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Carissa L. Gervasi, Matthew McPherson, Mandy Karnauskas, J. Marcus Drymon, Evan Prasky, Hannah Aycock

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Using stakeholder knowledge to better understand uncertainty in the Gulf of Mexico red snapper stock assessment model

Carissa L. Gervasi[1], Matthew McPherson[2], Mandy Karnauskas[2], J. Marcus Drymon[3,4], Evan Prasky[5], Hannah Aycock[1]

[1]University of Miami
Rosenstiel School of Marine and Atmospheric Science
4600 Rickenbacker Causeway
Miami, FL 33149

[2]Southeast Fisheries Science Center
75 Virginia Beach Drive
Miami, FL 33149

[3]Mississippi State University
Coastal Research and Extension Center
1815 Popp's Ferry Rd
Biloxi, MS 39532

[4]Mississippi-Alabama Sea Grant Consortium
703 east Beach Drive
Ocean Springs, MS 39566

[5]Northeastern University
Department of Marine and Environmental Sciences
430 Nahant Rd
Nahant, MA 01908

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1. Introduction

The research described here primarily addresses the SEDAR 74 Gulf of Mexico red snapper review workshop term of reference #3, to ***"consider how uncertainties in the assessment, and their potential consequences, are addressed, and comment on the likely relationship of this variability with possible ecosystem or climate factors and possible mechanisms for encompassing this into management reference points."*** This working paper builds off of the previous working paper submitted for the SEDAR 74 data workshop, SEDAR 74-DW-16 (Gervasi et al. 2022), and presents additional research findings and discussion. Conceptual models of the red snapper fishery were created for each stock assessment area (western, central, and eastern Gulf of Mexico) based on the local ecological knowledge of fisheries stakeholders. Our goal was to use the conceptual models to identify important ecosystem and socioeconomic drivers and linkages related to sources of uncertainty in the SEDAR 74 stock synthesis model and highlight significant shifts in fleet or fishing behavior that may need to be accounted for within the assessment framework.

2. Methods

Due to travel restrictions surrounding the COVID-19 pandemic, fishermen were consulted for this project via informal phone conversations, rather than via a series of in-person workshops that have been employed in other participatory modeling studies (McPherson et al. 2022). Knowledgeable red snapper commercial, recreational, and charter-for-hire fishermen throughout the Gulf of Mexico were identified via multiple "entry points" to ensure to the extent possible that a diversity of opinions were accessed. Contacts were recommended by state agencies, the Gulf of Mexico Fisheries Management Council, NOAA Fisheries, and snowball sampling (Atkinson and Flint 2001). From these contacts, we attempted to balance individuals who have been regularly involved in the management process as well as those who have not. Additionally, we searched the internet for charter-for-hire fishermen, fishing clubs, and other businesses to find individuals who are not a part of the abovementioned network. Finally, at the end of the phone conversations, we asked interviewees to recommend other contacts who might have differing opinions on the fishery, to help ensure that snowball sampling would not result in a limited set of perspectives. We began by identifying hotspots of red snapper fishing effort by considering published analyses (e.g., Gardner et al. 2022) and consulted charter-for-hire and

commercial stakeholders in those areas. We continued consulting stakeholders until we reached a saturation state, where little new substantive information was gained from additional conversations. We then proceeded to consult with charter-for-hire and commercial stakeholders in other regions of the Gulf where red snapper is a smaller percentage of the fishery, to capture any regional differences in perspectives. Finally, a small number of private recreational anglers were consulted to ensure that any differences in perspectives among fishing fleets were accounted for. However, the universe of private recreational red snapper anglers is incredibly vast and diverse, so we did not expect to reasonably encompass all the perspectives from that sector. The local knowledge compiled for this study therefore represents a thorough but not exhaustive collection of the observations and opinions of Gulf of Mexico red snapper fisheries stakeholders. Via informal phone conversations, each angler was asked a series of open-ended questions with the goal to address the following research questions:

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?

Transcribed interviews were then used to draft regional conceptual models. Each regional model was created based on the knowledge and expertise of local red snapper commercial, recreational, and charter-for-hire fishermen. The western Gulf model included fishermen from Texas and Louisiana, the central Gulf model included fishermen from Mississippi, Alabama, and the Florida panhandle, and the eastern Gulf model included fishermen from west central Florida (roughly coinciding with the current stock assessment boundaries). Regional models were created so that any spatial differences in socio-ecological drivers and linkages were at the same spatial scale as the stock assessment model. Linkages between factors (edges) were weighted by the number of individual stakeholders who mentioned that particular linkage. These weights were used to assess aspects of the system of particular interest to a wide range of stakeholders.

Participatory modeling and local ecological knowledge are particularly well suited to help inform parameters relating to fleet behaviors, such as selectivity, retention, and discarding, as well as environmental drivers impacting processes such as recruitment. The conceptual

models were therefore used to determine which ecosystem and socioeconomic factors may have an impact on these parameters. Transcribed interviews were then reviewed for any mentions of specific changes in these factors, and timelines of these changes were compiled where possible.

3. Results

3.1 Regional conceptual models

A total of 53 fishermen were consulted for this project between 2021 and 2023, representing the charter-for-hire (29 captains), commercial (13 captains) and private recreational (11 fishermen) sectors (Table 1). Three regional models were created via conversations with these stakeholders; the eastern Gulf model (informed by 12 fishermen, Figure 1), the central Gulf model (informed by 26 fishermen, Figure 2), and the western Gulf model (informed by 15 fishermen, Figure 3). The eastern Gulf model contained 61 nodes and 77 linkages between them. The central Gulf model contained 78 nodes and 118 linkages. The western Gulf model contained 61 nodes and 82 linkages. For all three regional models, red snapper local abundance was the central hub of the model, with the highest degree centrality, or number of connections (Table 2). Recreational effort had the second highest degree centrality for all models, suggesting that recreational effort is one of the most important components of the red snapper system. Other important nodes that were central to each regional model included depredation or scavenging and high-grading & discarding. There were many more similarities than differences among the regional models, but there were a few identified factors unique to specific regions. The main regional difference was the type of habitat where anglers target red snapper. In the east region, there is a limited number of artificial reefs in deep enough water to attract red snapper. Therefore, anglers mostly fish the natural hard bottom habitat, including small rock piles and other natural structure:

"We concentrate 99% of our efforts on tiny, little potholes and little roll offs in the bottom, things like that, spots that are the size of my boat had 300 or 400 pounds of snapper on every single one of those spots. And there'll be hundreds and hundreds of spots in you know, a five mile by five mile area, and each one of them will be loaded with red snapper." - *east region charter captain*

Conversely, in the central region the dominant fishing grounds are artificial structures, due to less natural hard bottom habitat. The reliance on artificial habitat poses a unique challenge for central region stakeholders during hurricanes, which can move or destroy smaller artificial structures and impact catchability as well as fish distribution:

"When [hurricane] Michael rolled through here, it took out a big part of our artificial reef system, especially in state waters and in inshore waters. And some of those have been replaced, but like I said, there's been no real movement of fish from anywhere to repopulate the areas where they once were." - central region charter captain

"We build a lot of wrecks, a lot of private wrecks. Once that wreck gets moved or some of them destroyed, those fish get moved. You can imagine; if [a hurricane] can move a wreck, it's gonna definitely move the fish. And then they don't have a little wreck to come back to. We still have a bunch of reefs that maintain, and that helps, but some of the smaller inshore wrecks, they're just gone. They get tumbled and destroyed or covered up." - central region recreational fisherman

In the west region, offshore oil platforms are prominent fishing grounds for red snapper. Numerous stakeholders mentioned that the decommissioning and removal of oil rigs has had an impact on the fishing industry:

"Well, the only negative thing that I would see on the population of the fish is the lack of habitat that's been taken down with the oil industry in the last 20 years. That's destroying where the fish live, of course, and spawn and feed. But, we have not seen a negative impact with that. You would think there would be. Inshore, yes, because places where there used to be rigs where we used to fish, of course we can't fish there anymore because there's not any fish." - west region commercial fisherman

3.2 Changes in fleet targeting

Selectivity refers to the probability of capture by age or length for a given fleet. Multiple interrelated factors dictate selectivity, including gear type, targeting behavior, and availability of fish due to spatial and temporal constraints on fishing effort. Selectivity estimations are a

common source of uncertainty in stock assessments because changes in angler behavior (such as changes in targeting or fishing locations) can be difficult to observe and measure. In our conceptual models, stakeholders identified several drivers that may have resulted in changes to selectivity over time. These include management changes that have altered targeting behavior, and socioeconomic drivers that affect how accessible certain fishing grounds are to recreational anglers.

The commercial fleet transitioned from a derby-style fishery to an IFQ fishery in 2007, and stakeholders reported impacts of this change on where and how they fish. During the derby fishery, commercial anglers rushed to catch as many fish as possible over a short period of time, often fishing in inclement weather or in areas where they wouldn't normally choose to fish. The institution of an IFQ allowed commercial anglers to distribute fishing effort over the entire year, and be more selective about when and where they fished and what sizes of fish they targeted. This change in the spatiotemporal distribution of fishing effort due to regulatory change could feasibly have impacted selectivity.

"The size of the fish and the population of big fish, and when I say big fish, the red snappers that are over 10 pounds, is better today than I've ever seen it. Offshore, they don't try and target the big fish as much as they do 2 to 10 pound fish, perhaps. So, they might hit someplace where there's a whole lot of big fish and they drop the net one time, and they pick it up and there's a whole bunch of captains: "Hey guys. Hold the boat. We're gonna go someplace else. You never saw that during the derby fishing. During the derby fishing, when we were catching big fish and we had a 200 hour or 240 hour season to catch fish every month, and that's the only money we made for the whole month to feed everybody, whatever we had to do to catch fish and get up to that 2,000 pound limit, that's what we did." - west region commercial fisherman

Stakeholders widely mentioned that changes in boat and fishing technology have made it easier for recreational anglers to target red snapper, and have led to both increased recreational effort as well as increased catchability. Stakeholders from both the east and central regions stated that because of this technology, recreational anglers are fishing further offshore than they used to, encountering larger fish that inhabit deeper waters. One east region charter captain noted that 20 years ago (~2002) it was much harder for novice anglers to target red snapper, but

technological advancements have made it much easier. An east region recreational fisherman reported an increase in large vessels over the past 15 years (since ~2007), and a commercial fisherman in the same region similarly noted that dealers have been continually selling bigger and faster boats since 2010. These changes in technology since the mid 2000s may have led to an increase in size selectivity of red snapper by the recreational fleet. On top of the technological advancements, several stakeholders noted that localized depletion over the course of the fishing season is a common problem that has been particularly bad in recent years. Anglers are often forced to go further offshore to find fish once the nearshore habitats get fished out:

"This is the first year in the past seven or eight, like the first of July at our state sites in closer, like 25 to 30 miles. They got beat up this year. There wasn't much. I get enough money and I carry more people so I can go out by the Alabama dumping ground and wrecks that are further offshore. This year I had to go 38 to 45 miles, the whole month of July. But I can do that, and there's fish there but in our state sites, up in 60, 70, 80 foot of water, they got beat up." - central region charter captain

However, stakeholders also mentioned that gas prices can dictate how far offshore recreational anglers are willing to go for red snapper. When gas prices are particularly high, anglers may run shorter trips closer to shore, where they would be targeting smaller red snapper. There may therefore be some interannual variability in selectivity due to fluctuations in the economy.

"What I would say is you see more people trout fishing, red fish, staying – or if they do go snapper fishing, they fish the closest wrecks that they can. Especially when Joe Blow just takes his family, he doesn't have other fishermen to split gas with. When he has to bite off the whole cost, it's like, "Come on now. We gotta – we can't go as far as what we'd like to." - central region recreational angler

3.3 Retention and discarding

In a stock assessment context, retention is an important parameter that describes how fish are landed vs. discarded in targeted fleets. Discarding behavior, specifically why anglers choose to keep or discard particular fish and how those choices change over time, is difficult to observe

and monitor. Retention estimates and estimates of the magnitude of fisheries discards in general therefore tend to have high uncertainty. Conceptual models revealed several factors that stakeholders felt impacted discarding behavior, and anglers described how these factors have changed over time. Many stakeholders reported that the amount of recreational discarding in general has increased due to a variety of factors. Across all regions, there has been a perceived increase in the number of recreational anglers targeting red snapper over time, due to human population growth, technological advancements that have made targeting red snapper easier, and recently the COVID-19 pandemic. This increased recreational effort is thought to have led to increased discarding. Several stakeholders also noted that the institution of a red snapper season greatly increased levels of discarding, since red snapper are often caught incidentally when other species are being targeted during the red snapper closed season:

"And I'm gonna tell you something, our closures and our seasons, I don't have the right answers for all this, and I know you don't either. But our discards, whether it be triggerfish today, red…today it's a red snapper, they're 100% discarded. 100% of the red snapper I catch from now until June 1st will be discarded. And I don't know what the actual numbers are on survival, but I'm pretty sure popping holes in their bellies or in their mouth or wherever it is and making them disappear on you is not that great of an answer." - central region charter captain

"I think that our seasons are messed up because on recreational sides, you're keeping red grouper part of the year and you're gonna be throwing gags of those snappers back. Red grouper's gonna close sometime mid-summer, and red snapper seasons are gonna be extended. So, you're gonna be discarding the red grouper while you're keeping gags of red snapper. And, the next year when they have a two month season or one month season that maybe starts in September, we're gonna be discarding all the way across the board across every season at least one to two of our primary species." - east region commercial fisherman

Highgrading, or discarding of legal sized fish either intentionally or due to regulatory limitations, was one factor mentioned by both commercial and recreational stakeholders. In the recreational fishery, several anglers noted that because the bag limit is only two fish per person, it encourages highgrading by inexperienced anglers in particular, who want to retain the largest

fish they can find. These anglers will therefore discard previously caught red snapper above the size limit if a larger red snapper is encountered and landed during a fishing trip:

"So, you have boats out there and they're limited on the amount of fish they can catch so they're trying to highgrade on what they catch. And, that's a lot more detrimental to the industry than people think. They go out and catch a five-pound fish. They might throw 10 five-pound fish back in the water to be able to keep one 10 pound fish. And then, that has a drastic impact on the mortality rate of the fish, as well." - *west region commercial fisherman*

"I think that the creel limit needs to be raised up to four or maybe five fish per person to maybe reduce some of the bycatch that might be happening. If they know they can keep four fish per person instead of just two, I think they might have a tendency to keep some of the fish they might otherwise discard because two just seems to be almost none. Four or five fish, I think, would actually help some of the bycatch because it's not doing the stock any good for people to go out there and they catch let's say a 10-pound snapper. And they're like well, that's a nice snapper but I know there are some bigger. So, they're going to throw that fish back and there's a chance it's not going to make it because sharks are terrible right now." - *central region recreational fisherman*

One central region recreational angler gave an account of his own discarding behavior, specifically noting how legal or barely legal red snapper are often caught while targeting other species, but these barely legal fish are less desirable and so are discarded:

"This past Monday, of this week, we went out and we were targeting triggerfish first and so we actually caught I think 11 undersized triggerfish and caught one legal that we could keep. And then we changed our tackle and what I talked about before, using whole bait, and then we end up catching our limit in snapper. But while we were trying to catch triggerfish on the smaller circle hooks, and just using squid, we ended up catching probably 20 red snapper that we threw back. They were right around the 15-inch long type – some of them were legal, but I went ahead and just threw them back until we ended up catching four that was good enough to keep." - *central region recreational fisherman*

It is likely that discarding of legal-sized fish increased once the bag limit was reduced to two fish per person. There was also a previous reduction in the bag limit in 1995, to five fish per person. According to one central region recreational angler, this management change likely did not cause increased highgrading, because the abundance of red snapper was so low the average fisherman had a hard time even reaching the five fish per person limit:

"Back to the early 2000s, the fish were hard to catch, and you really, really had to be on your A-game to catch a limit of red snapper on your boat, even if you only had two people. I mean, you really had to know what you were doing. But your average fisherman was not catching a limit of fish. I mean, they may catch one or two, maybe three or four, but a lot of those fishermen would target something else, king mackerel, Spanish mackerel, whatever, because snapper fishing was so hard." - central region recreational fisherman

On the commercial side, the institution of an IFQ fishery had both a positive and negative effect on retention according to stakeholders. Commercial fishermen from all three regions agreed that the switch from a derby-style fishery to an IFQ generally decreased discards overall (of all sizes), because there was less of a rush to fish:

"Which just goes to show what a terrible fishery management tool [the derby] was. I mean, to open the season on the first of the month; for 10 days, every single person with a permit going out there trying to catch them, and the amount of discards were unbelievable. That's one of the biggest differences between the old management and the new management. But now with the IFQ, I can go further out and not have to throw so many fish back because I have plenty of time. I'm not restricted to 10 days of the month to make as many trips or catch limits of 2,000 pounds a trip. I can take my time and be more selective and not have to worry about discarding a whole bunch of fish because I have to hurry up and get back in. So, that's been a huge difference." - west region commercial fisherman

However, the allocation structure of the IFQ fishery (specifically quota leasing) was thought by stakeholders from all three regions to cause increased discarding of legal-sized fish. If

commercial fishermen catch more red snapper than they have available quota, those excess fish must be discarded. High lease prices make it difficult for some commercial fishermen to lease enough red snapper quota to account for fish that are caught while targeting other species (e.g., red grouper). Regulatory discarding was thought to be particularly prevalent in the east region, since commercial fishermen in that region received little red snapper allocation when the IFQ was implemented:

"It happens with me and it happens with a lot of the other fishermen. We catch those fish. And I know a big problem is the throwback or the discards. Well, when you can't harvest that fish or it costs you too much to harvest that fish, you're not gonna put that fish in your box when you can put something in a box that's gonna pay you some money, more than $2 a pound or more than $1.50 a pound." - east region commercial fisherman

"And I mean there's piles of them and I'm discarding them because there's really no sense in leasing a quota. With the price of the quota, I don't even want it to take up room in my box. My parents own a longline boat, the captain told us that he's discarding probably 2000 pounds per trip." - east region commercial fisherman

In all conceptual models, high levels of highgrading and discarding in both the recreational and commercial fisheries among other factors were thought to have led to increased scavenging and depredation (the complete or partial removal of a hooked fish by a predator before it can be retrieved by a fishing vessel; Mitchell et al. 2018). High incidence of depredation could feasibly affect retention rates, influencing the size of discards. Anglers reported having to discard fish above the legal size limit due to predators removing the fish from hooks before they could be fully landed:

"It's gotten ridiculous. I have pictures of snapper that would've been in the high 20s, close to 30 pounds, that have gotten ate off at the boat. I've had days where I've lost a dozen snapper in a row by sharks." - central region recreational angler

3.4 Discard mortality

Discard mortality is an important component of stock assessment models, as changes in discard mortality over time can affect estimates of total fishery removals. However, direct observations of the mortality of discarded fish are limited and mortality estimates can therefore have high uncertainty. Red snapper stakeholders observed several factors that they believed affect survival of discarded fish, including fishing depth, water temperature, and depredation. Many stakeholders felt that discard mortality overall was fairly low for red snapper:

"And when I say throw a lot back, generally, we catch our big ones, or our bigger ones, and then where we run into the issues of having to throw a lot back is like, we go to other wrecks, or we're at a particular wreck. We caught red snapper on. Well, we change our rigging to catch vermillion snapper, and then we catch vermillion snapper plus a bunch of small baby snapper. So, we are throwing a lot of those back also, but honestly, we really haven't had a lot of mortality rate. We have the venting tool… So, I would say maybe out of – if you caught 10, I'd say maybe one, maybe one or two that we had an issue with." - central region recreational angler

However, some people identified certain situations where mortality rates increased substantially. A charter captain who operates a large headboat in the central region commented about the negative effects of having the open season in the summer months. According to the captain, survival rates for discarded fish are much lower in warmer water than in cooler water. On top of that, there are more tourists in the summer months, so boats are fuller and it's more difficult for deckhands to help passengers release fish in a timely manner:

"The cooler the water, the easier it is on the fish. When the water's hotter and we have packs of anglers fishing on the boat, not only is it better for the fish that we discard in cooler water than to stress it out in the hot water. But, also, we have all these anglers, all this effort that's happening and a finite amount of crew members that know how to properly handle the fish. So, we pull up and we're catching a bunch of red snappers. I have a higher dead discard rate in warm waters with a packed boat than I do in the spring with cooler waters and a better deckhand to passenger ratio if that makes sense." - central region charter captain

Barotrauma was mentioned by a few anglers, but for the most part it seemed to only be a real issue in very deep water, especially since descender devices became widely available. If recreational anglers are fishing further offshore than they used to, barotrauma may be more of an issue than it was in the past.

"I would say most of our fish runs we've been on, we don't have any issues about [discard mortality]. Now, there are some times when we're catching grouper in 300 or 400 feet of water, it's the craziest thing to reel up a snapper in 350 feet of water. And that fish is not going to live. There is absolutely no way to send that fish back down." - central region recreational angler

As mentioned previously, many stakeholders felt that depredation has increased over time. Increased discarding, increased shark populations, and generational learning by bottlenose dolphins to follow fishing vessels were cited as causes of the increased depredation. There is limited data regarding the frequency of shark depredation, and the only standardized method of data collection of depredation is from NOAA observers within commercial fisheries (NOAA Fisheries 2023). As such, shark depredation is a source of cryptic mortality within commercial and recreational fisheries, meaning that its contribution to fish mortality is not considered within stock assessments. One charter captain in the east region noted a substantial increase in depredation by bottlenose dolphins since about 2010 that he reported has gotten worse every year, and he noted the effects on discard mortality:

"Currently, in my industry, my bite-catch discard rate or my bite-catch mortality rate is somewhere around 20%, give or take how deep we're fishing. When the dolphin packs show up – and they're everywhere on every boat multiple times a day – follow you around, take 100% of the fish off your string; you don't even get them to the boat, and if you do get them to the boat and you throw them back they keep them and they follow you around and they surf your wake and it's gotten worse and worse and worse and worse and worse and worse." - east region charter captain

A workshop specifically aimed at characterizing depredation in the Gulf of Mexico reef fish fishery was held on April 4, 2022 in Gulf Shores, AL. Details of the workshop goals are described in Drymon et al. (2022). During the workshop, twenty-three charter-for-hire captains were asked to draw trendlines of depredation beginning in the first year they began working. These drawings were used to develop a time series plot to understand how depredation has changed through time. The first observable year was 1985, and most observations began between 2000-2005. Blank graphs only contained unlabeled X and Y axes, and captains were responsible for labeling and adding a trendline for the frequency they encountered depredation. Plots were digitized using the R digitize package (Poisot 2011). Several plots contained unlabeled depredation rates but lined up with other charter-for-hire captains' plots. To reconcile unlabeled depredation rates, several assumptions had to be made. The first was adding a depredation baseline derived from historical data. Mandelman et al. (2008) and MacNeil et al. (2009) provided historical estimates of depredation on pelagic longline sets in the Northwest Atlantic starting in the 1900s; their rates were at a minimum of 4% and 2.3%, but the results were highly skewed. A baseline was established at 4% for observations prior to 2010, and all results after 2010 were taken from charter-for-hire labeled observations. The second assumption was that for those with unlabeled depredation frequencies on their axes, trendlines would be fit to match those of their peers. The consensus when talking with all charter-for-hire captains was that depredation has significantly increased since 2015. Thus, the second assumption reflected the collective view. Observations before 2000 were potentially biased due to a low sample size. A 95% confidence interval was added using the polygon function in R. The trends identified from the charter-for-hire captain plots align with trends from private recreational anglers in the same region (Prasky et al. 2023). Trendlines drawn by charter-for-hire captains revealed relatively low levels of depredation until 2005, when depredation incidence was perceived to increase exponentially (Figure 4). The timing of increased depredation coincides with stabilizing coastal shark populations (Peterson et al. 2017; Pacoureau et al. 2023). An increase in depredation since the mid-2000s has likely led to an increase in discard mortality that is currently being unaccounted for in stock assessments.

3.5 Recruitment

In stock assessment models, population processes such as recruitment are often estimated with high uncertainty as they can be influenced by a myriad of unknown ecosystem drivers. Although red snapper stakeholders did not specifically refer to recruitment as it is defined in a stock assessment context, they did have several observations of ecosystem drivers that might impact settlement or colonization of new recruits. Specific ecosystem drivers included installations of artificial reefs, hurricanes, and red tide events. One central region charter captain explained his observations of how new artificial reefs become entire ecosystems and potentially create new settlement areas for red snapper recruits:

"...the carbon steel within a month will have barnacles on it already and then it's the whole food, the whole food chain starts quicker… Once that food chain starts and the cigar minnows, the alewives, they start showing up on these reefs as bait. And in this area you have so many, you know, the shrimp and the crabs that are flushing out of Mobile Bay, which is what feeds our area, snapper move. And if they come up on a new reef, man they'll stay there… But once they spawn you can take a Sabiki rig for bait and go up to some of these spots in the fall and you'll catch red snapper an inch or two long." - central region charter captain

Hurricanes were observed to have varying impacts on red snapper populations and fisheries. One charter captain from the central region noted that large recruitment events appeared to be tied to active hurricane seasons, but he was not sure why:

"The interesting thing to me is you look at the recruitment in '04 and '05 and '06, it's through the roof. Well, you look even further… why are those three years so high? Because it ties directly to the three most active hurricane seasons we've ever had. And why is that? And you know, what is the best action? I have no idea." - central region charter captain

Strong hurricane seasons may have some effect on red snapper recruitment, but the direction and intensity of individual hurricanes may also be important. One central region charter captain observed that while smaller hurricanes may benefit fisheries, large, powerful hurricanes may have a negative impact on fish populations:

"The small hurricanes are good to an extent, and it kind of lets, the fish will move in the local area; it'll kind of bring some fish in from offshore, it'll help stock the nearshore reefs. But a big baddie like Sally, you know, it sat on us for five hours at 125 miles an hour, and nothing else is going to survive that nearshore; it ain't gonna happen."

In August 2014, a massive red tide event occurred off the Big Bend region on the west Florida Shelf. According to one fisherman, the red tide caused substantial grouper mortality, which allowed red snapper to recruit into and occupy reefs in more shallow waters than they were typically encountered, where they remained until about 2019:

"[Eight] years ago, there was a drastic increase in red snapper, which directly correlated with the previous red tide. After that red tide decimated that bottom, red snapper was the first fish to fill back in and repopulate that bottom. We noticed from diving it, I dove probably 200 to 300 dives a year on the Gulf Coast in the big bend area… After that, the red snapper pretty well held their own in that fishery until the year before last. Once the displaced gag grouper and red grouper started to move back into those areas from offshore structure outside of 100 foot, they were large enough to push that red snapper that historically had never been in those spots, back off that natural shallow water grouper bottom. That started to happen about three years ago. Wasn't real apparent until last year that that was, you know, I guess you might say reverting back to what it had historically been." - east region charter captain

Based on this stakeholder's observations, red tide events may benefit red snapper recruitment in instances where the event causes high mortality of species that typically compete with red snapper for habitat and food resources (e.g., grouper).

3.6 Historical perceptions of the red snapper population

Historical abundance estimates can have high uncertainty in stock assessments due to a lack of data. Fisheries-dependent and -independent data sources also typically lack fine-scale spatial information about abundance patterns. Experienced fisheries stakeholders can provide substantial and nuanced information about perceived fish population trends. Gulf red snapper

stakeholders seemed to be most concerned about and familiar with red snapper abundance in their local fishing area rather than abundance of the entire stock. Some anglers believed Gulf-wide stock abundance may have decreased slightly over the past few years due to increasing recreational effort, but most anglers thought the population as a whole was doing well. Several veteran stakeholders were able to supply timelines of perceived changes in red snapper abundance via personal observations and/or community knowledge. An east region commercial captain provided knowledge of relative abundance patterns back to the 1940s. According to the observations of a commercial captain he once worked with, red snapper were prolific in the eastern Gulf in the 1940s:

"You could get 20 cents a pound for red snapper, and grouper was a nickel a pound if you could sell them. That was in the '40s and actually before that. He was fishing over here in the '40s. 1940s after World War II. He was in the Navy. He said there was times they were in 300 to 350 feet of water and the snappers were on the surface. He's got an eight millimeter video of the '40s when they were at one of those wrecks down there. They pulled about 20,000 pounds off of one place." - east region commercial fisherman

In the 1950s and 60s, there were still a lot of red snapper in the area, but in the 1970s populations began to decline markedly, such that the east region became more of a red grouper fishery than a red snapper fishery:

"So, the '70s, we were grouper fishing 'cause there wasn't enough snappers to really keep the fleet going." - east region commercial fisherman

In the 1980s and 1990s, the perceived abundance of red snapper in the east region was still very low. For example, one commercial fisherman reported he never saw a red snapper when he first got involved in fishing in the Gulf of Mexico in the late 1990s / early 2000s:

"Well, I got involved in fishing here in the Gulf of Mexico probably about 20 years ago. I moved here from Ohio. During those first few years while I was fishing here just doing some

recreational fishing, I never saw a red snapper. I always heard about them, but I'd never seen one." - east region commercial fisherman

Numerous stakeholders agreed that management regulations allowed the red snapper population to begin rebounding in the 1990s, and really starting to come back in the early to mid-2000s, especially once the commercial fishery transitioned to an IFQ:

"This has really gotten to be a, you know, 2007 onward fishery even here in Steinhatchee where I've been out for a good number of years." - east region commercial fisherman

Most stakeholders agreed that the red snapper population in the east region is currently healthy, but may have declined slightly or at least leveled out over the past 3-5 years due to recreational fishing pressure. Similar historical observations were made by stakeholders in the central and west regions. There was general consensus that abundance was very depleted in the 1980s and 1990s but started rebuilding in the 2000s with changes in management. In the central region, several anglers perceived a decrease in abundance in recent years. In the west region, most anglers agreed the population appeared to be continually increasing. Although stakeholders generally agreed that the Gulf red snapper population appears to be currently healthy, localized depletion of the resource appears to be a prominent and worsening issue, particularly in the central and east regions. According to one central region charter captain, *"localized depletion is spreading like a red tide"*. Other stakeholders provided specifics about where localized depletion is occurring, mainly in areas where recreational effort is particularly high, and especially inside of 30 miles:

"I think we've been blessed with a lot of beautiful weather. And with that, especially with COVID with everybody not working and having all that free time, I think that we've seen a big increase in effort in the eastern Gulf. And I think that kinda contributes to the more localized depletion that we see in the bigger ports, such as Destin, Pensacola, and Orange Beach and Panama City where you have these armies of anglers." - central region charter captain

“When they started to up the quota and then we've had here in the last probably seven to eight years, the absolutely out of control, explosive effort that we've had, it's steadily going downhill. Everybody's having to go 30 to 50 miles to catch anything. Localized depletion inside of 30 miles, it’s an issue.” - central region charter captain

According to stakeholders, localized depletion seems to be a more recent issue, since about the mid 2010s and again mainly due to increased recreational effort:

“Now, they’ve built all these artificial reefs and what's happening now is we've been negative trending in that the rate of removal off the reefs is faster than the rate of replenishment. So, in a nutshell, we've been, in the banking terms we used to call it the negative trend. So now, five years ago I warned the council that out to about 10 miles, there's becoming a depletion zone, and then they started using the term localized depletion. Now that zone is out to about 35 miles now, and still, and my message is still falling on deaf ears.” - central region charter captain

"Back in, you know, '08, '09, '10. Then we had that red tide in '14. I could stop in 50'-60' of water and catch a couple hundred pounds of snapper on each of, say, three or four different spots before I moved offshore to maybe do a little bit more grouper fishing. That local depletion now is because of the rec effort. It's not because of me, because you gotta figure, there's only seven commercial boats, and I was one of the few that was actually releasing snapper. So, no, it's made a difference now. Because of the long season, we have almost a 57-day recreational season, anything near shore – so, I'm offshore. I don't even stop until I get to 60 miles now." - east region commercial captain

As mentioned previously, localized depletion may force fishermen to alter where they fish, going further offshore than they normally would. Not only could this impact selectivity, but it also likely has an economic effect on the fishery that could have implications for fisheries management.

4. Conclusions

It is well understood that fisheries are socio-ecological systems, and as such are impacted by a variety of interacting factors. Our research has shown how stakeholder knowledge can help to tease apart these factors, and better understand uncertainties in stock assessment models. Conceptual models created from conversations with Gulf of Mexico red snapper fishermen revealed several socio-ecological drivers that likely have an effect on selectivity and retention rates, discarding and discard mortality, and recruitment. Further research into these drivers could help decrease model uncertainty in future SEDAR assessments. 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 fishermen consulted for this project by region and fleet.

	West region	Central region	East region	*Total*
Charter anglers	8	16	5	*29*
Commercial anglers	5	2	6	*13*
Recreational anglers	2	8	1	*11*
Total	*15*	*26*	*12*	***53***

Table 2. List of nodes with degree centrality of 5 or more for each model. Parentheses denote degree centrality value (i.e., number of connections) for each node.

Degree ranking	West model	Central model	East model
1	Red snapper local abundance (17)	Red snapper local abundance (16)	Red snapper local abundance (19)
2	Recreational effort (13)	Recreational effort (15)	Recreational effort (11)
3	Depredation or scavenging (8)	Red snapper CPUE (10)	High-grading & discarding (8)
4	High-grading & discarding (6)	High-grading & discarding (9)	Red snapper lease price (7)
5	Red snapper lease price (6)	Red snapper movement inshore (9)	Depredation or scavenging (5)
6	Tourists (5)	Depredation or scavenging (7)	
7	Red snapper movement inshore (5)	Length of red snapper season (5)	
8	Commercial profit (5)	Post-release mortality (5)	
9		Hurricanes (5)	
10		Local economy (5)	
11		Number of recreational anglers (5)	
12		Human population (5)	

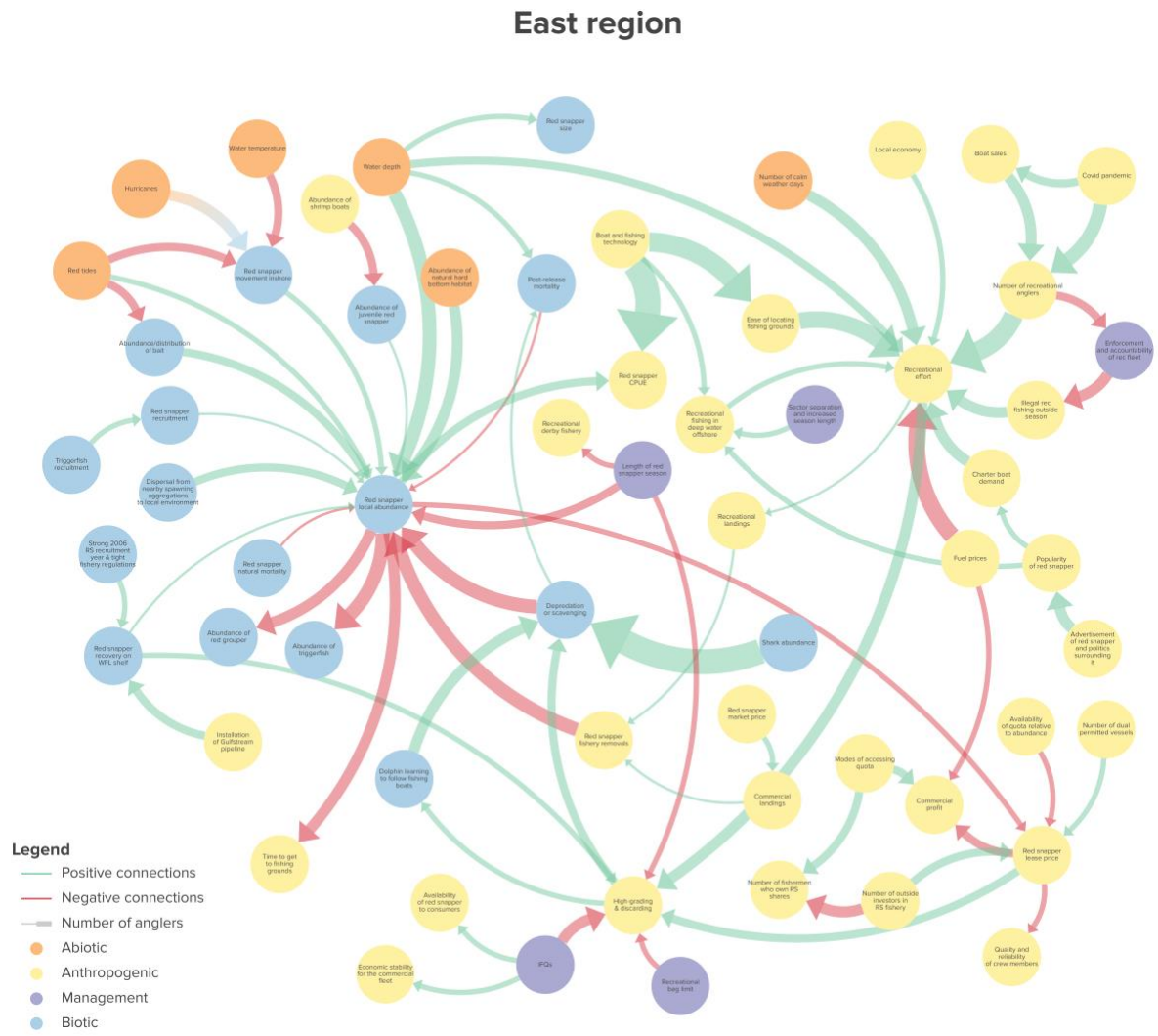

Figure 1. Red snapper conceptual model of the east region (west central Florida). Arrows show directionality of connections between nodes. Green arrows denote positive connections and red arrows denote negative connections. Nodes are colored by the broad category each factor belongs to (abiotic, anthropogenic, management, or biotic). The width of each arrow represents the number of anglers who mentioned a particular linkage, with wider arrows indicating more mentions.

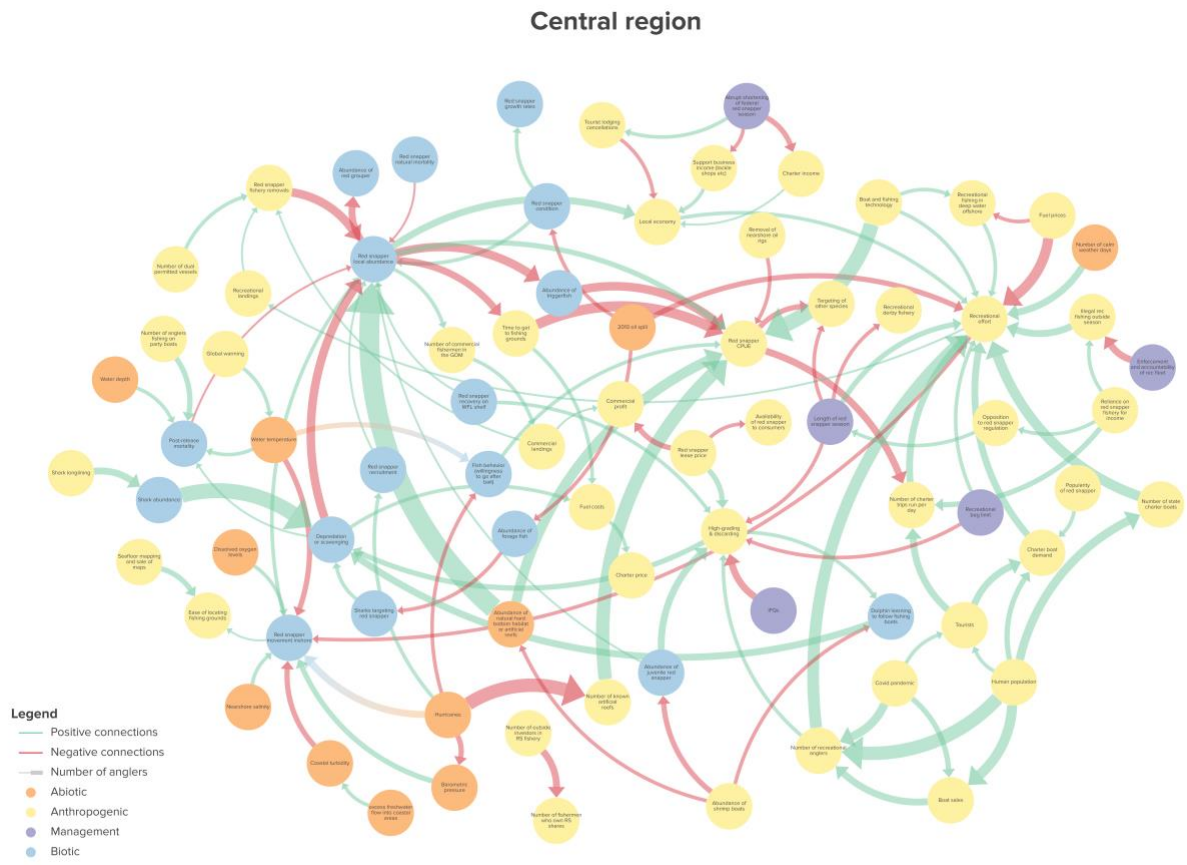

Figure 2. Red snapper conceptual model of the central region (Mississippi, Alabama, and the Florida panhandle). Arrows show directionality of connections between nodes. Green arrows denote positive connections and red arrows denote negative connections. Nodes are colored by the broad category each factor belongs to (abiotic, anthropogenic, management, or biotic). The width of each arrow represents the number of anglers who mentioned a particular linkage, with wider arrows indicating more mentions.

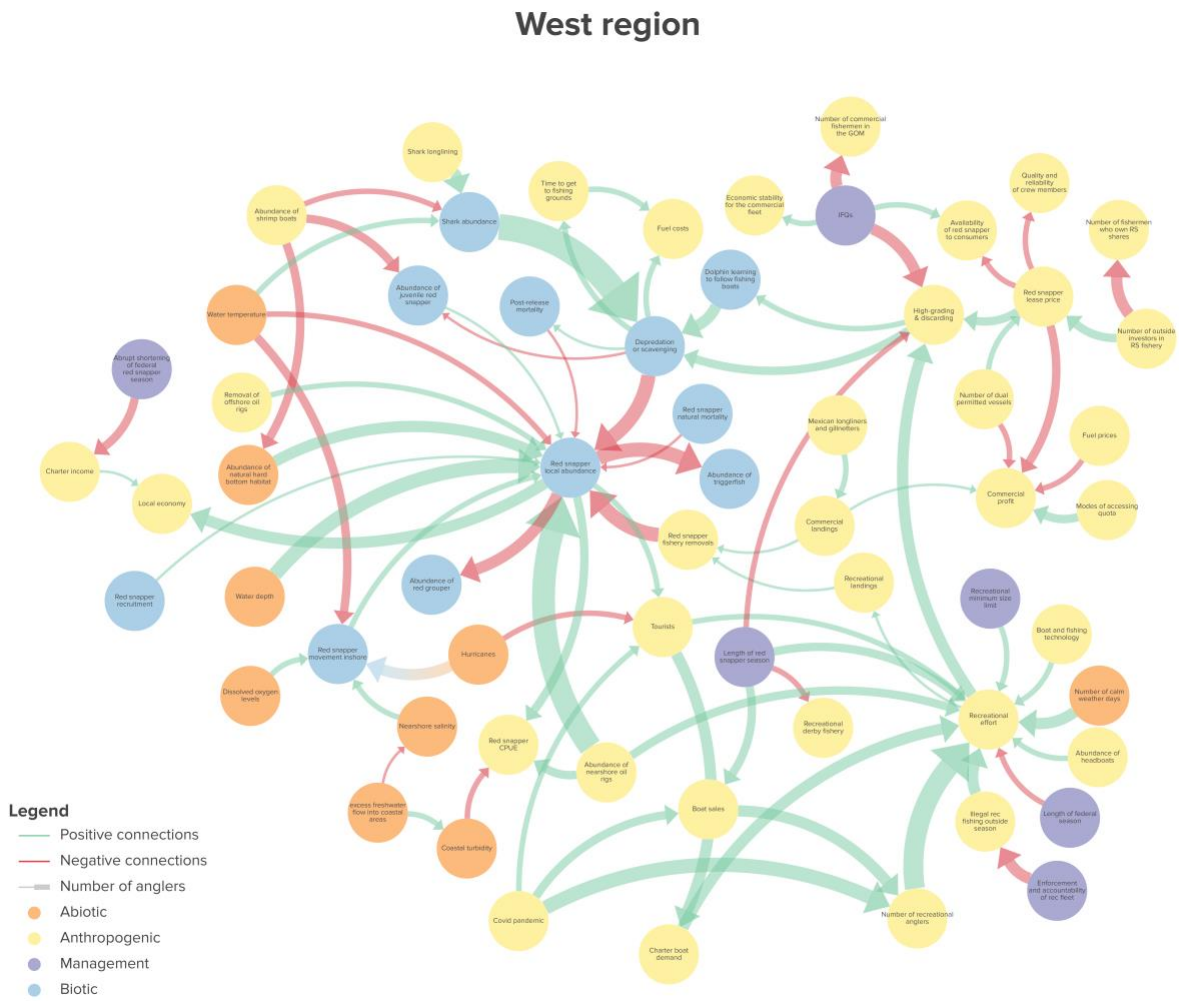

Figure 3. Red snapper conceptual model of the west region (Texas and Louisiana). Arrows show directionality of connections between nodes. Green arrows denote positive connections and red arrows denote negative connections. Nodes are colored by the broad category each factor belongs to (abiotic, anthropogenic, management, or biotic). The width of each arrow represents the number of anglers who mentioned a particular linkage, with wider arrows indicating more mentions.

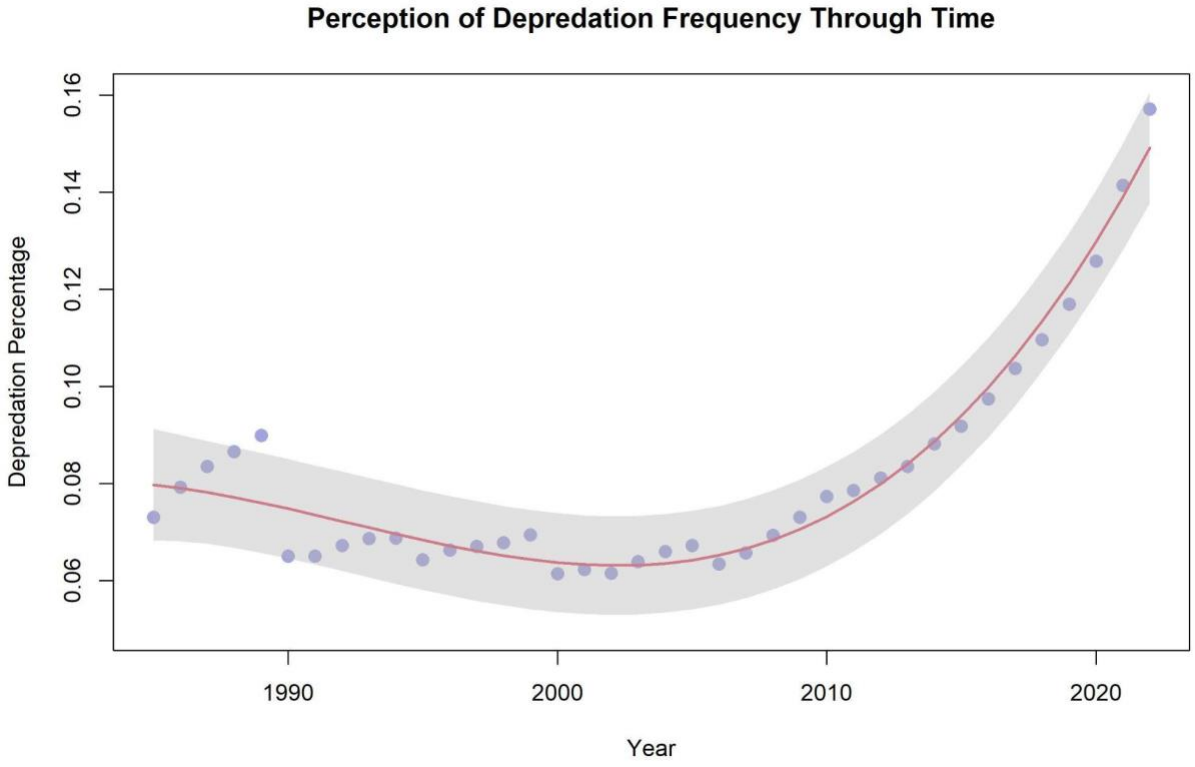

Figure 4. Charter-for-hire perceptions of depredation through time. The Y-axis displays the depredation percentage, the X-axis displays the year, and the red trendline is the mean reported depredation percentage. Blue dots are individual mean points corresponding to a particular year, and the gray-shaded region is a 95% confidence interval.