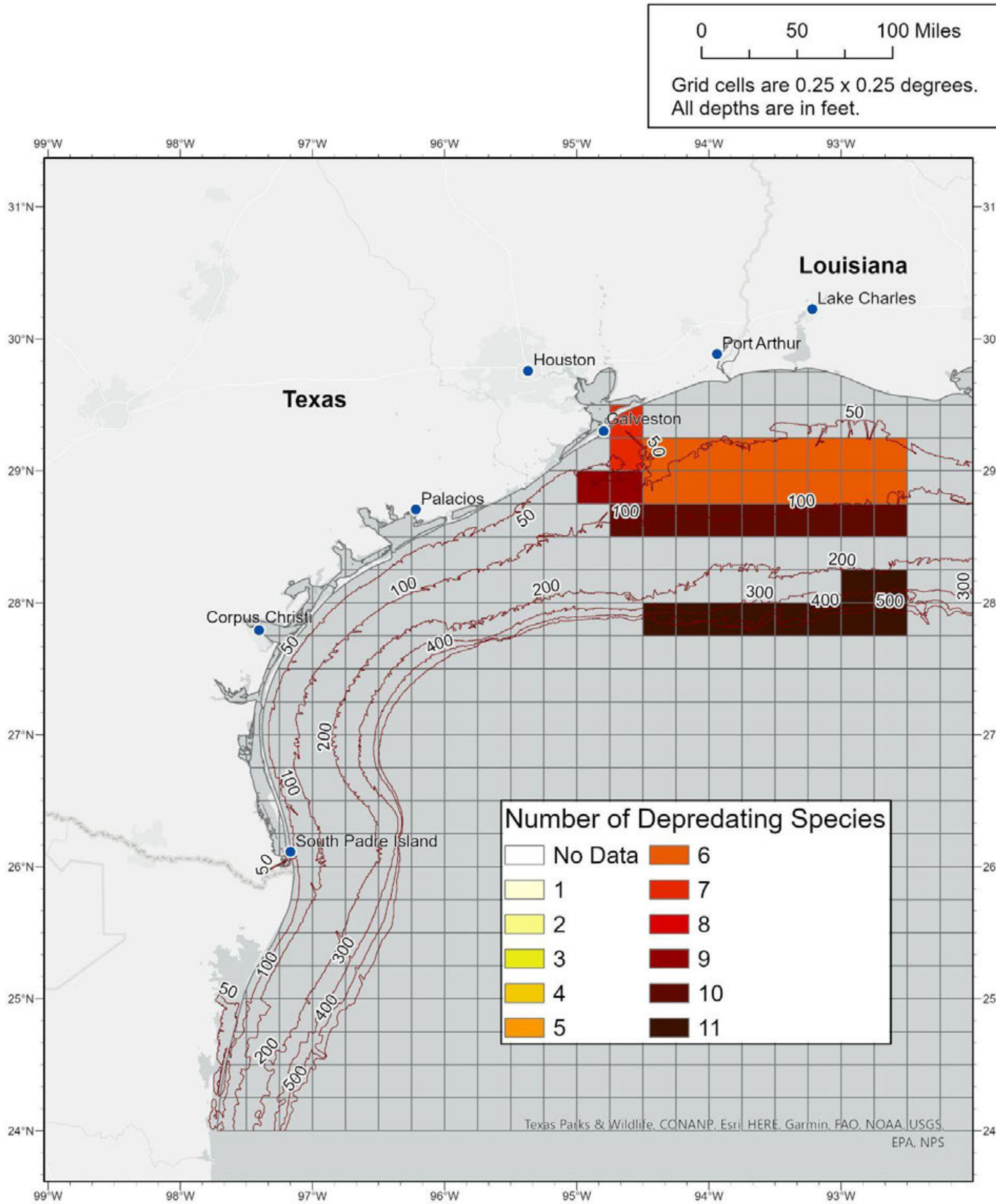


Figure 22: Reef fish depredation hot-spot map for Texas developed from breakout group discussion.

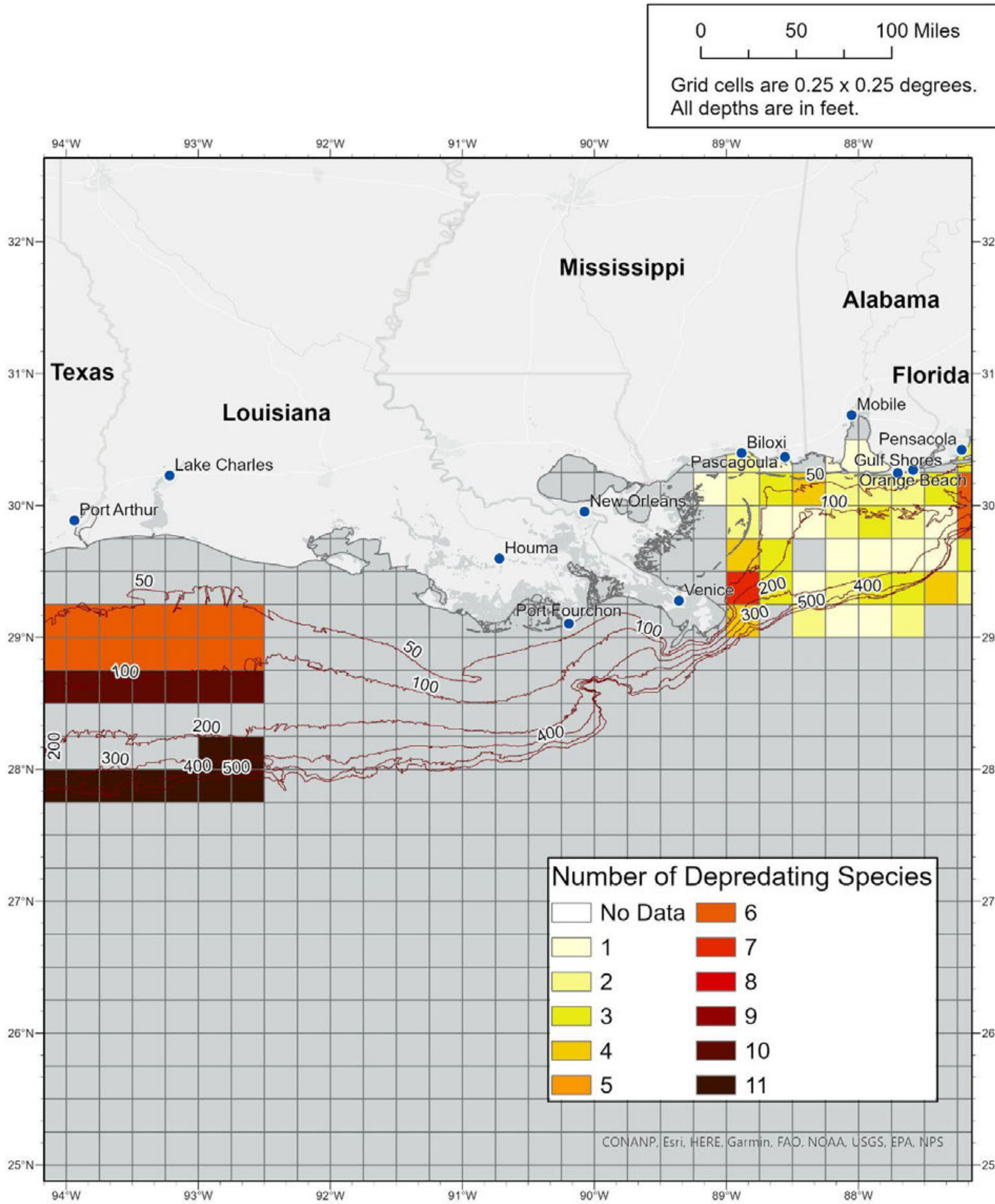


Figure 23: Reef fish depredation hot-spot map for Louisiana, Mississippi, and Alabama developed from breakout group discussion.

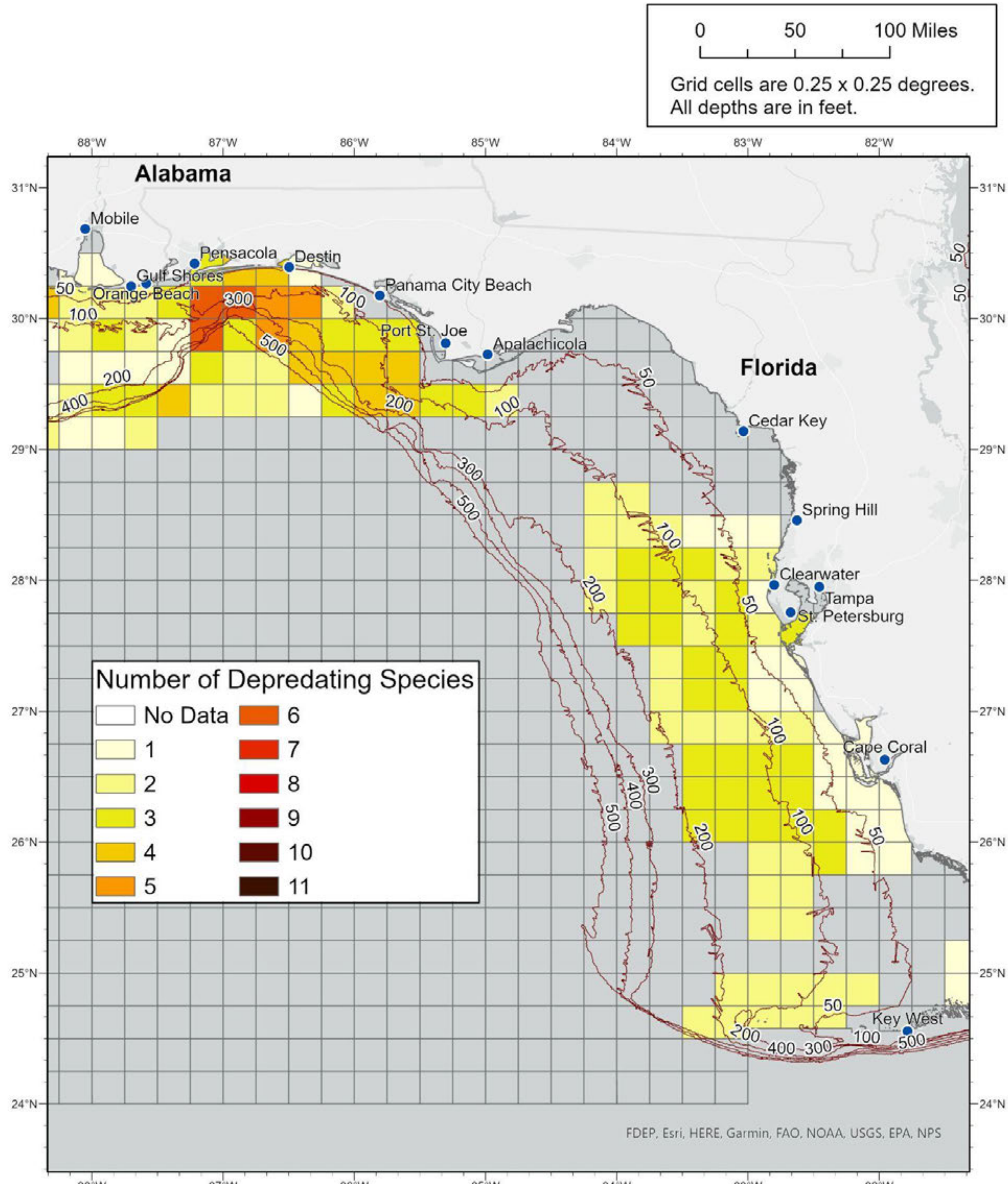


Figure 24: Reef fish depredation hot-spot map for the West coast of Florida developed from breakout group discussion.

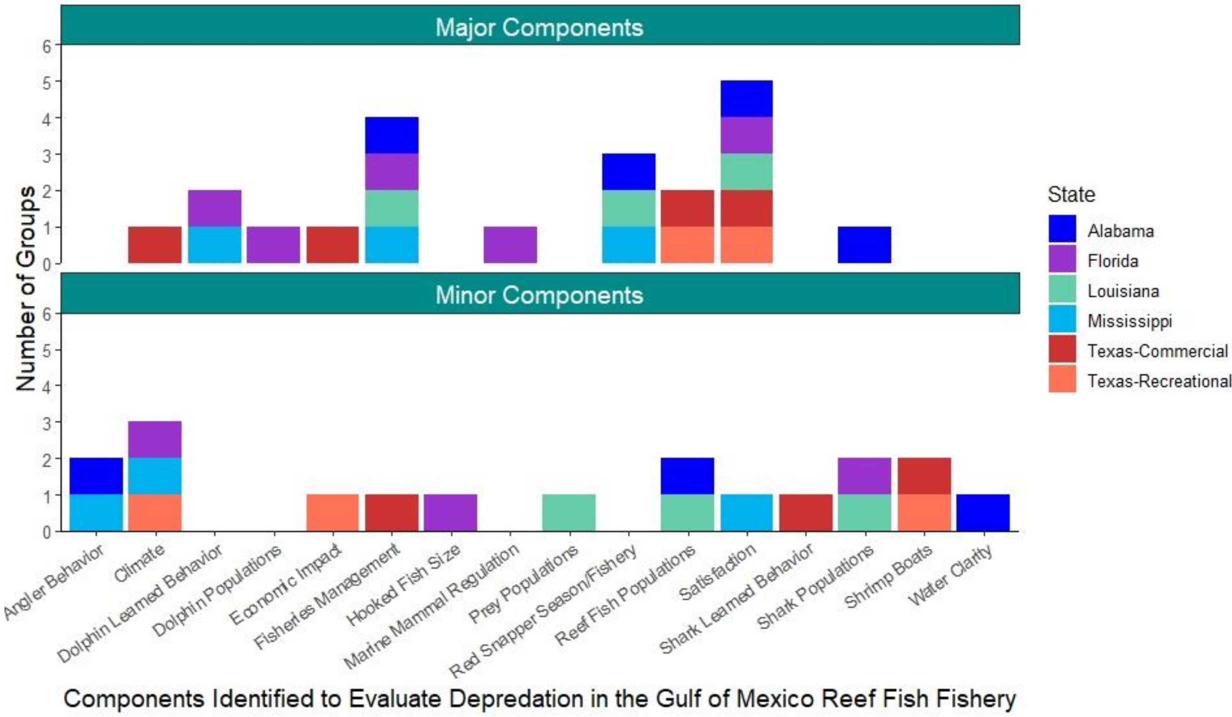


Figure 25: Distribution of major and minor components identified during group and breakout discussion at the depredation workshop identified by regions (State).

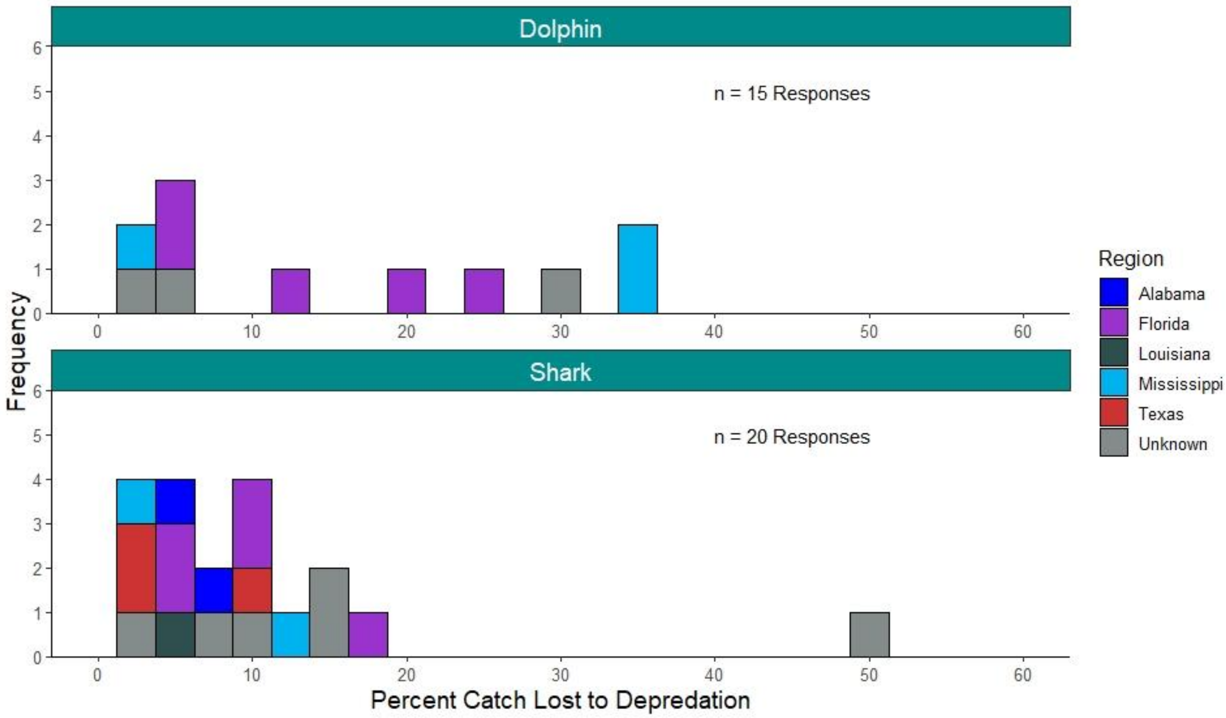


Figure 26: Frequency and distribution of responses regarding the percentage of stakeholder catch lost to common depredating species in the GoM.

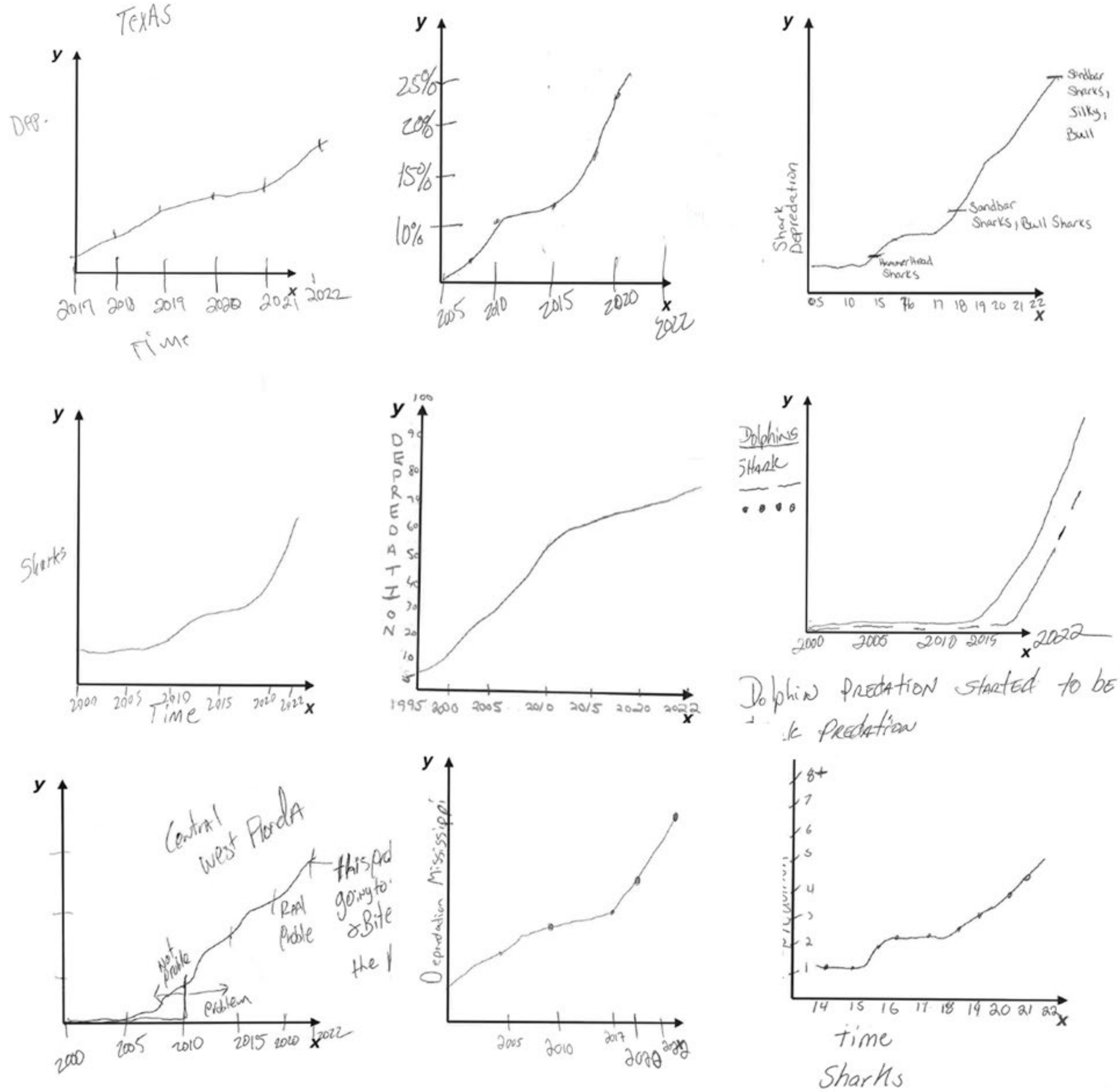


Figure 27: A selection of the individual time-series plots generated during the stakeholder workshop.

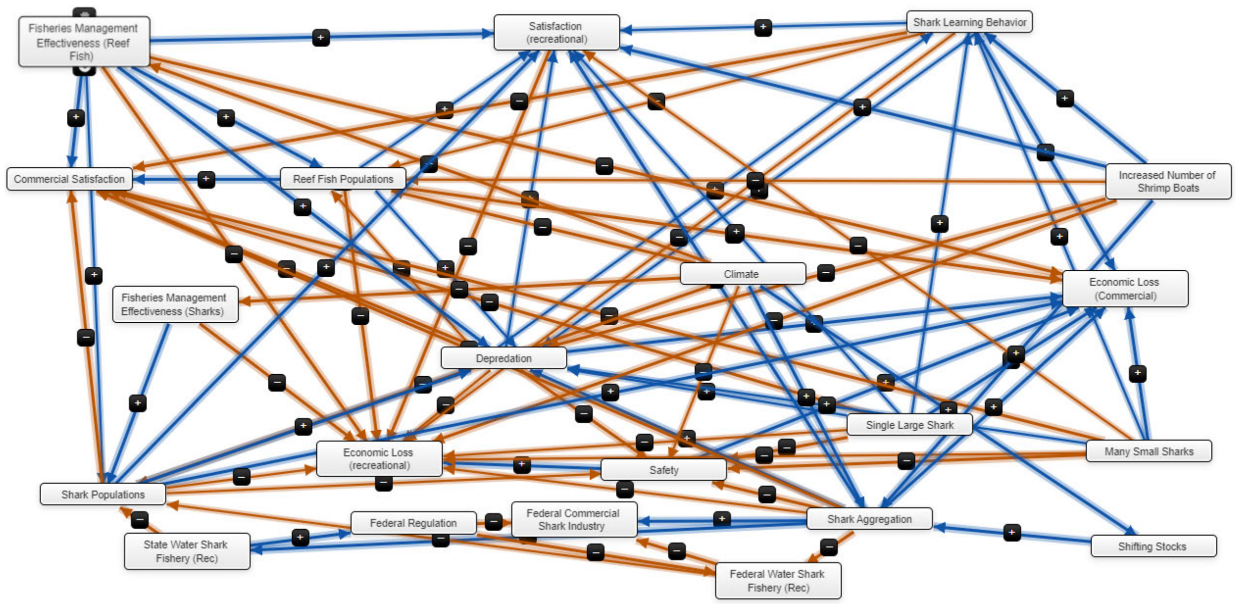


Figure 28: Texas community model developed in *Mental Modeler* based on breakout group discussion. Depredation drivers include climate, the increased number of shrimp boats, and the composition of shark depredation interactions (single large shark, many small sharks).

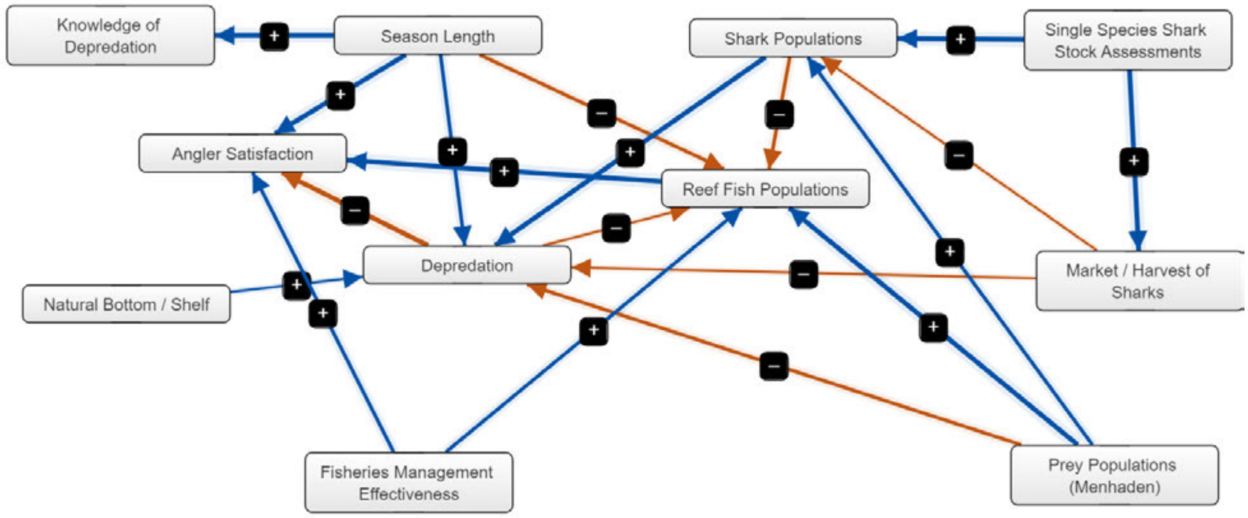


Figure 29: Louisiana community model developed in *Mental Modeler* based on breakout group discussion. Depredation drivers include season lengths, prey populations (menhaden), single species shark stock assessments, and fisheries management effectiveness.

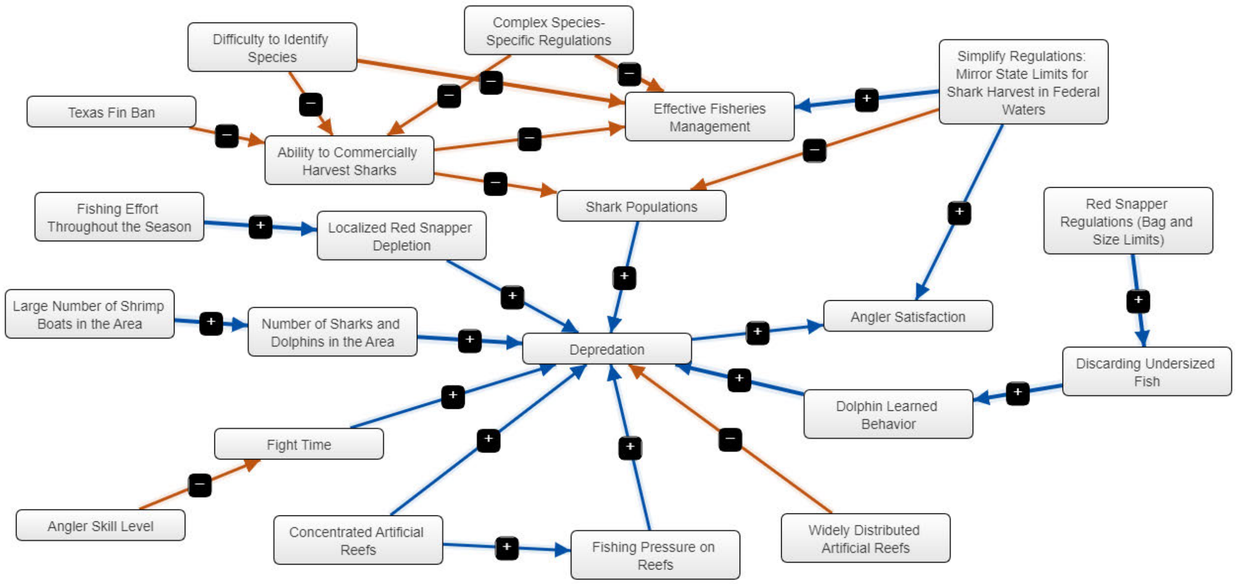


Figure 30: Mississippi community model created in *Mental Modeler* based on breakout group discussion. Depredation drivers include mirroring the state limits for shark harvest in federal waters, fishing effort throughout the season, red snapper size and bag limits, difficulty to identify species, the increased number of shrimp boats, and concentrated artificial reefs.

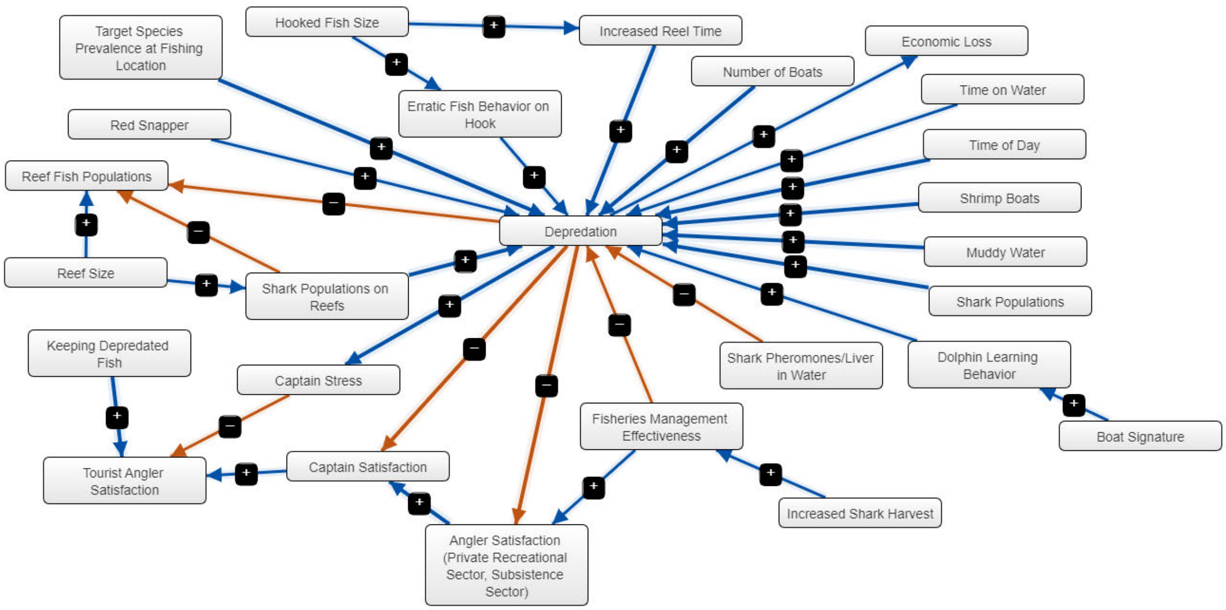


Figure 31: Alabama community model created in *Mental Modeler* based on breakout group discussion. Depredation drivers included the number of boats, hooked fish size, shark populations, and water clarity.

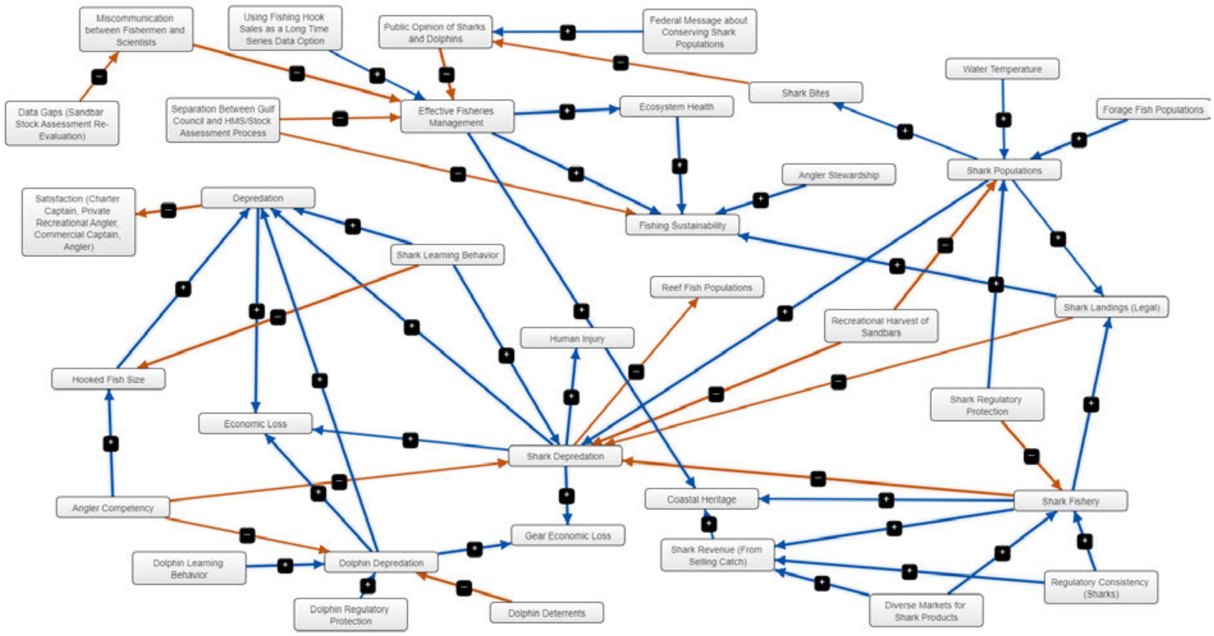


Figure 32: Florida community model created in *Mental Modeler* based on breakout group discussion. Depredation drivers included shark learned behavior, regulatory consistency, diverse markets for shark products, and angler competency.

6. References

Boas TC, Christenson DP, Glick DM. 2020. Recruiting large online samples in the United States and India: Facebook, Mechanical Turk, and Qualtrics. Political Science Research and Methods 8(2):232-50.

Coit J, Spinrad RW. 2022. Interactions between bottlenose dolphins and sharks and commercial, for-hire, and private recreational fisheries in the Gulf of Mexico and South Atlantic. Report to Congress. Available here.

Consolidated Appropriations Act (Public Law 116-260). 2021. Available here.

Drymon M, Osowski A, Jefferson A, Anderson A, McAree D, Scyphers S, Prasky E, Swinea S, Gibbs S, Karnauskas M, Gervasi C. 2022. Co-producing a shared characterization of depredation in the Gulf of Mexico reef fish fishery: 2022 workshop summary report. SEDAR74-DW-32. SEDAR, North Charleston, SC. 25 pp.

Drymon JM, Cooper PT, Powers SP, Miller MM, Magnuson S, Krell E, Bird C. 2019. Genetic identification of species responsible for depredation in commercial and recreational fisheries. North American Journal of Fisheries Management 39(3):524-534.

Gervasi C, McPherson M, Karnauskas M. 2022. System dynamics of red snapper populations in the Gulf of Mexico to support ecosystem considerations in the assessment and management process. SEDAR74-DW-16. SEDAR, North Charleston, SC. 21 pp. Available here.

Gilman E, Clarke S, Brothers N, Alfaro-Shigueto J, Mandelman J, Mangel J, Petersen S, Piovano S, Thomson N, Dalzell P, Donoso M, Goren M, Werner T. 2008. Shark interactions in pelagic longline fisheries. Marine Policy 32(1):1-18.

Gray SA, Gray S, Cox L, Henly-Shepard S. 2013. Mental Modeler: a fuzzy-logic cognitive mapping tool for adaptive learning management. In 2013 46th Hawaii International Conference on System Sciences, pp. 956-973.

Gray SA, Chan A, Clark D, Jordan R. 2012. Modeling the integration of stakeholder knowledge in social-ecological decision-making: benefits and limitations to knowledge diversity. Ecological Modelling 229:88-96.

Hanselman DH, Pyper BJ, Peterson MJ. 2018. Sperm whale depredation on longline surveys and implications for the assessment of Alaska sablefish. Fisheries Research 200:75-83.

Harlan SL, Sarango MJ, Mack EA, Stephens TA. 2019. A survey-based assessment of perceived flood risk in urban areas of the United States. Anthropocene 28:100217.

Miller CA, Guidry JPD, Dahman B, Thomson MD. 2020. A tale of two diverse Qualtrics samples: information for online survey researchers." Cancer Epidemiology, Biomarkers & Prevention 29(4):731-735.

Mitchell JD, Drymon JM, Vardon J, Coulson PG, Simpfendorfer CA, Scyphers SB, Kajiura SM, Hoel K, Williams S, Ryan KL, Barnett A, Heupel MR, Chin A, Navarro M, Langlois T, Ajemian MJ, Gilman E, Prasky E, Jackson G. 2022. Shark depredation: future directions in research and management. Reviews in Fish Biology and Fisheries.

Needham MD, Sprouse LJ, Grimm KE. 2009. Testing a self-classification measure of recreation specialization among anglers. Human Dimensions of Wildlife 14(6):448-455.

Powell JR, Wells RS. 2011. Recreational fishing depredation and associated behaviors involving common bottlenose dolphins (*Tursiops truncatus*) in Sarasota Bay, Florida. Marine Mammal Science 27(1):111-129.

R Core Team. 2022. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing.

Scyphers S, Drymon J, Furman K, Conley E, Niwa Y, Jefferson A, Stunz G. 2021. Understanding and enhancing angler satisfaction with fisheries management: insights from the “Great Red Snapper Count”. North American Journal of Fisheries Management 41:559-569.

SEDAR. 2020. SEDAR 74 Gulf of Mexico red snapper research track terms of reference. Available here.

Shideler GS, Carter DW, Liese C, Serafy JE. 2015. Lifting the goliath grouper harvest ban: angler perspectives and willingness to pay. Fisheries Research 161:156-165.

Streich MK, Ajemian MJ, Wetz JJ, Stunz GW. 2018. Habitat-specific performance of vertical line gear in the western Gulf of Mexico: a comparison between artificial and natural habitats using a paired video approach. Fisheries Research 204:16-25.

Zack ES, Kennedy J, Long JS. 2019. Can nonprobability samples be used for social science research? A cautionary tale. Survey Research Methods 13(2):215-27.

7. Appendices

Appendix A: Workshop Agenda

Co-Producing a Shared Characterization of Depredation in the Gulf of Mexico Reef Fish Fishery

Monday, April 4th, 2022, 9am-5pm
The Lodge at Gulf State Park
21196 East Beach Blvd.
Gulf Shores, AL 36542
(251) 540-4000

Workshop Purpose:
To co-produce a shared characterization of depredation in the Gulf of Mexico reef fish fishery through discussion and reciprocal learning among researchers, resource managers, and stakeholders.

Workshop Objectives:
1. Present the reef fish depredation data synthesis and the core concepts of the mental models from the reef fish depredation survey to stakeholders.
2. Allow stakeholders to develop, assess, discuss, and refine regional mental models.
3. Identify additional knowledge gaps concerning Gulf of Mexico reef fish depredation.

Workshop Agenda:

Time	Topic
9:00-9:40am	**Session 1**: Welcome and introductions
9:40-10:00am	**Session 2**: Characterizing the problem: Project phases and workshop goals
10:00-10:15am	Break
10:15-12:00pm	**Session 3**: Stakeholder engagement: Developing regional reef fish depredation mental models and contributing to the participatory mapping process
12:00-2:00pm	Lunch (offsite)
2:00-3:30pm	**Session 4**: Stakeholder engagement: Managing depredation, assessing hypothesized impacts, and discussing research recommendations and subsequent actions
3:30-4:00pm	Break
4:00-4:30pm	**Session 5**: Workshop summary and concluding thoughts
4:30-5:00pm	**Session 6**: Exit surveys and depart

Appendix B: Workshop Attendees

Project Team

J. Marcus Drymon, *Lead investigator*, Mississippi State University and Mississippi-Alabama Sea Grant Consortium
Angela Collins, *Co-investigator*, Florida Sea Grant
Bryan Fluech, *Co-investigator*, Georgia Sea Grant
Steven Gray, *Co-investigator*, Michigan State University
Mandy Karnauskas, *Co-natural resource manager*, NOAA Fisheries
Steven Scyphers, *Co-investigator*, Northeastern University
Alena Anderson, Mississippi State University
Carissa Gervasi, NOAA Fisheries
Sarah Gibbs, Northeastern University
Danielle McAree, Mississippi State University
Ana Osowski, Mississippi State University and Mississippi-Alabama Sea Grant Consortium
Evan Prasky, Northeastern University
Savannah Swinea, Northeastern University
Laura Picariello, Texas Sea Grant
Butch Ayala, Florida Fish and Wildlife Conservation Commission

Reef Fish Fishery Representatives

Texas:
Louisiana:
Mississippi:
Alabama:
Florida:

Appendix C: Workshop Notes

Depredation Trends Captured from Group Discussion

Temporal

- Some stakeholders agreed with a finding from the data synthesis portion of this project (Phase I) that depredation started increasing dramatically in 2017.
  - GoM states have been able to set their own red snapper seasons since 2017, so there may be more private recreational fishing activity than in the past for each individual GoM state.
- Some stakeholders strongly feel the large increase in depredation over the last few years cannot adequately be captured in a graph because it is simply too much of an increase.
- Anglers could target more fish species historically than they can today.
  - Currently, all anglers are competing to harvest only a few species, small numbers of those species, and (in some cases) only within a few days every year.
  - Instances of depredation are increasing, but personal costs are increasing at a faster rate.
    - Personal costs include: increased time traveling to multiple sites to catch fishes (for harvest or clients), stress and frustration of captains due to increased operation costs (more resources devoted to fuel and gear replacement), pressure to please clients, and increasing safety concerns for clients and crew.
    - Short-season species that clients view as important are getting depredated.

Environmental

- Some stakeholders expressed their belief that climate plays a significant role in the rate of depredation. Specifically, areas with low dissolved oxygen (e.g., the "Dead Zone") seem to have expanded in recent years, and the locations of these areas result in shifts of fish stocks. Sharks (and other predators) follow these shifts and are often concentrated in areas off the coast with higher dissolved oxygen, which may increase the rate of depredation interactions.
- Freshwater runoff seems to compound this dynamic.
- Sea surface temperature is also correlated with low dissolved oxygen areas, and may influence depredation trends.
- Water clarity may also be a potential predictor of shark depredation.
  - Blue, clear water seems to have fewer sharks and more dolphins and amberjack.
  - Murky waters tend to have more instances of shark depredation.

Shark Populations

- There does not seem to be a strong consensus among stakeholders on whether GoM shark populations have significantly increased or decreased in recent years, or whether fisheries management efforts are responsible for the rise in depredation interactions.
- Some stakeholders are not convinced there are more sharks in GoM waters now compared to 50 years ago.
  - The GoM does not have the same fish populations (food source) that it did 50 years ago, so it cannot support the same shark populations as it did historically.
  - Some agree with current shark population assessments, which do not show significant increases in shark population numbers.

        - Several agree that there are significantly more anglers on the water now compared to 50 years ago.
            - Increases in depredation interactions may be the result of more anglers (increases in the number of recreational anglers and charter-for-hire fishermen) rather than increases in shark populations (particularly during the red snapper season).
                - Some stakeholders feel the sharp increase in shark depredation in 2017 may be due to all five of the GoM states obtaining red snapper exempted fishing permits under the Trump administration and establishing their own season lengths.
        - There are fewer shrimp boats on the water today than in the past. Sharks are concentrated around these vessels because they are drawn to the copious bycatch from the shrimp boats. The lack of shrimp boats compounds shark-human interactions (less shrimp boats on the water results in higher depredation interactions for the individual shrimper or fisherman).
        - The accuracy of current shark population assessments is questioned.
- Other stakeholders have seen an increase in interactions immediately after shark fishery closures.
    - Some feel the ridgeback (sandbar, silky, dusky) shark populations have significantly increased due to the implementation of shark regulations.
    - Regulatory changes to protect sharks have resulted in population recovery, and allegedly, increased interactions (more anglers, more sharks, fewer prey items).
- Some blame NOAA and HMS for ineffective fisheries management and creating misguided public opinion on shark conservation.
    - Anglers are observing increased shark populations. Should these fisheries be opened to address increased shark numbers?
- Other viewpoints emphasize that increases or decreases in shark populations simply do not matter.
    - The issue is there are more shark-human interactions, and they are growing more frequent and more problematic.

<u>Responsible Species</u>

- Ridgeback sharks
    - This characterization includes multiple species that are at various levels of recovery. This makes it difficult to make recommendations regarding which species can be safely harvested, but all ridgeback species are common in depredation interactions.
        - Sandbar sharks
        - Large silky sharks that are found in 300-ft+ depths
            - They are easily identified by stakeholders because of their dark brown color compared to sandbar and dusky sharks.
        - Large dusky sharks (~14 ft)
- Bull sharks
    - Bull shark interactions tend to be very bad in the springtime.
    - According to some, bull shark populations have “exploded”.
    - Bull sharks are also known to be very territorial and aggressive, so they will stay on a reef for some time. If bull sharks are on a reef, it is better to simply leave the reef entirely, and fishermen will avoid going back to that particular reef for some time.

- Dolphins
- Tiger sharks are less of a problem.
- Some captains mentioned amberjack and goliath grouper, although these species were not discussed as in depth as sharks.

Regional Dynamics of Reef Fish Depredation in the GoM

Texas

Overview:

- Some differences in viewpoints exist between the commercial and recreational sectors.
    - The commercial fleet is highly impacted by depredation from an economic perspective (loss of time, increased medical costs, loss of gear).
    - Overall, depredation decreases safety, decreases satisfaction, and increases economic loss for both commercial and recreational sectors, but economic loss is greater for the commercial sector.
        - Depredation strongly decreases commercial captain satisfaction.
    - Impacts to the recreational fishery are more complex.
        - Depredation has a higher impact on satisfaction than economic gain or loss.
        - Clients enjoy catching sharks (increases customer satisfaction), but they lose interest if they are only catching sharks, or if sharks are severely limiting their harvest (decreases customer satisfaction).
        - Media content of catching sharks can be used to market future trips (economic gain).
        - Safety is a concern with respect to bringing sharks onboard.
- Depredation encounters can be categorized into many small sharks responsible or a single large shark responsible.
    - This influences angler satisfaction: many small sharks decrease angler satisfaction, whereas fighting one large shark may increase angler satisfaction.
    - This also influences economic loss, as large sharks cause more damage to gear.
    - There is some division on whether or not there is a learned-behavior component affecting shark depredation.
        - Some agree there is no learned-behavior component affecting shark depredation.
        - Others think depredation increases shark learned behavior, which increases commercial loss for both sectors, increases angler satisfaction, decreases reef fish populations, and strongly decreases commercial satisfaction.
            - There is not a consensus on whether learned behavior differs based on the size of the shark, or whether large sharks depredate more often.
- Depredation may not be affecting reef fish populations.
    - Sharks do not naturally catch these fishes; they only catch hooked fishes because it is easy.
        - Overall, 3-5% of hooked fishes are depredated by sharks or dolphins.
        - Shark learned behavior increases depredation and depredation increases shark learned behavior.
            - Learned behavior increases economic loss in the commercial sector, but may increase angler satisfaction in the recreational sector.

- There are strong correlations between reef fish populations and angler satisfaction.
  - Increases in reef fish populations decrease economic loss for both recreational and commercial sectors, and satisfaction for both sectors increases.
    - However, increases in reef fish populations will increase depredation interactions.
- The number of shrimp boats influences depredation.
  - Depredation in the reef fish fishery would decrease if there were more shrimp boats because sharks and dolphins concentrate around shrimp boats, and would not be going after charter-for-hire or recreational boats if more shrimp boats were on the water.
  - Shark learned behavior increases depredation and depredation increases shark learned behavior.
    - Learned behavior increases economic loss in the commercial sector, but may increase angler satisfaction in the recreational sector.
- Environmental (climate) changes have resulted in shifting fish stocks.
  - Results of climate change (fewer forage fishes, low dissolved oxygen) have a significant impact on depredation.
  - This has resulted in shark aggregations, which has strongly impacted (increased) depredation interactions.
  - Shark populations may not be increasing, but shark aggregations are becoming more common.
  - Regulations do not accurately reflect ecological dynamics as a result of the changing climate – management cannot keep up with the rapidly changing climate.
    - Effective fisheries management (that leads to increased reef fish populations and increased shark populations) would increase commercial and recreational satisfaction.
- There is a significant problem with illegal shark harvest off the Texas coast by Mexican fishermen. Their catch (sharks and red snapper) is not incorporated into current stock assessments.
  - This may be reducing shark depredation interactions off Texas for recreational and commercial fishermen.
    - There are more boats off Texas than are accounted for, so depredation interactions may be more dispersed (less depredation for the individual fisherman).
- There is a significant difference between state and federal shark fisheries.
  - In state waters, there is virtually no depredation, but high levels of shark harvest.
  - In federal waters, there is very little shark harvest, but high levels of depredation.
    - The state shark fishery strongly impacts the federal shark fishery. There are stronger regulations in federal waters because of the high level of shark harvest in state waters.

Depredation Drivers Identified:

- Climate
- Number of shrimp boats
- Many small sharks versus a single large shark present

Important Components Identified:

    - Shark aggregations
    - Shark populations
    - Economic loss (commercial)
    - Economic loss (recreational)
    - Commercial fishermen satisfaction

<u>Louisiana</u>

Overview:

- Depredation is more common offshore than inshore.
- Depredation is more common on natural bottom areas compared to artificial reefs.
    - Natural bottom areas have large silky and sandbar sharks.
- Primary species responsible vary based on where fishing effort occurs.
    - Inshore areas have Atlantic sharpnose and blacktip sharks as primary depredators.
    - Nearshore areas do not have as many depredation interactions, although blacktip sharks are somewhat common.
    - Offshore areas have both sandbar and silky sharks, and stakeholders have caught these species.
- Depredation is worse when catching grouper compared to red snapper.
    - This is a result of the areas where grouper fishing effort is concentrated (natural bottom).
- Many charter-for-hire clients are most interested in catching a quality fish and do not want to see sharks or dolphins.
- There is a strong desire to see regulations mirror what is “accurate”.
    - If there are differences between what the stock status assessment says versus what stakeholders are experiencing, then fishery managers and scientists must evaluate these differences and implement regulations based on what the reality is.
- Like in Mississippi, depredation interactions may be closely linked with the red snapper fishery. Thus, it is difficult to compare populations (reef fish and shark) and depredation rates and trends, as well as to determine what the depredation “baseline” historically was.
- Red snapper season lengths influence rates of depredation.
    - As season length (charter-for-hire and recreational) increases, there is increased exposure to depredation (longer time to catch fish).
    - More concentrated fishing effort also leads to increases in depredation.
- Menhaden removals affect rates of depredation.
    - Decreased prey populations lead to increased depredation interactions in the reef fish fishery.
- Barotrauma of hooked fishes may also affect depredation rates, both in deep and shallow waters.

Depredation Drivers Identified:

- Season lengths
- Prey populations (menhaden)
- Single species stock assessment for sharks
- Fisheries management ineffectiveness

Important Components Identified:

- Reef fish populations
- Shark populations
- Angler satisfaction

<u>Mississippi</u>
Overview:

- Depredation is common both nearshore (3 mi out from the barrier islands) and offshore (3-9+ mi offshore). Depredation has become more of a problem in inshore (north of barrier islands) areas in recent years.
- Depredation interactions are closely linked with the red snapper fishery.
    - Most stakeholders target this species.
    - Changes in red snapper regulations throughout the years makes it difficult to determine when depredation became an issue.
    - Red snapper season length influences the frequency of depredation interactions.
        - Towards the end of the red snapper season, fishermen need to fish longer to catch the same amount of fish, so they have a greater chance of experiencing shark-human interactions.
        - Recreational (charter) fishermen report depredation is less common earlier in the red snapper season.
            - Stakeholders recognize that several components may contribute to less frequent shark interactions earlier in the red snapper season. These components may include lower water temperatures, red snapper biology and behavior, fisheries management and regulations, or a combination of these factors acting together.
        - Commercial fishermen report shark interactions are becoming more frequent earlier in the year (primarily in April, May, and June, but sometimes even February and March have heavy shark depredation).
            - Stakeholders acknowledge climate change may be contributing to increased shark interactions.
- Angler skill level may also influence rates of depredation.
    - Less skill means the fish may not be brought up as soon, which will result in more sharks being attracted to the movement of a struggling fish.
- Dolphins display a strong learned behavior component in this region.
    - Dolphins seem to recognize individual boats, know which boats to follow, and share this knowledge among pod members, which has strongly influenced increases in dolphin depredation.
    - This learned behavior may also be tied into management regulations and angler behavior.
        - Regulations prevent anglers from keeping an unlimited number of fishes, and inevitably anglers must throw a hooked fish back.
        - Recreational anglers want to keep only the best fishes they catch, so even if their bag limit is not met, they will throw a fish back if they catch another that is more desirable.
- Depredation is more prevalent on artificial reefs.
    - However, fishing effort is largely concentrated on artificial reefs.
- Shark depredation is not a learned behavior.
    - Sharks are found on artificial reefs because that is where reef fish are concentrated.
    - Fishing effort is also concentrated in these areas.
- The fluctuation of depredation rate throughout the year is unknown.
    - Fishing effort is concentrated primarily in summer months, with very little fishing effort occurring in fall or winter months.
- The primary species responsible for depredation largely depend on where fishing effort occurs.

    - Nearshore areas have bull sharks, blacktip sharks, and spinner sharks as common depredators, with bull sharks being the most common depredators.
    - Inshore areas have blacktip sharks as primary depredators.
    - The most common depredators in offshore areas are bull sharks, tiger sharks, and hammerhead sharks.
    - Species identification in offshore areas is difficult because stakeholders rarely see the shark, although hammerhead sharks are known to come up to the surface.
- Very few stakeholders take advantage of the blacktip shark harvest.
    - Smaller sharks are better to harvest (and promote) because they contain lower mercury levels and fishermen can keep more of them on the boat.
        - However, HMS currently does not allow undersized blacktips to be harvested.
        - It is difficult to find or catch blacktips at the current regulation size.
        - Mississippi fishermen do not need to fish far offshore; unlike in other states, there is a large inshore artificial reef complex, so many of them do not have an HMS permit.
    - Complex regulations and difficulty with species identification compound shark harvest opportunities.
        - It is easier to just not target sharks instead of learning the different size limits for different species and how to identify those species with enough certainty.
    - Regulations in other states (e.g., Texas fin ban) effectively shut down the market for selling shark products.
- Most charter-for-hire trips are tourist-focused, so some clientele enjoy seeing, catching, and keeping sharks.

Depredation Drivers Identified:

- Mirror state limits for shark harvest in federal waters
- Fishing effort
- Red snapper bag and size limits
- Difficulty to identify shark species
- Number of shrimp boats
- Artificial reefs concentrated in a small area

Important Components Identified:

- Discarding of small fishes (angler behavior)
- Dolphin learned behavior

Alabama

Overview:

- Sharks tend to target hooked fishes.
    - Some stakeholders feel sharks only target large, hooked fishes. However, these stakeholders only target large fishes.
    - Other stakeholders say most hooked fishes are smaller in size (16 in or less).
    - Many stakeholders are fishing on reefs.
- Depredation is not significantly impacting reef fish populations, but depredation is significantly affecting captain (and by extension, angler) satisfaction.
- There is discord between captain satisfaction and client satisfaction.
    - Some clients (novice anglers or tourists) want to see sharks and dolphins. If there are dolphins, they will take photos and in some cases, want to feed them too. They are also entertained by depredation. Shark depredation can increase angler satisfaction in this capacity.

- On the other hand, captains are frustrated when they run trips to only catch sharks.
- To alleviate captain stress and increase captain satisfaction, some captains ask clients what their target catch species is.
- This communication between captains and clients increases both angler and captain satisfaction if clients are able to catch their target species. However, captains would rather avoid sharks altogether.

- Stakeholders feel shark populations have been increasing every year, and depredation is becoming worse of a problem.
    - They are uncertain whether anglers are contributing to depredation interactions.
        - Discarding undersized fishes and depredated fishes (if the heads are undersized) may create a learned behavior component for both dolphins and sharks.
        - Some clients want to see – and feed – dolphins.
    - There are significantly more boats on the water today than in the past.
    - Longer reel times lead to increases in depredation interactions.
- Many stakeholders are discouraged by losing time and resources when they must leave areas where there are both fishes and high instances of depredation.
    - More interactions occur in the summer months.
    - Typically, if depredation interactions begin, anglers must leave the area for another.
    - Captains' satisfaction is influenced by their own past experience, and they have their own standards for fishing trips. Catching an undersized or depredated fish or shark may in some instances increase angler satisfaction, but overall decreases captain satisfaction.
    - In some instances, angler satisfaction is partially determined by captain satisfaction.
- Clarity and salinity of the water seems to affect the number of shark interactions.
    - More shark interactions occur in waters with less clarity.
    - There may also be differences on each side of Mobile Bay.
        - Shark encounters increase west of Mobile Bay when there is significant runoff (less water clarity, less salinity).
    - Some areas have very large sharks (200-300 lb) that are primarily responsible for depredation, while other areas have small sharks responsible for most of the depredation.
- Shark depredation may be correlated with the red snapper fishery.
    - The red snapper fishery is experiencing a generalized depletion.
    - Shark depredation was not common when artificial reefs had high numbers of reef fish.
        - Half day charters are operating in areas where there is depletion. In order to get to areas with more red snapper, fishermen must go further offshore where sharks are more of a problem.
    - Angler behavior may contribute to depredation interactions.
        - The practice of high-grading – selectively harvesting fishes so only the best quality fishes are brought ashore – is popular because only a limited number of fishes are permitted to be harvested, and fishes being caught are not big anymore. Fishes that are thrown back are easy prey.
    - States opened their own red snapper fisheries and exacerbated localized depletions.
    - Stakeholders question the accuracy of data collection and fisheries management.

                - In 2021, anglers caught 50% of red snapper landings in the first 7 days but took another 117 days to catch the other half million pounds to fulfill the quota.
                    - Is this the result of anglers stopping fishing, or the need for anglers to make further and longer trips in order to catch the same number of fish?
                    - There is a strong feeling that state fisheries management is driven by politics.
- Time of day may influence depredation rates, but this statement is complicated by varying lengths of charter-for-hire trips (full versus half day).
    - Some stakeholders attest there are more instances of depredation in the afternoon, whereas others do not see these mid-day interactions because they are not running trips at these times.
    - There is a general consensus that the longer they fish one spot, the higher the chances are for depredation interactions.

Depredation Drivers Identified:

- Number of boats
- Hooked fish size
- Shark populations
- Water clarity

Important Components Identified:

- Captain satisfaction
- Angler satisfaction
- Reeling time
- Captain stress

<u>Florida</u>

Overview:

- Depredation decreases angler satisfaction. Anglers pay for a trip, but do not want to "pay to feed the dolphins".
    - For the commercial sector, depredation represents economic loss.
    - For both commercial and charter-for-hire sectors, safety (of both clients and staff) is a significant concern (it is difficult to land a shark alive).
- The outcome of both shark and dolphin depredation is the same, even if this characterization is made.
- Large sharks (ridgeback and lemon sharks) are frequently responsible for depredation among recreational anglers.
    - Sandbar sharks and bull sharks are also common depredators that are mentioned.
    - Since the 1980s, there has been movement of these large sharks into bays and estuaries in alarming numbers.
    - In coastal areas, Atlantic sharpnose sharks are primarily responsible for depredation interactions and cause extensive gear damage.
- Some species-learned behavior may be climate-driven.
- Sharks may not be targeting large fishes that are hooked.
    - However, large, hooked fishes struggle more and this struggle is easier for sharks to track.
- There is difficulty with identification of shark species on the water, even among experienced fishermen.

- Fishery managers are taking regulations for one shark species that may need protection and applying these protections to all shark species, which is creating imbalances in the GoM.
    - Stakeholders emphasize the need for ecosystem-based management with a focus on specific species.
    - NGOs drive pressure on NOAA to continue shark protections and limit management efficiency and effectiveness.
    - Stakeholders blame HMS because HMS determines regulations.
- There is a strong disconnect between fishery managers and fishery stakeholders.
    - Ridgeback sharks continue to require protection, but their population numbers have significantly increased.
- Large sharks living on natural bottom areas are one primary cause of depredation.
    - These large sharks live in this habitat year-round (so depredation is not seasonal).
- Dolphin depredation is significantly more detrimental than shark depredation, and is also more challenging to address.
    - A strong dolphin-learned component increases depredation interactions.
        - Dolphins know the sound of engines and will follow boats or wait for boats.
        - Not all fishes are eaten in dolphin depredation interactions – there are many instances where dolphins “play” with the fishes.
        - The creation of an effective dolphin deterrent is hindered by marine mammal protections, cost, and long-term effectiveness.
            - In some cases, deterrents lose effectiveness over time (e.g., acoustic deterrents).
            - Using deterrents may inadvertently train dolphins to know where there will be easy food sources.
            - Dolphins are more difficult to deter than sharks.
    - Sharks do not have a learned component – they do not follow the boat.
        - Shark depredation interactions are inconsistent, and stakeholders can move to another area to fish if there is shark depredation. Dolphins are “everywhere” and will follow boats.
    - Stakeholders must bring copious amounts of tackle to combat dolphin depredation.
        - Trip prices must be adjusted to account for the gear loss to dolphins.
    - Stakeholders can determine if the depredator is a dolphin or shark by the leader.
- There is a direct correlation between fish size and the likelihood of being depredated.
    - Average anglers struggle to land a large fish and the fight time is longer, so there is a higher probability a predator will take it.
- Sea surface temperature also influences the rate of shark depredation.
    - Sharks in the Northern GoM are not as problematic during November-February.
- There may also be differences in depredation between the panhandle and Southern portions of Florida.
    - Fishermen from the East coast of Florida will come to fish on the West coast of Florida because depredation is so frequent on the Atlantic side of Florida.
    - There may also be differences in primary depredators in Florida.
        - Blacktip and spinner sharks are not depredating as frequently in the Panhandle.
        - Dolphins are common around Panama City.
        - Bull sharks are found in the Middle Grounds in the summer (spearfishers).

Depredation Drivers Identified:

- Shark learned behavior
- Regulatory consistency
- Diverse markets for shark products
- Angler competency

Important Components Identified:

- Shark fishery
- Fisheries management effectiveness
- Shark revenue

<u>Potential Solutions to GoM Reef Fish Depredation and Challenges</u>

<u>Shark Harvest</u>

- Many stakeholders feel implementing a shark harvest is a viable solution to decrease the negative impacts of depredation.
    - Historically, there was a directed shark fishery and depredation was not a problem; thus, shark harvest would be an effective solution to depredation.
- Establishing an effective shark fishery encompasses addressing two primary challenges:
    - Changing negative public opinion on shark harvest
    - Incorporating effective fisheries management
        - This is needed in both the implementation of an expanded shark harvest and addressing public perception.
- Efforts to protect shark populations have been emphasized for many years.
    - Although these efforts have resulted in the recovery of some shark species, they have polarized public opinion on shark harvest.
    - Many stakeholders have been vilified in response to posting social media content of sharks caught and killed during fishing trips and trying to implement changes; the commercial sector is particularly criticized for these efforts.
    - In addition to social media, several stakeholders feel NOAA's outreach efforts to conserve shark populations have resulted in a perspective that even though many shark populations are doing well, there continues to be a need for stringent shark conservation.
        - This message – and the public opinion that emphasizes this perspective – has become extremely detrimental to stakeholders, both from a safety perspective and as an immediate threat to their livelihood.
        - This social dynamic actively prevents stakeholders from using resources already established for a managed shark harvest to their advantage as well as mobilizing efforts to try to address solutions for shark depredation.
        - Some stakeholders mentioned that those who have actively attempted to develop a shark harvest operation have been villainized and pushed out of business due to public pressure.
        - Others have dropped out because they are not able to collect enough money per pound to make their efforts profitable.
- Previous efforts to appeal to the state legislature to implement a shark harvest in Texas were also unsuccessful.
    - Despite dedicating copious resources in support of this effort, stakeholders were unable to overcome the public perception that has developed in response to historically depleted shark populations.
- Fisheries management must modify current shark harvest regulations and address negative public perceptions for shark harvest to be a viable depredation solution.

    - Florida currently has a ban on shark fins, so the opportunity for a shark harvest is not an option for Florida stakeholders – not only from a public opinion standpoint, but from a sustainable resource perspective as well.
    - Texas also has bans, preventing a commercial shark harvest.
    - Mississippi stakeholders are in favor of simplifying federal regulations (by mirroring state regulations), decreasing minimum size limits, and increasing the number of sharks that can be kept.
        - Fishermen can then keep more sharks to increase client satisfaction and profit potential.
        - However, stakeholders emphasize this will need to be revisited if implemented to confirm it is a viable solution to shark depredation.
        - Both Florida and Alabama stakeholders recognize that science must support the implementation of a shark harvest.
            - Stakeholders are not ignorant harvesters who want to "kill everything".
                - If they request a shark fishery, they will also be the same group that comes back to close the fishery if they notice a problem. Stakeholders are some of the biggest advocates for these resources.
- In addition to regulation barriers, there is little to no infrastructure or demand to support a market for sustainable shark products.
    - Despite an open harvest for blacktip sharks, the current quota remains unmet and small profit margins make it difficult to sustain a livelihood.
    - Historically, Florida had a viable and profitable shark market. However, it is unclear if there is still a viable market for shark products today, and Florida stakeholders recognize this may not be the case in the U.S.
        - There may be a small recreational market for some shark products (jaws, teeth, etc.).
    - Maintaining market consistency is necessary to establish a successful shark product market.
        - Finding a market may not be as difficult as overcoming public opinion.
- Solutions to address depredation will not only take significant effort from a management and litigation perspective; extensive education on current shark-human dynamics is needed to change the tide of public opinion.
    - A significant culture shift is necessary to ensure an established shark fishery is successful.
    - Fisheries management is responsible for leading efforts to implement these educational opportunities.
    - Reaching and educating consumers is a key component to solving depredation and implementing a successful shark harvest.
        - The message of sustainable shark harvest as a solution must be broadcast more effectively.
    - Stakeholders recognize that without consumers, they do not have a job or livelihood.
        - Many stakeholders feel there are many people who simply do not understand how detrimental a problem depredation is unless they see it.
        - Some feel education may be an incredibly valuable platform for non-fishermen to understand the problem.
        - Stakeholders emphasize that NGOs and fishermen must find common ground, and advocate for bringing opposite viewpoints together to find this common ground.

Considerations for the Development of an Expanded Shark Fishery

- Historically, there was a long-lived shark fishery that depleted many shark species in the GoM.
- Stakeholders recognize the need to harvest responsibly and sustainably.
    - Many are in favor of stock assessments being conducted on specific shark species (sandbar and bull sharks) to document their current population statuses.
        - Stakeholders are observing trends that do not correlate with what the assessment currently states.
    - Stakeholders emphasize that this research must be cooperative and involve fishermen in the process.
- Many stakeholders support an avenue to voluntarily provide information on shark interactions to capture the impact of depredation.
    - There may be meaningful information obtained from a voluntary reporting app.
    - Some stakeholders are, however, opposed to adding depredation-related questions to the mandatory reporting app that captains already use.
        - For some stakeholders, the app is already extensive in scope, and the addition of more components to report is not appealing.
        - Many fishermen are frustrated considering the recent shift from using a state reporting app to a federal one. This possibly altered the potential willingness to participate in an effort such as this during the workshop.
        - Some question the utility of including it if fishery managers are already aware they are coping with frequent shark-human interactions.
    - There are many channels that will need to be overcome to add this information to the reporting app.
    - Some suggest that this reporting should fall on dockside surveys.
    - Others suggest cooperative research is a more effective solution.
        - Future projects should be implemented that involve only a subset of commercial and charter-for-hire fishermen who have already been involved in past research.
        - This will not involve the whole fleet, so it will not be a burden on every fisherman and would also potentially illuminate the nuances to describe (and hopefully solve) the complex issue of depredation in the GoM.
    - Florida stakeholders proposed "how the number of hooks replaced has changed over time" as a new metric to measure depredation interactions.
        - The quota has not increased, so increases in the number of hooks replaced would quantify the impact of depredation.
        - Data from the NOAA longline survey can also be incorporated to track shark populations.
    - Others have significant doubts regarding fisheries management effectiveness based on their personal experiences.
    - If this effort is implemented and shows that there are specific shark species that can be safely harvested, fisheries management must act – both from a litigation perspective as well as an educational perspective.

Other Solutions Identified

- Some stakeholders – particularly those from Texas – do not feel they can "harvest their way out of this problem" and recognize implementing a managed shark harvest may not be the best way to address depredation.
    - This realization is based on experience and public perception and behavior.

    - Even if the stock assessment supports a sustainable shark harvest, public opinion will not change.
        - Historically, fishermen have made changes through litigation and have not needed to rely on public opinion.
        - Excessive resources are needed to pursue litigation efforts that depend on funding; very few will donate enough money to implement a shark fishery.
            - These efforts would need to be repeated in every GoM state.
    - Even if litigation efforts are successful, the success of a shark fin or other shark product market is crucially dependent on consumers.
        - Consumers must inevitably solve shark depredation.
        - Many stakeholders recognize this is not an uphill battle that can be won, and they realize the need to explore other options.
- Shark deterrents have moderate support among stakeholders.
    - AL stakeholders state some shark deterrents tend to be expensive.
        - Deterrents must be cost-effective to be a realistic solution.
        - Many Alabama stakeholders are interested in evaluating whether pheromones or shark liver could act as effective shark deterrents.
        - Several Alabama stakeholders are unfamiliar with or have not used the Zeppelin, a type of shark deterrent.
        - One (Florida) stakeholder says the Zeppelin was eaten the first time it was ever used.
    - The consensus is that some deterrents may be effective initially, but effectiveness is lost over time.
    - The Zeppelin has some promise regarding science and technology.
        - If there is a reduction (rather than elimination) in the interaction, is it worth it?
- Necromones are also considered as a deterrent, but again, there is not much research available, and some say sharks can acclimate and it loses effectiveness over time.
    - Many stakeholders are still willing to test the effectiveness of necromones on shark depredation and would like to see more collaborative research implemented on this topic.
- It may take a long time to develop an effective shark deterrent, but these efforts (potentially along with a shark harvest) may decrease shark depredation.
    - Some stakeholders feel sharks may have learned behaviors, and they have evolved specific behaviors to hunt. Thus, an effective shark deterrent may take some time to produce.
- There may be more anglers on the water, but that does not necessarily mean there are not more sharks.
    - If there are more anglers, theoretically there should be fewer depredation interactions, and this is not the case.
    - The solution to depredation must be multi-faceted in scope to be effective.
- Many stakeholders notice a correlation in the frequency of depredation interactions and the reef fish fishery seasons (particularly the red snapper season).
    - Depredation interactions seem to be most frequent in the summer months (August) and seem to decrease in later season months (October, November, December).
- Red snapper seasons have dramatically changed with fishery regulations.
- Historical red snapper abundances and distributions are not known, so it is difficult to compare the current ecosystem to that of years past.

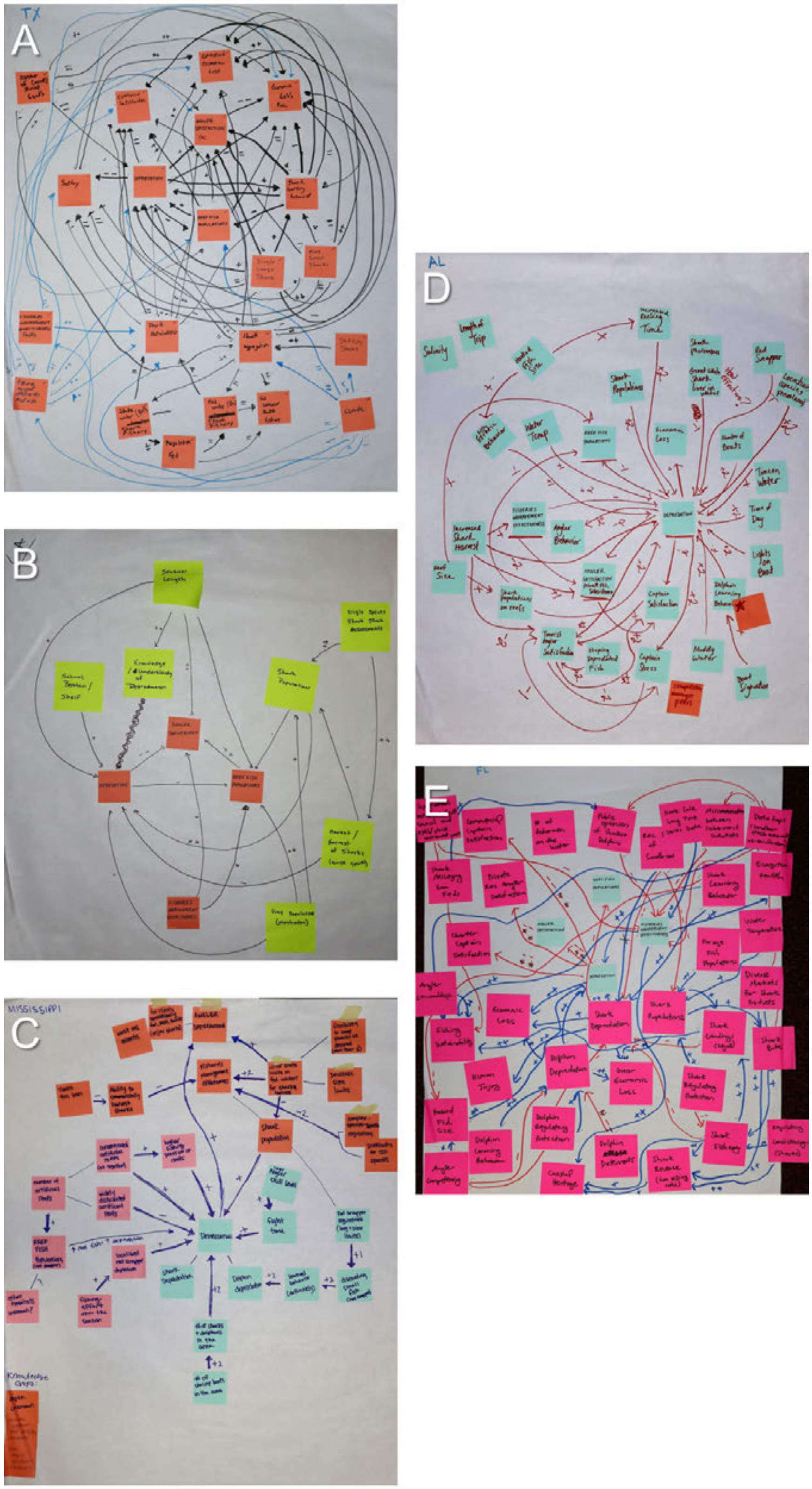
- There is little documentation available to measure the social and economic impacts of depredation, but this is a key component to implementing possible solutions to depredation.
- Some stakeholders suggest the SeaQualizer as an option to explore.
    - Currently, there is not a lot of data collected on the SeaQualizer's effectiveness with regards to shark depredation.

Depredation Baseline

- What is the "standard" amount of depredation?
    - Is the amount of depredation anglers are experiencing today "normal"?
    - Historically, what did depredation look like in the GoM?
        - Tarpon fishery – some of the earliest photographs showed half-depredated tarpon in the early 1900s.
        - Our knowledge baseline simply does not go back as far as necessary to determine this (HMS did not start managing sharks until the 1990s).

Appendix D: Workshop Photos

(**A**) Dr. Marcus Drymon begins the workshop by encouraging each captain to introduce themself; (**B**) Captains Dale Woodruff of Orange Beach (left) and Gary Bryant of Fort Morgan (right) contribute to the Alabama breakout group discussion; (**C**) Dr. Marcus Drymon details the *Mental Modeler* outputs created from the participatory models; (**D**) Captains pose proudly with the completed participatory models.



Photos of the (**A**) Texas, (**B**) Louisiana, (**C**) Mississippi, (**D**) Alabama, and (**E**) Florida participatory models generated during breakout group discussion.