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SEDAR74-DW-16

15 April 2022

Please cite this document as:

Gervasi, Carissa, Matthew McPherson, and M. Karnauskas 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.

SEDAR74-DWXX

System dynamics of red snapper populations in the Gulf of Mexico to support ecosystem considerations in the assessment and management process

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Introduction

In this research we build social-ecological conceptual models for the red snapper fishery in the Gulf of Mexico (GOM) through participatory systems dynamics modeling. Our goal is to gain an understanding of red snapper populations in the context of the larger social-ecological system in which they occur. This research addresses several terms of reference for the SEDAR 74 Red Snapper Research Track regarding environmental, social, and economic factors that should be considered for potential inclusion in the assessment process. The participatory approach used here recognizes that stakeholders often have extensive knowledge and experience on the water and are well qualified to help identify some of the major factors affecting population dynamics, fleet behaviors, and impacts to businesses and livelihoods. This approach has many benefits, allowing us to document stakeholder knowledge of the system in a consistent format, identify the important linkages of feedbacks present in the system, including physical, biological, social and economic ecosystem components, recognize key leverage points in the system which would serve as priorities for evaluating risk, highlight factors which are priorities for future targeted research and potential inclusion in the data interpretation, stock assessment, or management process, and understand what stakeholders value in the system.

This working paper primarily addresses the SEDAR 74 term of reference to ***"describe any known evidence regarding ecosystem, climate, species interactions (e.g., predation studies), habitat considerations, species range modifications (expansions or contractions) and/or episodic events (including red tide, upwelling events, and hypoxia) that would reasonably be expected to affect red snapper population dynamics."*** The participatory method is used to identify priority ecosystem factors that could be considered in the assessment framework. Based on preliminary information collected to-date from charter for-hire captains, we have identified four factors that may affect red snapper population dynamics to the extent that they might be considered in the stock assessment process. These include the effects of depredation on red snapper mortality, the episodic effects of hurricanes on red snapper catchability, the impact of increased recreational fishing effort (particularly due to COVID-19) on local red snapper abundance and catchability, and substantial improvements over time in fishing technology on red snapper catchability. This research is still in progress; the present working paper summarizes information gained to date, but further information will be presented during the assessment and review phases of SEDAR 74.

Methods

Our research aims to collect information on the status and trends of the GOM red snapper fishery using a social-ecological modeling approach. This approach has been used successfully to study GOM and South Atlantic scamp fisheries (McPherson and Karnauskas 2021), to examine how Florida's marine and human communities are impacted by red tide events (Spooner et al. 2021), and to examine the different roles of dolphin and wahoo across the South Atlantic management jurisdiction (https://safmc.net/cit-sci/dolphin-wahoo-participatory-workshops/). Via conversations with anglers, we developed conceptual models that encompass physical, biological, socio-cultural, economic, and regulatory drivers that influence the GOM red snapper fishery and assessed how these factors are linked. Our main research questions were:

1. What are the main factors (environmental or otherwise) that influence the GOM red snapper fishery and red snapper populations?
2. What do anglers perceive as the risks in the fishery and what do they value?
3. How do changes in the ecosystem affect businesses and communities?

In-person workshops with fishing industry members, which were historically held in collaboration with the Gulf of Maine Research Institute as MREP workshops (https://www.gmri.org/projects/marine-resource-education-program-mrep/), would typically be used to collect the information needed to develop conceptual models. However, due to ongoing travel restrictions, we developed a virtual methodology for carrying out these workshops. This virtual process was piloted for the scamp stock assessment (McPherson and Karnauskas 2021) and was expanded upon for the present work. Our ultimate goal is to seek input from the recreational, charter for-hire, and commercial sectors, though thus far we have only gained information from the charter for-hire sector. Our methodology involves an initial brainstorming phase during which input is sought from industry members and a draft conceptual model is developed. Then, a virtual workshop is organized, during which participants review the model, provide feedback on any missing linkages, and clarify any elements that were misrepresented. Due to the diversity of stakeholder groups involved in the red snapper fishery, and their unique needs, we plan to hold separate webinars by sector or geography to compare and contrast perspectives. Ultimately, all possible linkages will be included regardless of how many mentions they receive; therefore, the conceptual models will represent the cumulative knowledge and perceptions of all participants.

For the major hypothesized ecosystem factors that were identified to-date as influencing some aspect of the population dynamics, we sought data sources that would allow us to quantify changes over time. To quantify changes in depredation, we summarized the temporal trends as described by anglers, and extracted specific years or periods where possible. We did not explore additional analysis because there is a separate ongoing effort focused on quantifying trends in depredation over space and time (https://restoreactscienceprogram.noaa.gov/projects/reef-fish-depredation) and results from that project will be reported separately. To evaluate tropical storm activity, we used the International Best Track Archive for Climate Stewardship (IBTrACS) data set (Knapp 2010; Knapp 2018). Storm track data were downloaded for the North Atlantic, subset for the area of interest (85 - 90°W, 28.5 - 30.5°N), and we filtered out systems below tropical storm strength and time steps outside the standard 6-hourly reporting frequency. To quantify annual storm activity, we used the Accumulated Cyclone Energy (ACE) Index, a commonly used metric calculated by summing the squares of the estimated 6-hourly maximum sustained wind speed for all storm systems, during the points at which they are at tropical storm strength and higher. To examine potential changes in recreational fishing effort due to COVID-19, data on the number of saltwater recreational fishing licenses sold per year for each GOM state were collected from the National Saltwater Angler Registry (https://www.fisheries.noaa.gov/recreational-fishing-data/national-saltwater-angler-registry). To evaluate trends in fishing technology and the ability of the recreational fleet to pursue red snapper, we extracted available information on outboard engine sales trends for GOM states from the National Marine Manufacturers Association U.S. Recreational Boating Statistical Abstract (NMMA 2022). Data on sales for boats by engine size were available from 2013 to 2020.

Results

To-date, 27 charter for-hire captains throughout the GOM have participated in developing red snapper social-ecological conceptual models (Table 1). To evaluate regional patterns, conceptual models were created separately for five regions: (1) the Florida Panhandle & Alabama, (2) Mississippi, (3) Louisiana, (4) central Florida and the Big Bend region, and (5) Texas. These specific regions were separated due to the similarity in identified fishery characteristics and drivers among captains from each region and the differences identified between regions. We initially focused on building a conceptual model of the Florida Panhandle & Alabama region because estimated recreational landings of red snapper are highest in this area (Gardner et al. 2022).

Regional models

Conceptual models for the five regions highlighted similarities and differences in the perceptions of charter for-hire captains. Several drivers were mentioned by captains from all regions as factors affecting either catch rates or population dynamics of red snapper. Most captains, regardless of region, observed an increase in recreational fishing effort over time due to increases in the number of recreational anglers targeting red snapper as well as increases in boat and fishing technology allowing for an increase in catchability of red snapper. Furthermore, four captains claimed that red snapper fishing has grown in popularity in recent decades, potentially due to substantial media attention surrounding the fishery. Captains from the Florida Panhandle & Alabama, Louisiana, central Florida, and Texas regions all noted a significant increase in recreational fishing effort on red snapper specifically due to the COVID-19 pandemic. Captains from all regions of the GOM also mentioned that depredation of red snapper by sharks and/or bottlenose dolphins occurs, though the extent that depredation affects red snapper population dynamics appears to vary by region. Finally, guides from all regions noted that bathymetry and availability of structured habitat dictate the red snapper fishery, as fish are mainly targeted in deep water and on structured natural or artificial habitat. Regional variations in habitat and water depth influence where and how red snapper are targeted by recreational anglers and charter captains.

Captains in the Florida Panhandle & Alabama region mentioned some additional drivers and linkages in the red snapper fishery (Figure 1). One driver which was brought up repeatedly in this region was the presence of hurricanes, which were perceived to have the effect of dislodging artificial structures, redistributing red snapper biomass, and influencing the behavior of red snapper. One angler also mentioned that hurricanes may increase larval recruitment, thereby increasing local abundance of red snapper in the region. However, the mechanisms by which this occurs were unknown by the angler. Water quality was mentioned by one captain as possibly impacting red snapper local abundance. The captain observed that when freshwater flow from the large river systems of the northeastern GOM is high, it can lead to a decrease in water quality and a decrease in the abundance of red snapper close to shore.

Unlike the other regions, charter captains in Mississippi mentioned that interactions with shrimp trawlers affect the local abundance of red snapper as red snapper are commonly caught as bycatch in the commercial shrimp fishery (Figure 2). In Louisiana, a regional issue mentioned was freshwater flow from the Mississippi River, because high levels of flow can decrease local abundance of red snapper according to captains. Also, the main fishing habitat for red snapper in the region is large oil rigs, and several captains mentioned that recreational anglers are often competing with commercial anglers from other states on these structures (Figure 3). Central Florida captains mentioned the impacts of red tide, which can decrease the abundance of bait or shift bait distributions, thus impacting the local distribution of red snapper. Central Florida anglers also generally reported targeting red snapper on the natural reef and rock habitat present throughout the region, rather than congregating on artificial structures (Figure 4). A regional issue identified by captains in Texas was illegal longlining and gillnetting activity from Mexico, which has increased fishing effort on red snapper populations. Cold snaps were also mentioned as having a negative effect on the abundance of red snapper in state waters (Figure 5).

Factors influencing red snapper mortality

The most common driver in the red snapper fishery identified by captains throughout the GOM was depredation. Of the 27 captains who participated in conceptual modeling, 12 identified depredation as a major issue in the red snapper fishery, and 7 identified it as a minor issue. The remaining 8 captains either did not mention depredation or said that it was not an issue. Captains generally believed that discards and high-grading are the main reason why depredation is such a problem, as these practices attract predators to fishing vessels and fishing grounds. All fish captured under the size limit or out of season are discarded, so captains mentioned that short open seasons and restrictive size limits can exacerbate the problem of discarding. Specifically, many captains perceived that depredation increased around 2014, when the red snapper open season was dramatically decreased to 9 days (from 42 days in 2013), and at which point recreational discard rates would have likely increased substantially. Restrictive bag limits may also lead to recreational anglers throwing back fish above the minimum size limit in order to retain the largest individuals possible.

In addition to potentially increasing levels of discarding and high-grading in the recreational fishery attracting predators, many captains also observed that sharks have become more abundant since fishing pressure on their populations decreased in the early 1990s (Figure 6). Most anglers cited blacktip reef sharks and bull sharks as the main species engaging in depredation behavior (although many noted an inability to identify all sharks to species based on their observations). Many guides also mentioned that bottlenose dolphins have learned to follow boats, and adults are training their young to follow their boats for easy meals (Figure 7).

Although depredation was mentioned throughout the GOM, only captains in the Florida Panhandle & Alabama, Mississippi, and Louisiana regions identified depredation as a major issue. These areas also have the highest density of recreational landings (and thus discards) throughout the GOM, which could explain why depredation is a particular issue (Figure 8). In Texas and central Florida, several captains noted that depredation does occasionally occur, but it tends to be an issue localized to certain areas or times of the year and therefore has a limited impact on charter businesses. The main consequence of depredation on fishery operations is that captains are forced to avoid certain fishing grounds or leave and find alternative fishing grounds when depredation is occurring.

The issue of depredation in the red snapper GOM fishery was examined in more detail in a workshop hosted by Dr. Marcus Drymon on April 4th, 2022 in Gulf Shores, AL as part of a NOAA RESTORE project (https://restoreactscienceprogram.noaa.gov/projects/reef-fish-depredation). At this workshop, 22 anglers from the charter for-hire and commercial sectors throughout the GOM participated in creating detailed conceptual models of depredation and relayed information about observed trends over time. The data compiled from this workshop will provide more specific information about the effects of depredation on red snapper mortality in the GOM, as well as fishermen's perspectives on how depredation has changed over time, which could potentially be used to parameterize estimates of discard mortality in the stock assessment.

Factors influencing red snapper catchability

Conceptual models of the red snapper GOM fishery created by charter for-hire captains included three drivers that could have an important impact on catchability of red snapper. These factors are hurricanes, substantial increases in recreational fishing effort due to COVID-19, and changes in fishing technology over time. Several anglers mentioned that hurricanes can dislodge smaller artificial structures, which are the main habitats anglers target for red snapper in some regions. When the number of structures with known locations declines after a hurricane, it can lead to a decrease in red snapper catchability as anglers have to move to structures further away or locate new structures. This would particularly be the case for regions that have high dependence on artificial structures (Mississippi, Alabama, and the Florida Panhandle). Hurricane wind speed presumably affects the extent to which artificial structures are dislodged, and therefore can be used to estimate how much catchability might be impacted in a given year. Storm energy in the north-central GOM, as measured by the accumulated cyclone energy (ACE) index, was particularly high in recent years (2018 and 2020) which could explain why numerous charter captains mentioned hurricanes as major drivers of the red snapper fishery (Figure 9). Red snapper catchability may be expected to decrease during years with high storm energy. Some captains also perceived that hurricanes impact fish behavior, causing them to move away from the fishing grounds and even change their willingness to go after bait. However, captains reported hurricanes causing fish to both move in closer to shore and also further offshore depending on the direction and intensity of the hurricane. The exact relationship between hurricanes and fish behavior is, therefore, unclear.

Ten charter captains from all regions except Mississippi mentioned that the COVID-19 pandemic has significantly affected the red snapper fishery. These captains observed a substantial increase in the number of recreational anglers targeting red snapper since 2020 which has led to increased harvest and rapid declines in the local abundance of red snapper close to shore over the course of the red snapper season. Captions mentioned that this decline in nearshore abundance leads to a decrease in catchability as the season progresses, since anglers are required to travel further offshore to target red snapper. Trends in the number of saltwater recreational fishing licenses sold per year appear to confirm the observations of charter captains (Figure 10). In all states where data were available, the number of saltwater licenses sold increased from 2019 to 2020. Sales increased by 36% in Texas, 20% in Florida, 17% in Louisiana, and 2% in Alabama.

Charter captains from the Florida Panhandle & Alabama, central Florida, and Mississippi regions mentioned that red snapper catchability has greatly increased over time with advances in vessel and fishing technology. In regions where access to red snapper habitat (deep water) is further offshore (e.g., central Florida and Mississippi), captains noted that as reliable vessels with larger engines and higher maximum speeds have become readily available to recreational anglers and guides, it is now easier to access these offshore regions and thus target red snapper than it was in the past. Trends in outboard engine sales for all five GOM states (Alabama, Florida, Louisiana, Mississippi, and Texas) revealed patterns consistent with angler observations (Figure 11). For all GOM states, the number of boats sold per year with 50 hp or smaller engines has remained relatively constant from 2013 to 2020. The number of sales for boats with 50-150 hp engines has also remained fairly constant in Alabama, Louisiana, and Texas, but has increased slightly over time in Florida and Mississippi. Across all states, sales for boats with 150-300+ hp engines has increased fairly linearly over time, with the most dramatic increase being for Florida. The number of boats sold in Florida with 150-300+ hp engines has nearly tripled, from a minimum of 11,750 units sold in 2013 to a maximum of 32,098 units sold in 2020. Captains also mentioned that advancements in fish finder technology have allowed anglers to more easily locate fishing grounds (natural hard bottom or artificial structure). Once fishing grounds are located, advanced trolling motors with spot lock capabilities allow anglers to remain at lucrative fishing areas for extended periods of time. These observations suggest that red snapper catchability has likely increased over time and may continue to increase with future technological advancements.

Conclusions

The main purpose of this paper was to identify major environmental factors that are candidates for incorporation into the red snapper stock assessment. Through the participatory method, we homed in on four factors that are perceived to be highly influential by charter-for-hire captains: depredation mortality, hurricanes and their episodic impact on catchability, the effects of COVID-19 on recreational effort and red snapper catchability during the season, and the effect of increased fishing technology over time on recreational catchability. Future work will incorporate the perceptions of recreational and commercial anglers in addition to charter captains, and we will examine the similarities and differences in perceptions among the sectors. Our future research also aims to address the SEDAR term of reference to ***"incorporate social and economic information into the stock assessment considerations as practicable."*** The participatory method allows us to compile detailed information about the social and economic effects of physical and biological drivers that exist within the red snapper fishery, as well as the consequences and stakeholder opinions of management actions. Our research is therefore well suited for addressing this term of reference. Throughout the remainder of the red snapper assessment process, we will be providing additional information from our continued research and subsequent papers will be submitted.

The scientific results and conclusions, as well as any views or opinions expressed herein, are those of the author(s) and do not necessarily reflect those of NOAA or the Department of Commerce.

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Table 1. Number of charter for-hire captains involved in developing conceptual models by region.

Region	Number of captains
FL Panhandle & Alabama	13
Mississippi	3
Louisiana	2
Central FL & Big Bend	5
Texas	4

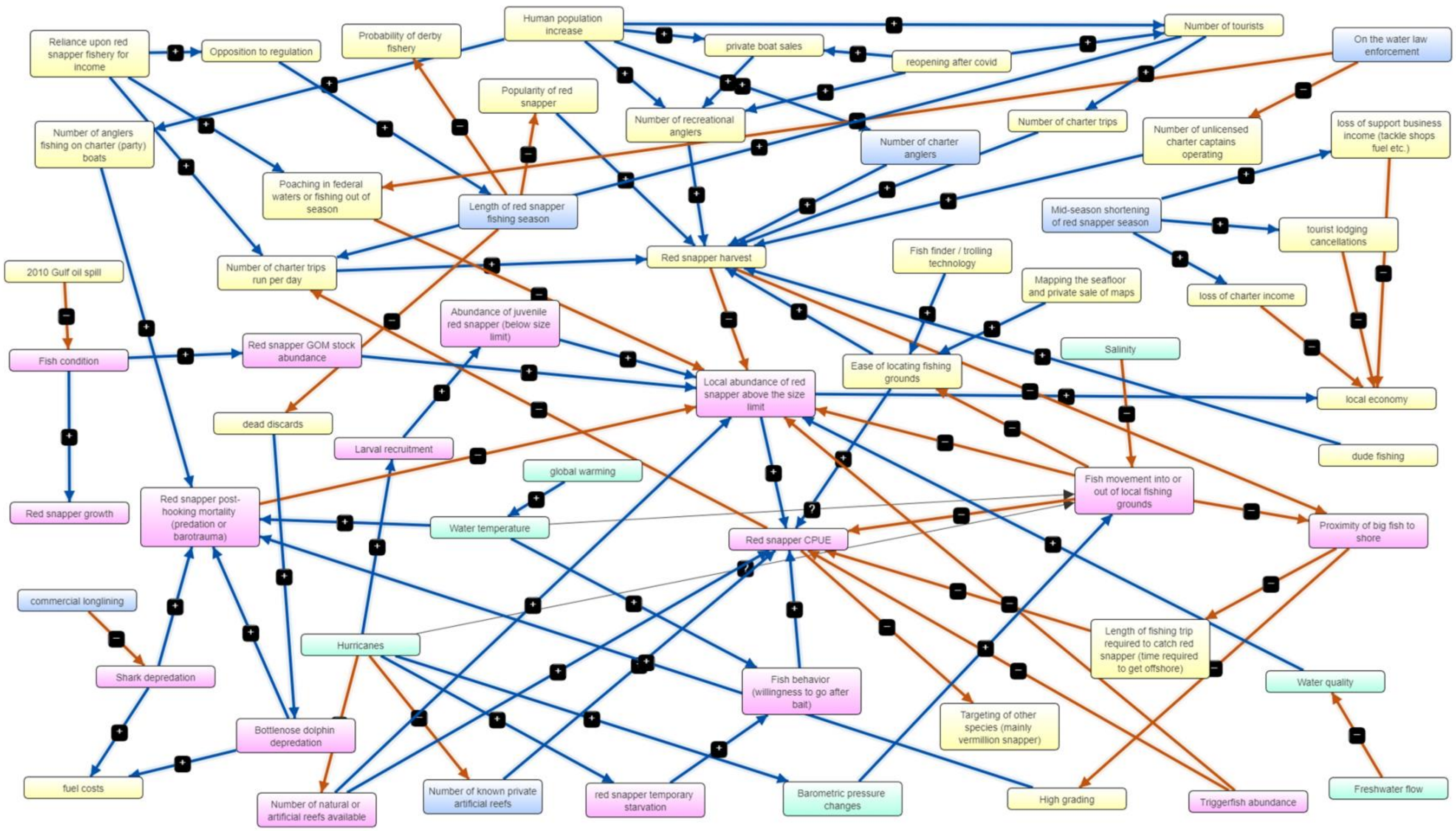

Figure 1. Conceptual model of the red snapper fishery in the Florida Panhandle & Alabama region based on the observations of 13 recreational for-hire charter captains.

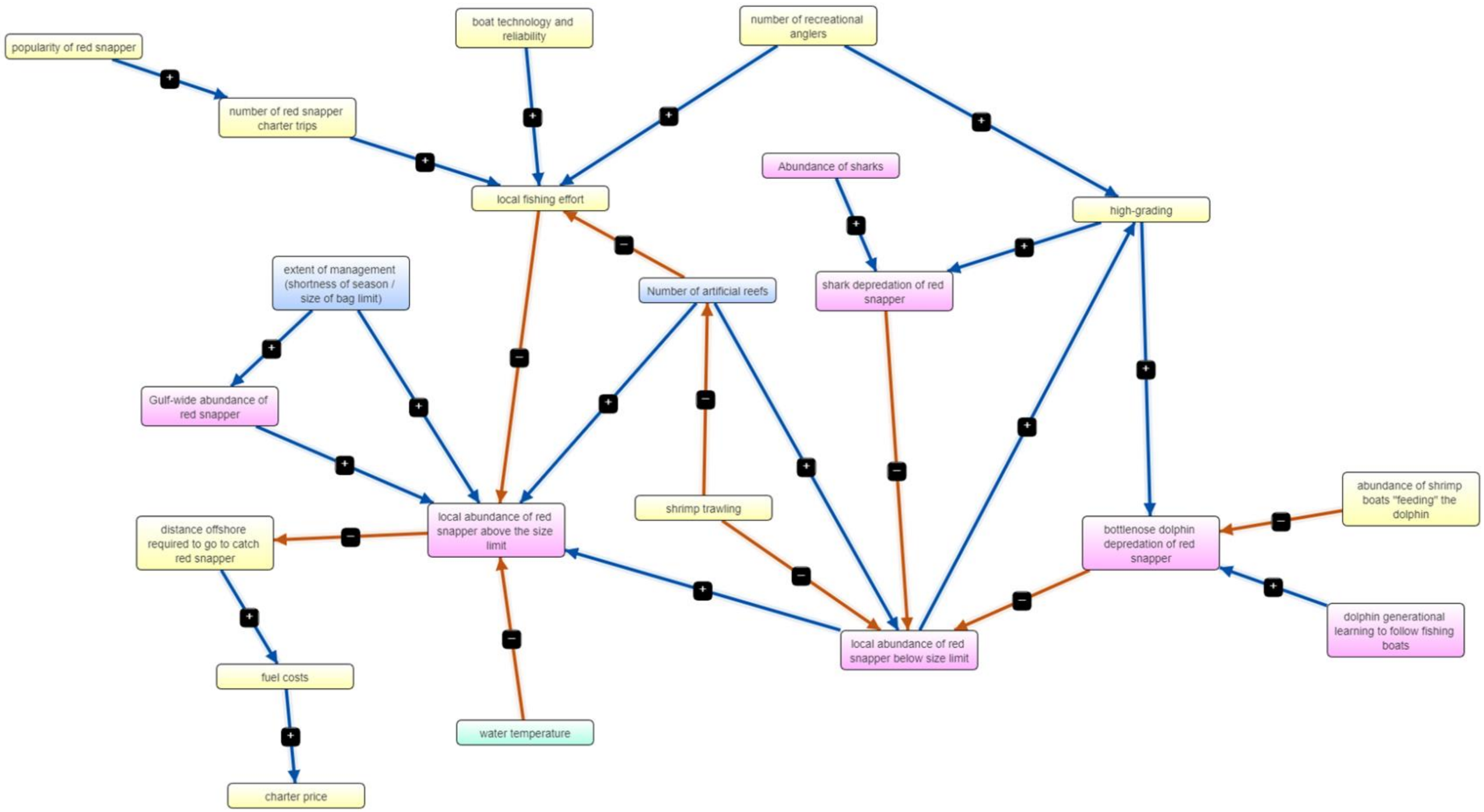

Figure 2. Conceptual model of the red snapper fishery in the Mississippi region based on the observations of three recreational for-hire charter captains.

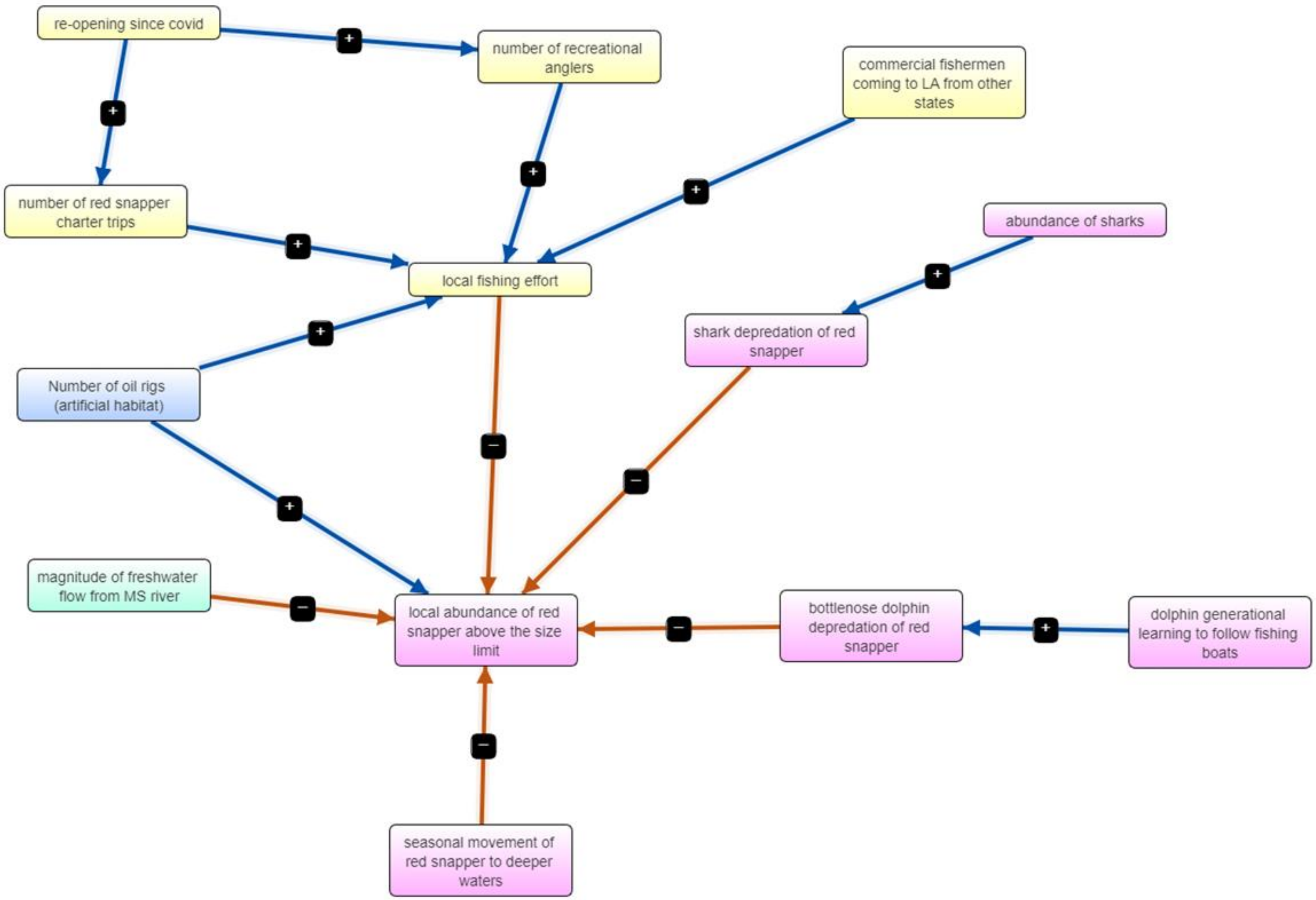

Figure 3. Conceptual model of the red snapper fishery in the Louisiana region based on the observations of two recreational for-hire charter captains.

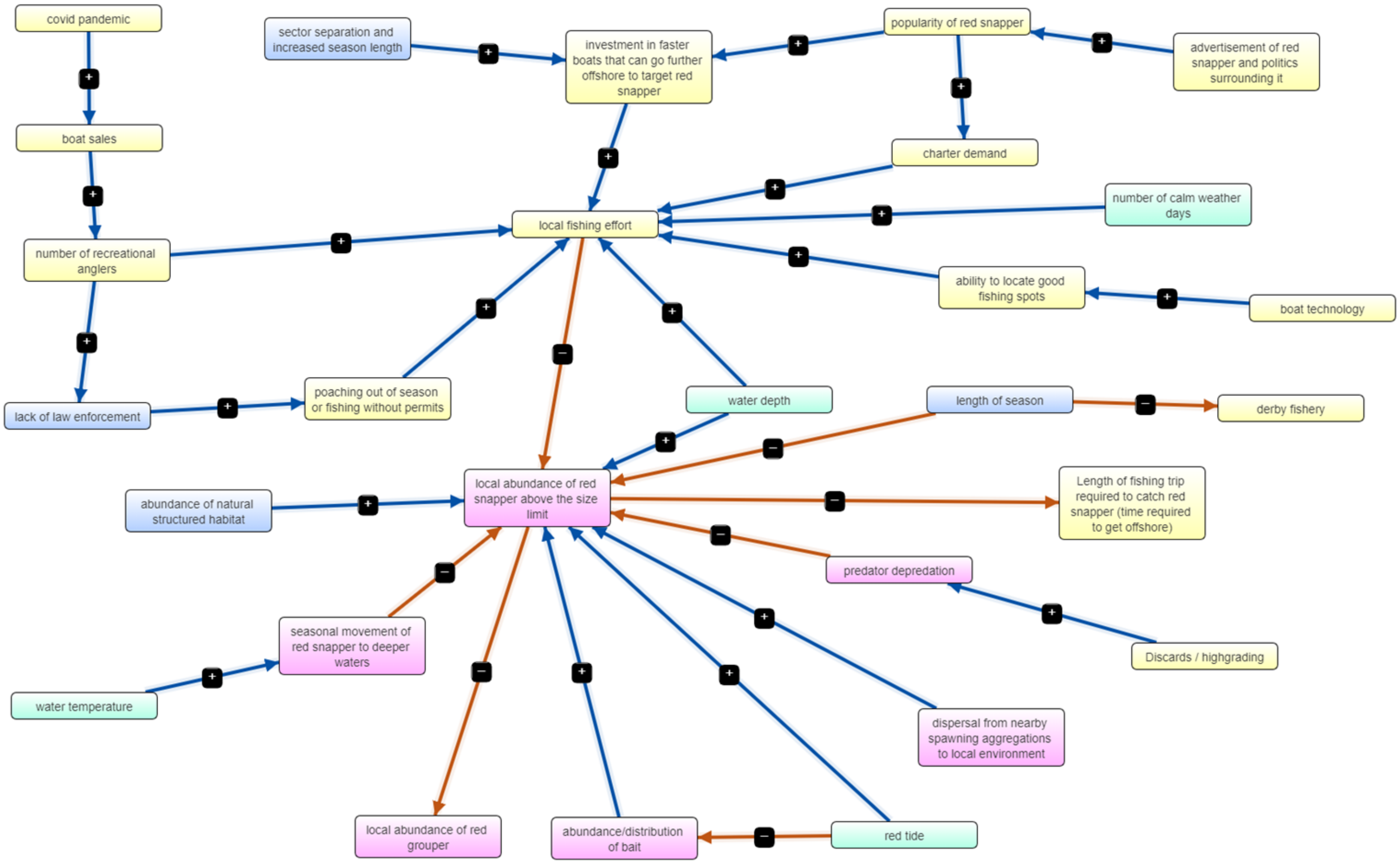

Figure 4. Conceptual model of the red snapper fishery in the central Florida & Big Bend region based on the observations of five recreational for-hire charter captains.

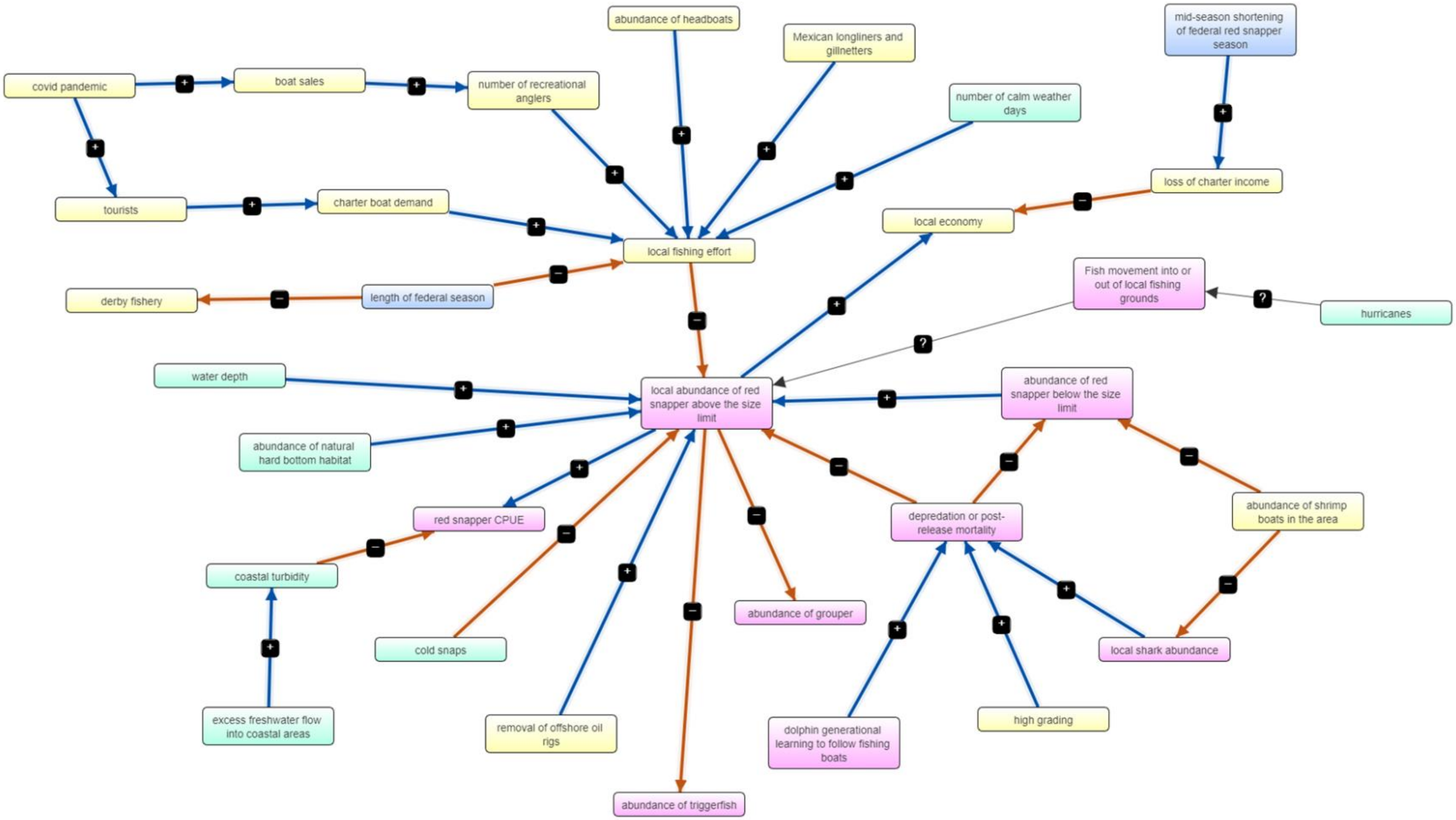

Figure 5. Conceptual model of the red snapper fishery in the Texas region based on the observations of four recreational for-hire charter captains.

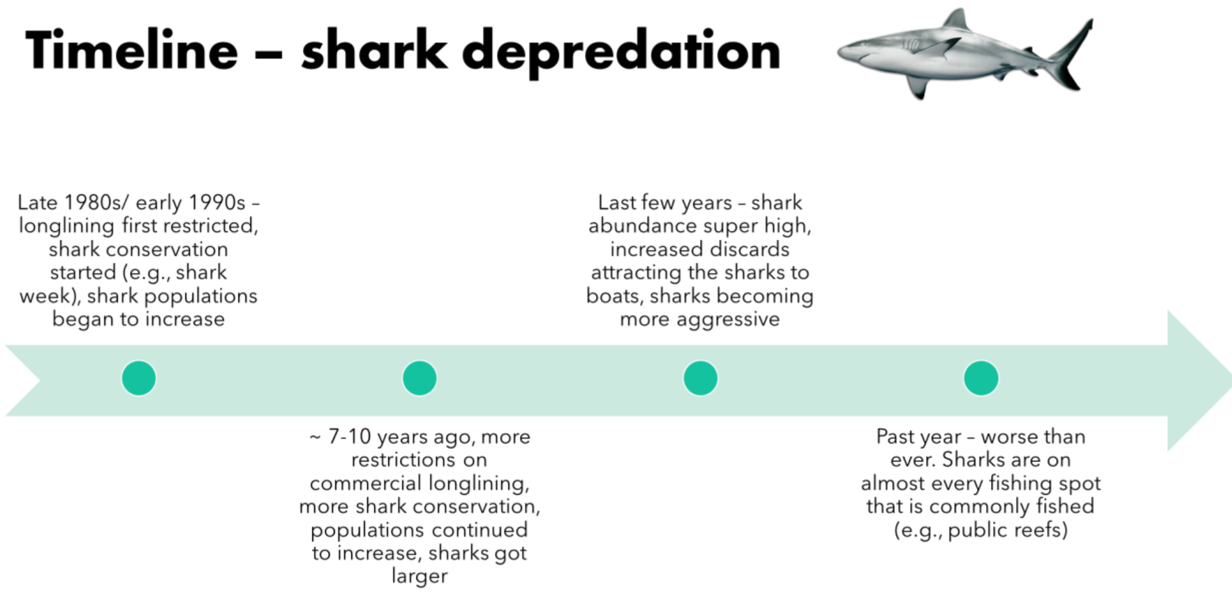

Figure 6. Estimated timeline of shark depredation on red snapper in the GOM according to the observations of recreational charter for-hire captains.

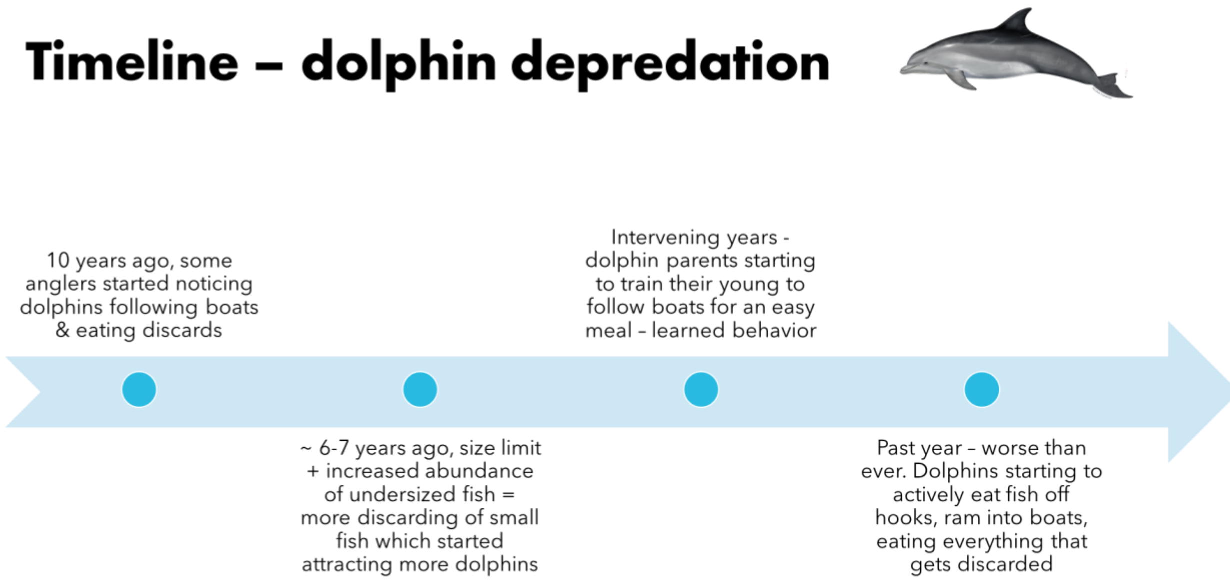

Figure 7. Estimated timeline of dolphin depredation on red snapper in the GOM according to the observations of recreational charter for-hire captains.

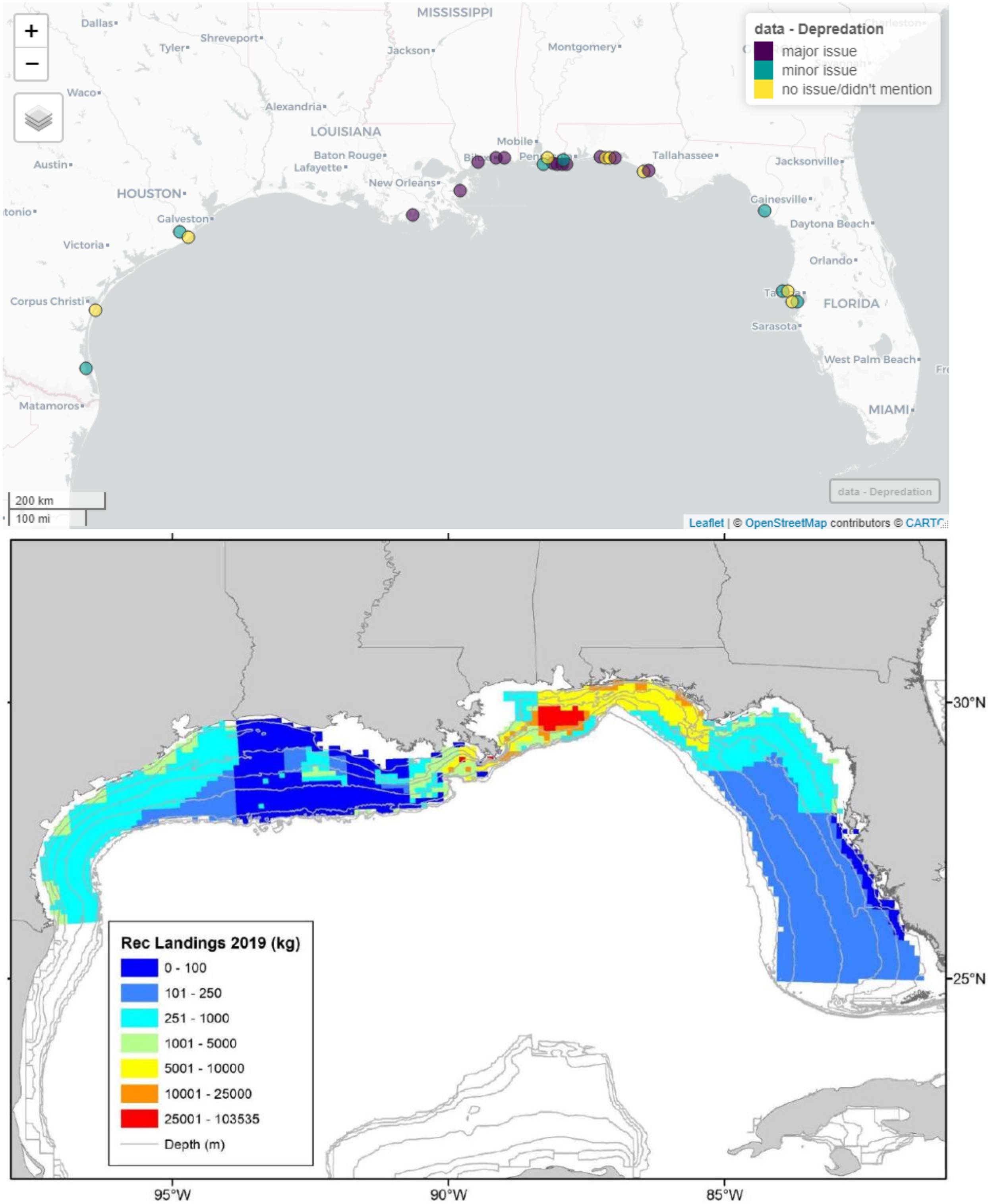

Figure 8. Map showing the incidence of depredation as reported by each charter-for-hire captain for their specific fishing area (top) and 2019 estimated red snapper recreational landings (kg per 10 x 10km block) estimated from individual state reporting programs (bottom; C. Gardner pers. comm.).

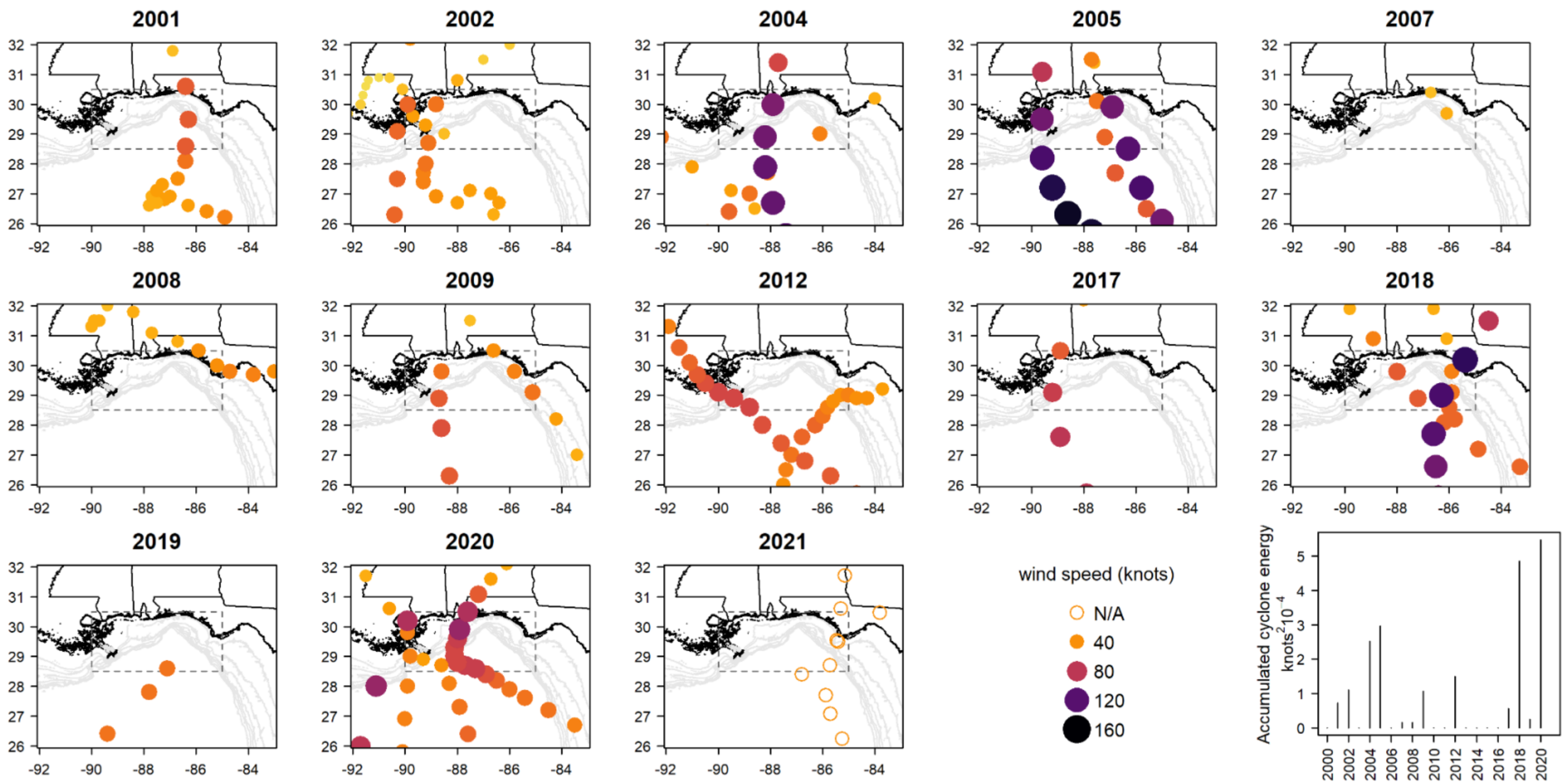

Figure 9. Six-hourly tracks of all tropical storm systems in the north-central Gulf, shown by year (years with no storms not shown). Track locations are color-coded and sized according to maximum sustained wind speed (wind speed data were not available for 2021 at the time of publication). The lower right panel shows the accumulated cyclone energy index by year, calculated over the area indicated by the dashed gray box. Depth contours are at 20m intervals from 20m - 140m.

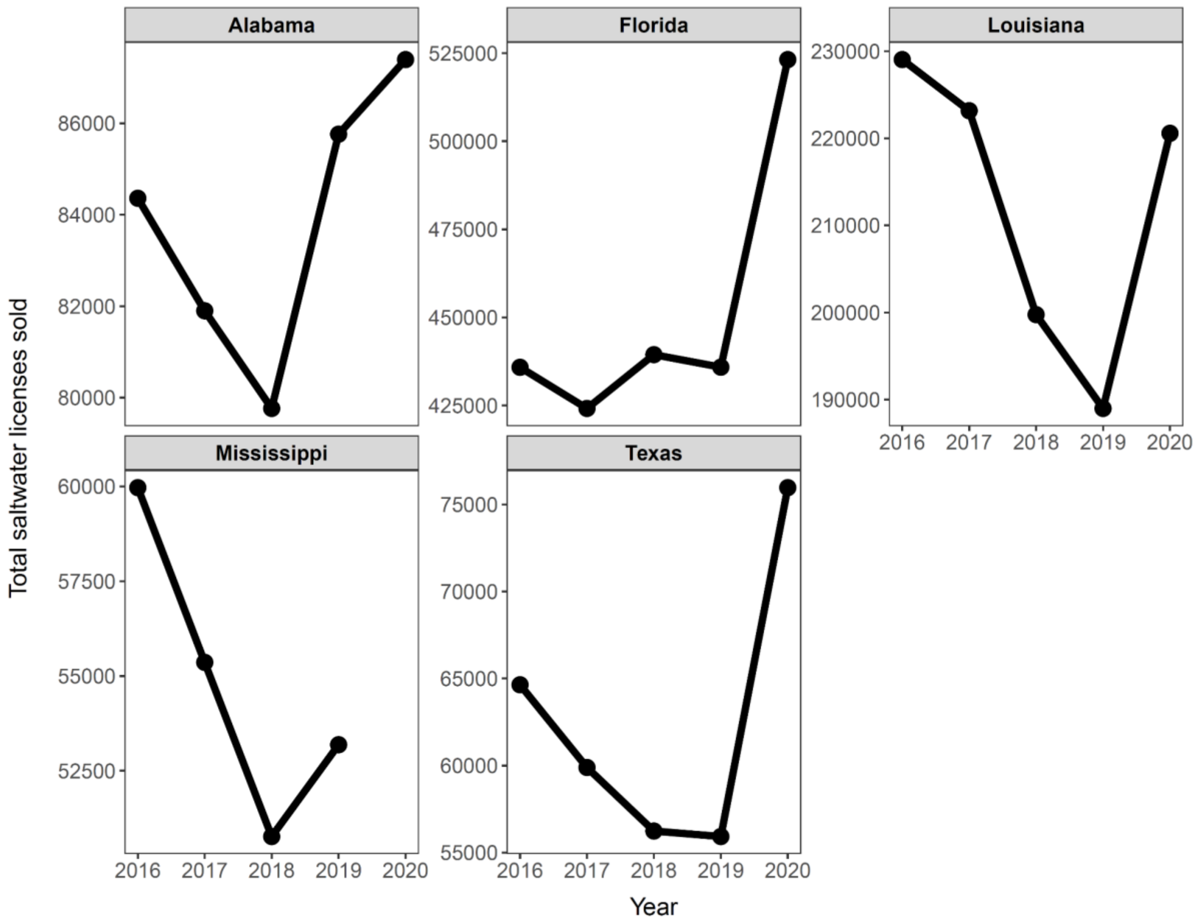

Figure 10. Total saltwater recreational fishing licenses sold per year by state from the National Saltwater Angler Registry. Y-axis scales differ by state. Mississippi data for 2020 were unavailable.

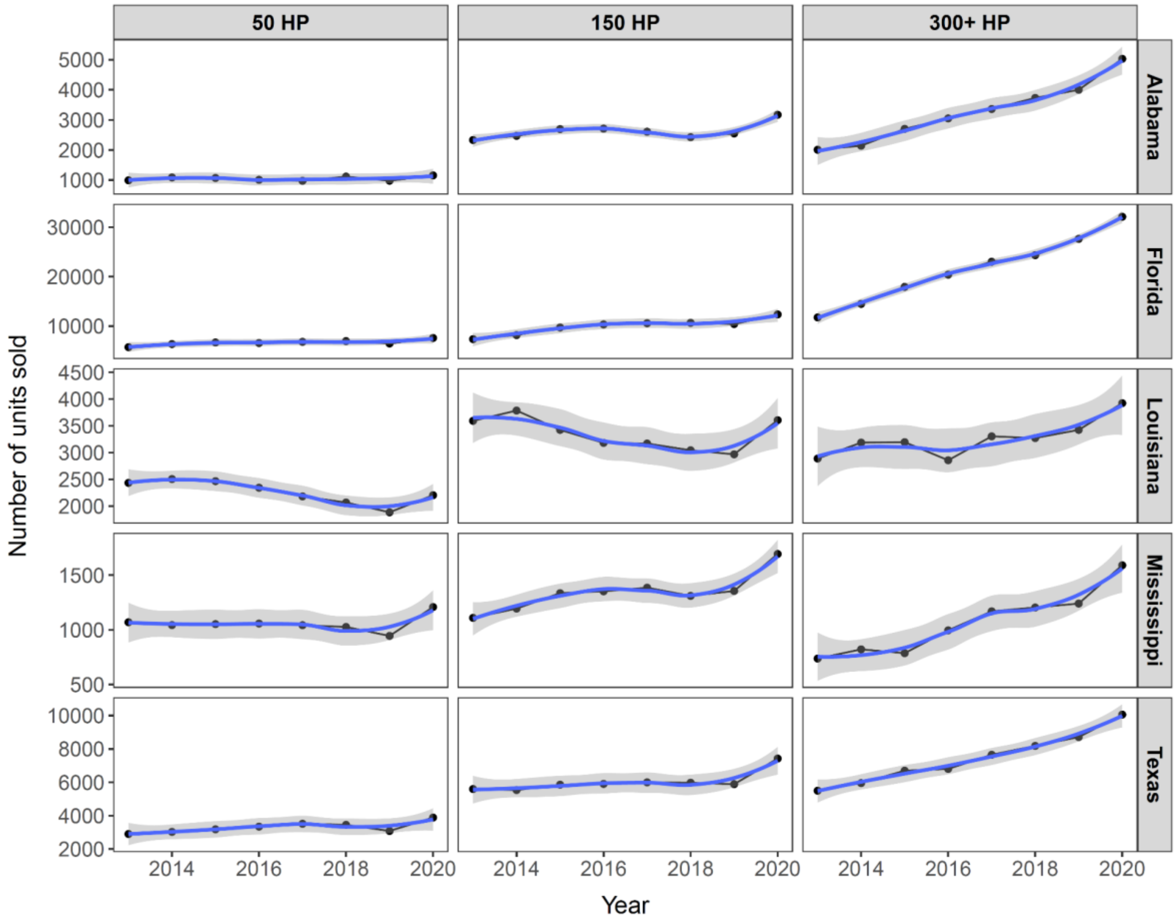

Figure 11. Outboard engine sales by GOM state from 2013 to 2020 for three different engine size groups: up to 50 hp (left panels), 50-150 hp (center panels), and 150-300+ hp (right panels). Blue lines denote loess smoothers and gray shading the corresponding 95% confidence intervals. Y-axis scales differ by state.