Use of Fishermen's Local Ecological Knowledge to Understand Historic Red Tide Severity Patterns

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1. Introduction

Red tide events, caused by *Karenia brevis* algae blooms, are common, almost yearly occurrences along the southwest coast of Florida (Kusik et al. 1999). Data and anecdotal accounts suggest that in some years, red tide events last longer and cover a wider area resulting in massive fish kills, while in other years red tides are patchy, short-term events without much observed impact on the ecosystem (Maze et al. 2015). Severe red tide events, however, can also have extremely negative impacts on the local economy (Adams, 2017). The causes and local triggers of these blooms as well as some of the key attributes of the bloom events, such as spatial and temporal extent or how red tide events affect species and habitat, remain uncertain (Kusik et al. 1999). Much of the research conducted to date on the spatial and temporal extent of red tides in Florida uses two main data sources: satellite imagery (e.g., Sea-viewing Wide Field-of-view Sensor [SeaWiFS], Moderate Resolution Imaging Spectroradiometer [MODIS]) and the Florida Fish and Wildlife Conservation Commission's Fish and Wildlife Research Institute (FWRI) database of cell counts from in-situ water samples. Satellite data are useful for detecting surface blooms in offshore areas, although it can be challenging to distinguish between red tide and other algal blooms (Voiland 2018). In contrast, the FWRI data collection is focused mostly in inshore areas, and often is not able to sample offshore blooms (Voiland, 2018). The FWRI historic database is a mix of systematic, opportunistic, and event-response sampling lacking the necessary consistency to accurately understand decadal trends and patterns (Christman & Young, n.d.). Additionally, the satellite data and the FWRI count data can only provide information on the presence or absence of blooms and show the areas of concentration, but miss critical information on the larger ecosystem impacts of the bloom, such as mortality, habitat loss, or ecosystem recovery. Finally, there are potential side effects of red tide that may have a substantial influence on the ecosystem but cannot be tracked in the satellite data or cell count data. For example, an offshore 2014 bloom was associated with hypoxia (Driggers et al. 2016), which can augment fish mortality and impact benthic habitats (Gravinese et al. 2020). Overall, there is a lack of understanding of historical patterns in red tide severity and associated impacts.

1.1. LEK and Fisheries Science

Given the limitations of existing red tide data sources, there is a need for data collection methods that can complement the current spatial and temporal scale coverage (Stauffer et al. 2019) and, at the same time provide other important information related to the short and long-term ecosystem changes related to red tide events. A growing body of research discusses and demonstrates the importance of fishermen LEK in providing valuable insights for fisheries science and management (Neis et al. 1999, Huntington 2000, Berkes 2000, Johannes et al. 2000, Drew 2005, Johannes and Neis 2007, McCay et al. 2006, Stanley and Rice 2007). LEK has successfully been used in data-poor contexts (Tibby et al. 2007, Lopes et al. 2018) particularly to assess the dynamics of fish populations, often from a historical perspective (Saenz-Arroyo & Revollo-Fernandez 2016). Trend estimates provided by fishermen often strongly concur with other data sources, and can provide a good understanding of abundance (Saenz-Arroyo & Revollo-Fernandez, 2016) or environmental degradation trends (Bunce et al. 2008).

Hind (2015) provides a comprehensive overview of the past century's fishermen LEK research and shows that an interdisciplinary and applied social science approach to gathering fishermen LEK facilitates the integration of fishermen's knowledge with science and management. Some of the first fishermen's LEK research to be referenced in the management of commercial fisheries is Hanna's (1998) study on the soft shell clam (*Mya arenaria*) fishery of Maine, United States. Hanna's (1998) study was followed by the integration of fishermen's LEK research on the orange roughy (*Hoplostethus atlanticus*) in Ireland (Shephard et al. 2007) to inform the stock assessment. Other LEK research informed the management of marine habitats in Norway (Maustard, 2000) and the design of marine protected areas (Nenadovic et al. 2012; des Clers et al. 2008). More recently, Stephenson et al. (2016) documented an uptake in the use of LEK knowledge in fisheries science and management.

Less referenced in fisheries science and management is the use of fishermen LEK to inform the magnitude and impact of environmental stressors on the marine ecosystem, particularly with a historical lens. The human dimensions of HABs have been previously explored by anthropologists who have provided insights on the importance of cultural models in shaping how stakeholders interpret scientific results and policy interventions (Paolisso & Chambers 2001). Notably, cultural models can explain why at times, public reactions to HABs are poorly matched to actual risks, and can improve communication and education programs (Kempton & Falk 2010). Furthermore, ethnographic research methods have been employed to further assess how stakeholders with a variety of political and socioeconomic concerns can work collaboratively with scientists to develop mitigation efforts (Van Dolah et al. 2016). Some studies have documented the use of citizen science or stakeholder observations on harmful algal bloom (HAB) occurrence and severity (Anderson et al. 2019, Schlacher et al. 2010). We are unaware of studies where local knowledge on HABs, including fishermen LEK, has been integrated into fishery science and management. This paper, in addition to supplementing the historic record, brings attention to the wealth of information that fish harvesters, processors and dealers can supply to the study of the ecological and socio-economic impacts of chronic maritime stressors such as HABs.

1.2 Scope of this Study

Fishermen in the Gulf of Mexico have voiced concerns regarding the impacts of red tides on fish populations for decades, particularly in relation to grouper species (SEDAR, 2006). Concerns regarding a long-lasting 2005 red tide event motivated stock assessment scientists to quantify red tide severity, given the suspected impacts of these episodic mortality events on fish populations (Walter et al. 2013). In 2018, National Oceanic and Atmospheric Administration (NOAA) Fisheries scientists initiated a workshop with constituents to understand key factors affecting snapper-grouper fisheries in the region, and at that time additional concerns were raised regarding the deleterious impacts of red tide events on marine populations and fishing community resilience (Spooner et al. 2021).[1] In addition to the ubiquitous fish kills and water quality issues, workshop participants reported extensive habitat damage related to red tides and noted that recovery of some fish populations following recent and frequent red tides was slow. Participants also described how red tides were affecting their local communities by restricting aquaculture activities, limiting recreational fishing, reducing tourism visitation rates, limiting the commercial activities of the local seafood markets, causing respiratory distress and depressing local real estate values.

Workshop results highlighted the need to learn more about the changing impacts of red tide events along the Florida Gulf Coast to identify opportunities to build socio-economic and ecological resilience, and inspired research to explore LEK using oral history interviews. This paper describes the use of fishermen LEK to provide information on red tide severity patterns and their correlates, as well as to provide a more nuanced understanding of how red tides affect the marine environment. Red tide severity is analyzed in relation to its temporal and spatial extent, fish mortality and behavioral changes, as well as other human and marine ecosystem impacts. Finally, this paper describes how LEK can augment fisheries management by providing data for consideration in stock assessments, among other applications.

2. Methods

2.1. Study Region

Oral history interviews were conducted in 16 fishing communities along the Florida Gulf Coast from Everglades City in southernmost Collier County to Destin in the Florida Panhandle (Figure 1). Interviewing began in communities known to experience major red tide blooms around Charlotte Harbor in south-central Florida and then extended north into areas of the Panhandle and south into Collier County until communities were reached where interviewees noted that red tide events were rarely experienced. Also, the communities visited were identified using the NOAA Fisheries One Stop Shop (FOSS) database (NOAA, n.d.). Among the coastal communities affected by the 2017-2019 red tide event, we targeted communities that had historically experienced relatively high commercial fish landings or for-hire recreational fishing activities. For classification purposes, respondents were grouped into four major regions: the Southwest Florida region included respondents in Collier, Lee and Charlotte Counties (n = 28); the West Central Florida Region included respondents in Sarasota, Manatee, and Pinellas counties (n = 18); the Big Bend Region included respondents in Taylor County (n = 3); and the Panhandle region included respondents in Bay County (n = 6). During the planning phase of the project, the researchers did not identify a specific number of interviews to conduct; rather,

[1] The workshop was conducted under the Marine Resource Education Program (MREP) in support of its goal to "Create avenues for scientists and managers to learn from fishermen who have unique insights into the fisheries they are familiar with" (https://www.gmri.org/projects/marine-resource-education-program-mrep/. Accessed March 31, 2022). The oral histories were conducted with support from the NOAA Integrated Ecosystem Assessment (IEA) program to support scientific research on the impact of red tides in the Gulf of Mexico. The information obtained does not constitute official stakeholder input to the fishery management process or represent the official positions of NOAA Fisheries.

interviews were conducted until the point at which subsequent interviews provided largely redundant information regarding the red tide events experienced in that area (Bernard 2017).

Figure 1. Interview Regions. For data analysis purposes we grouped interviews from each community in four major regions. Not all cities where we conducted interviews are highlighted on the map.

2.2. Interviewee selection

The research team contacted community members and other stakeholders to identify key informants from these communities to participate in red tide oral history interviews. Key informants primarily included current or retired commercial and for-hire fishermen with extensive time and experience fishing in state and federal waters along the Florida Gulf Coast (Figure 1). Dealers and processors were also interviewed if they possessed considerable fishing experience. We reached out to community members and other stakeholders to identify key informants from these communities. We used a snowball sampling technique (Bernard 2017) where with each interview conducted we asked for further recommendations on fish harvesters, dealers and processors that had a long history of fishing in that community. This method of sampling created an opportunity for more reticent fishermen to learn about our work from the trusted sources in their own network before accepting to be interviewed. We were able to reach in this way both active and retired fishermen, dealers and processors. At the end of the interviewing process, 41% of the interviewees were active commercial fishermen, 27.9% were active charter or for-hire fishermen, and 13% worked in both sectors. Around one-fifth of the interviewed fishermen (18%) were retired. Many of the interviewees were able to provide robust historical information as they had been involved in the industry for decades and/or were born in fishing families that went back to two or more generations (Figure 2).

2.3 Interview and participatory mapping process

Fishermen were asked to discuss the major red tide events that they had experienced during their fishing careers and how these had affected their fishing activities, livelihoods and the marine environment. Some interviewees discussed their perception of red tide severity trends over time. These discussions also provided a more nuanced understanding of what elements of a red tide event are important for the way fishermen experience red tide severity. Fishermen described the history of their own fishing practices and fishing communities and how these have

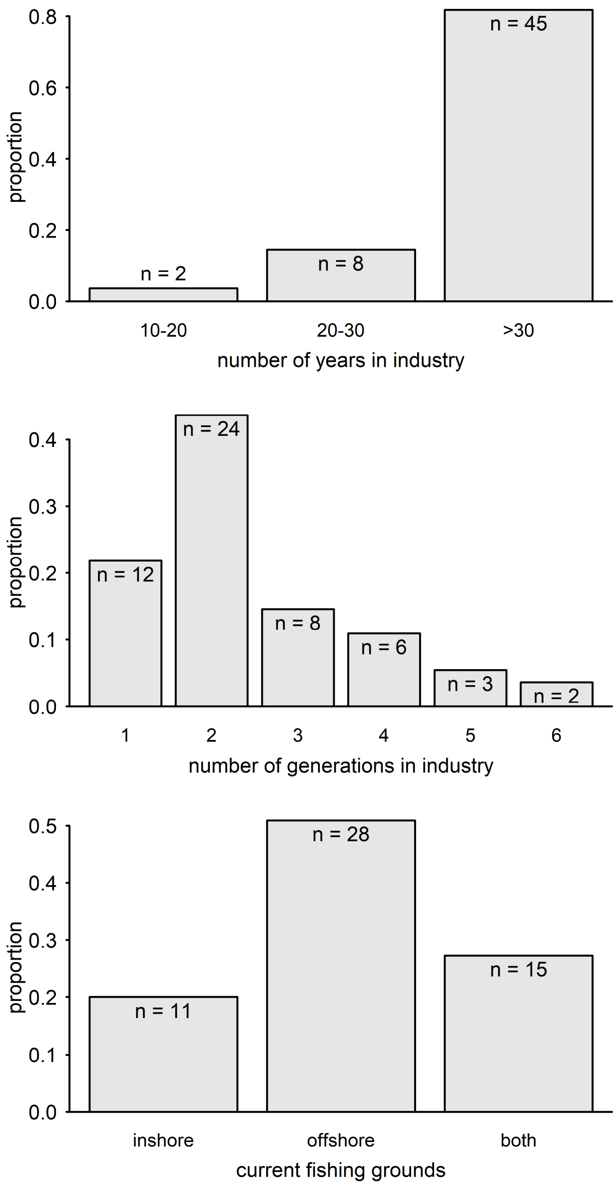

Figure 2. Biographic information for interviewees.

changed over time. For a more detailed description of the interview methodology used see Karnauskas et al. (2019).

An interdisciplinary team (typically a social scientist working in tandem with a fisheries biologist or ecologist) conducted each oral history interview. The interdisciplinary approach helped to ensure that insights regarding biological and socio-economic impacts were being correctly interpreted and helped generate observations about the interconnections between natural and socio-economic systems. Using two interviewers also allowed for a division of labor, generally with the social scientist leading the interview and the biologist taking notes and asking follow up questions. Most interviews lasted from 1 to 2.5 hours. All of the interviews were digitally recorded and written consent was obtained so that the recordings could be added to the NMFS Voices oral history collection (https://www.voices.nmfs.noaa.gov).[2]

Oral histories rely heavily on memory and thus the accuracy of individual interviews may be affected by factors like subject recall limitation and recency bias. Studies indicate that requesting information in chronological sequence can help facilitate informants' memories of events. Furthermore, the kinds of events that are likely to endure in memory are those that are highly emotional at the time, perceived as turning points or relatively unique (Hoffman and Hoffman 1994). Asking the fishermen to recall red tide events in chronological order and associate their memories with impacts on their fishing businesses and families provided cues to help them remember important details. For example, interviewees could easily recall years in which they had to change business practices, shift industries, or seek alternative employment in response to major red tide events or other shocks. Furthermore, using multiple interviews in each location allowed the researchers to identify commonalities and validate the information provided by different informants. To triangulate the information received on the red tide events, informant accounts were compared to accounts obtained from newspaper archival research as well as data from the FWRI HAB database (Florida Fish and Wildlife Institute, n.d.).

2.4 Identification of Red Tide "Events"

All of the recorded interviews were first transcribed and then coded using the MaxQDA qualitative analysis software. The interviews were coded for several important themes, such as environmental change, adaptation, socio-ecological impacts, and red tide severity. Sub-themes were also identified and coded under each of these broader themes. A team of three social scientists identified themes and sub-themes, defined the codes and then worked on intercoder agreement until a high degree of agreement was reached (Kuckartz and Radiker 2019).

To quantify and analyze information related to red tide occurrences, a spreadsheet was created with each row representing one of the discrete red tide occurrences mentioned in the interviews. Most of the interviewees were able to provide a specific year for the red tide occurrence they described. However, when they provided an approximate date to describe the timing of an occurrence, the researchers used a best estimate to assign a date (as described below). Red tide occurrences described by interviewees that pertained to the same year were considered to be related to the same red tide event (Figure 3).

A difficulty in designating red tide events resulted from the fact that some events span two or more years. While some interviewees could remember the exact months and years that a particular red tide occurred, others had more difficulty pinpointing the exact length. A validation protocol was therefore used to corroborate the recall of red tide events to establish the most likely red tide event dates. For the validation protocol, researchers reviewed archived newspaper articles using the NewsBank database (NewsBank, inc, n.d.), and the FWRI HAB database (Florida Fish and Wildlife Conservation Commission, n.d.). Once the red tide years mentioned in interviews were compiled in a table, those years were compared to red tide years mentioned in newspapers and in the FWRI HAB database. The two databases allowed for the identification of

[2] voices.nmfs.noaa.gov/collection/history-red-tide-events-west-coast-florida?order=title&sort=asc&page=2

dates for red tides when the dates provided by the interviewee were not precise. In particular, there were several instances where interviewees mentioned red tides occurring in the "mid-1960s" and "mid-1970s"; for these, the newspaper database and the FWRI database indicated that they were likely referring to the red tide events that occurred in 1964 and 1973-1974. The FWRI HAB database also provided information on the months when medium and high concentrations of *K. brevis* were sampled in the waters of Florida's West Coast. This information allowed the researchers to identify which red tides spanned more than one year, and helped distinguish between annual red tide events, and red tide event periods (i.e., spanning more than one year). In addition, *K. brevis* archived status maps (Florida Fish and Wildlife Research Institute, n.d.) were used to correct the record on more recent red tide event mentions. For example, in a few instances interviewees described red tides that had the spatial pattern of the 2014 red tide event but said that it happened in 2013 or 2015. In this case we considered 2014 the most likely red tide event described. We have made such corrections in three instances. Overall, for analysis purposes, the most likely event year was used and records were kept on how the most likely red tide event years were identified for each occurrence described. Ultimately, the goal of the analysis was to establish the broader patterns of red tide occurrence and severity in the Gulf rather than determine the exact years and months of red tide events.

2.3 Development of Severity Rankings

An attempt was made to rank all 201 red tides occurrences mentioned by interviewees according to a three-point severity scale: minor, major or extreme. The ranking process involved a two-step approach. The first step involved assigning a ranking to all of the occurrences where interviewees described the overall impact of the red tide using general terms like "bad", "minor", or "devastating". Many of the red tides were easy to categorize based on this approach. For example, one interviewee from Madeira Beach recalled about the 2004-2005 red tide "it was the worst I remember". This occurrence was therefore ranked as "extreme". Through this approach, 104 out of the 201 red tide occurrences were ranked. For more details about the way ranking of the first 104 red tide events or event periods was done, see Supplemental Table 1.

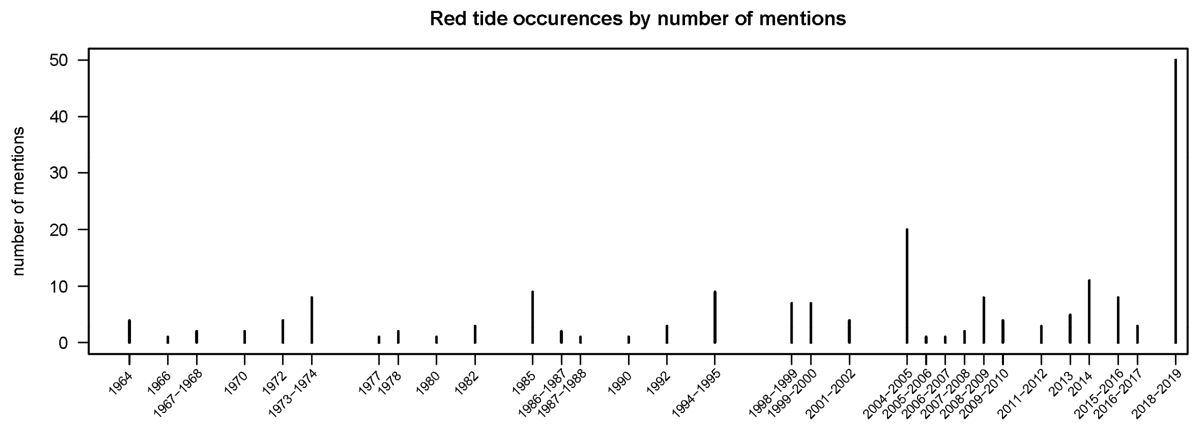

Figure 3. Red Tide events in the Gulf of Mexico based on the number of event descriptions by interviewees that mentioned a red tide occurrence in a given year (or approximate time-period)

The second step involved quantifying the descriptions of event duration and environmental recovery using the 104 ranked occurrences and applying those to help rank the remaining unranked 97 events. Instances where interviewees said, "a long time" or "didn't last long" or "short/long" were not quantified. However, interviewees often provided descriptions of duration in months, weeks and days. The numeric descriptions of red tide duration and environmental recovery were standardized to months. Interviewees also often used descriptions of fish kills or spatial extent in addition to duration and environmental recovery time to provide a sense of red tide severity. For example, one interviewee recalled a 2016-2017 red tide occurrence that caused *"massive amounts of dead fish"*; another interviewee recalled a 2004-2005 red tide occurrence that *"went pretty far in places. We had to go 25 miles to get a grunt"*. These descriptions were harder to place in a severity category using one or two descriptors. Therefore a spreadsheet was compiled for the 97 unclassified occurrences that included quotes related to spatial extent, fish kills, descriptions of water quality changes, temporal extent and environmental recovery for each event. The spreadsheet was distributed to six members of the research team (including this paper's authors) who were asked to independently rank the severity of each occurrence using the information provided in the table. Information that could bias the severity evaluation (including year, location and interviewee names) was not included in the table. When four or more of the research team members provided the same severity rank for a red tide occurrence, that ranking was assigned. When the team did not reach a consensus, usually because of lack of sufficient information in the description, no severity ranking was assigned to the reported red tide occurrence. Using this approach, severity rankings were assigned to seventy-two additional red tide occurrences. Eighty-eight percent of the 201 total red tide occurrences described by interviewees (176) received a severity classification.

3. Results and Discussion

On average, each interviewee identified four distinct red tide events; but this varied, with some interviewees identifying seven or eight red tide events and others identifying only one red tide event. Collectively, interviewees recollected red tide events occurring in 66% of the years between 1965 and 2019. There were particular red tide events that were described by 8 or more interviewees occurring in 1973-1974, 1985, 1994-1995, 2004-2005, 2008-2009, 2014, 2015-2016 and 2017-2019. These major red tides were mentioned by one or more interviewees in all of the different regions, with the exceptions that none of the interviewees from Taylor County (Big Bend Region) described having experienced red tides during the 1973-1974, 1994-1995, and 2017-2019 periods, and interviewees from the Panhandle region (Bay County) did not identify the 2004-2005 and 2014 events. One or more interviewees from the southern and central regions of the west coast of Florida mentioned having experienced red tide occurrences during all eight of these red tide events (Figure 4).

3.1 Severity of Red Tide Occurrences and Events

Interviewees discussed red tide occurrence spanning eight decades, from the 1930s to the 2010s. Of the 201 red tide events that were identified, 28% were classified as "minor" events, 38% were "major" events, and 21% were "extreme" events; 12% could not be classified based on severity. The frequency with which fishermen report red tides is high, especially for the more recent decades. For example, out of the last 29 years prior to the interviews, fishermen reported red tide events in 23 of those years, which concurs with the high frequency of red tides documented in the FWRI HAB database (Florida Fish and Wildlife Conservation Commission, n.d.).

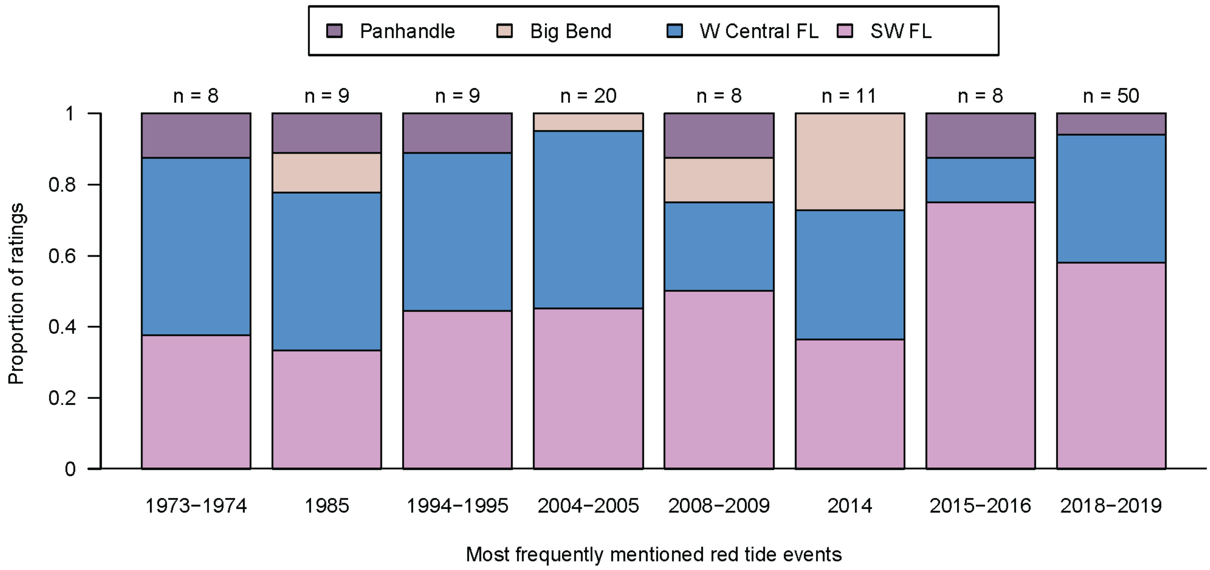

Figure 4. Most frequently mentioned red tide events or event-periods identified across the four coastal regions. The 2018-2019 red tide event in the figure refers to the 2017-2019 red tide event.

Red tide events occurring in a given year were often experienced by interviewees as having a different degree of severity (Figure 5). Interviewees commented on the ways a bloom may settle into and linger in one area, disperse, spread, or move based on storms and changing oceanographic conditions. For that reason, the same red tide event may have been experienced by interviewees at different times and levels of intensity due to the fact that they live in different communities and fish in different locations. For example, interviewees in Madeira Beach described the 2004-2005 red tide event as devastating (extreme severity) whereas an interviewee located in Naples described it as minor.

Most interviewees equated their experiences with the 2017-2019 event as extreme (Figure 4). The extreme nature of the 2017-2019 event was most frequently linked to the spatial extent of the event, which was described as being much larger than previous events. As one interviewee noted regarding the 2017-2019 red tide: *"Usually with red tides they are pronounced in a certain area. So, you can move… But this last one was so big we had to move completely out of the area."* Red tide severity was also often discussed in relation to the size of fish kills, the duration of the red tide itself, recovery times for species and habitat and health impacts. For example, a fisherman from Steinhatchee noted about the 1985 event: *"This one down here was catastrophic. You couldn't go through there. You'd throw up…There were so many – every kind of fish there was: from little tropical fish to flounder, everything that was there died."*

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Figure 5. Red Tide Severity: Severity level of events mentioned in eight or more interviews, based on the number (n) of event descriptions that could be classified by severity. The 2018-2019 red tide event in the figure refers to the 2017-2019 red tide event.

3.1.1 Event Severity and Temporal Extent

Temporal extent refers to the duration of a bloom as observed by fishermen. The interviewees conveyed that the duration of a red tide event plays a significant role in determining its severity. Interviewees generally described minor red tide events as short-lived, dissipating in a couple of weeks to a couple of months in some instances. In comparison, major red tide events lasted much longer than the minor events, generally 1 to 3 months and the extreme red tide events generally lasted from 1 to 6 months but could exceed a year or more.

Interviewees perceive the more recent events to have lasted longer than past events (Figure 6). However, this increase in duration was not perceived uniformly. The same red tide occurrences between 1990 and 2000 were described as lasting from 1 month to more than 10 months by interviewees residing in the same region. The increase of variability likely reflects the fact that red tides that last longer tend to expand in fringe areas towards the end of the red tide cycle. Therefore, it is likely that some of the interviewees in these fringe areas reported these shorter experiences of the red tide.

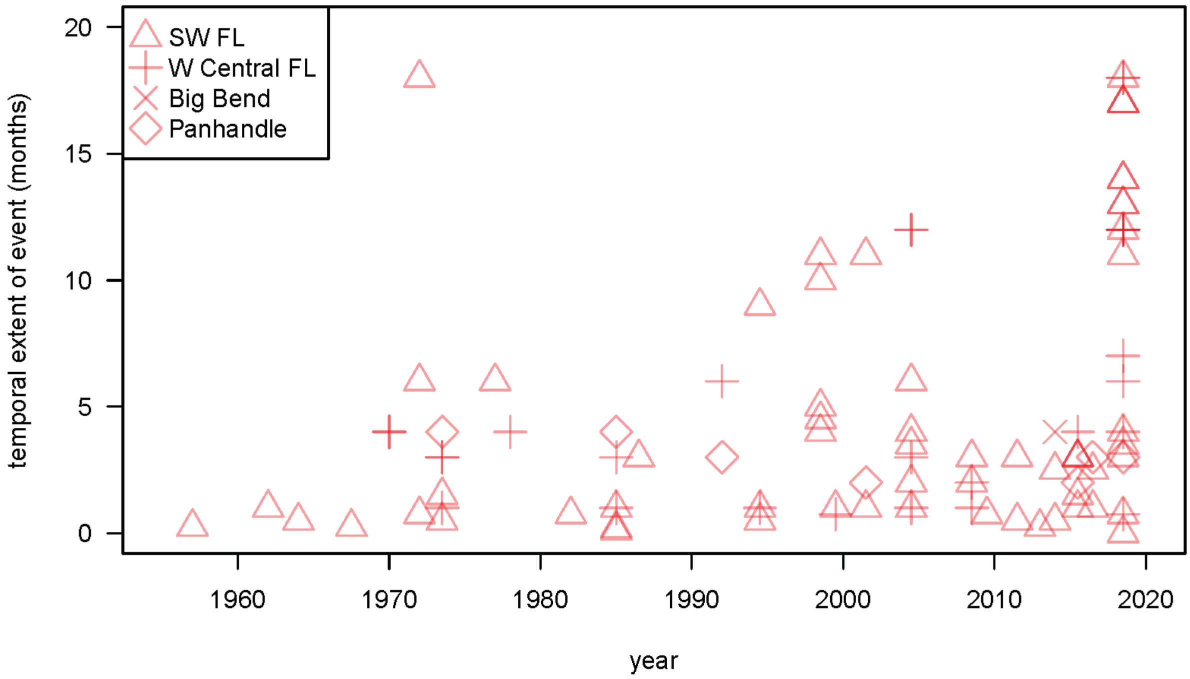

Figure 6. Red tide temporal extent in months as estimated by interviewees. Each point is a separate description; shapes denote region of interviewee.

3.1.2 Changes in red tide severity observed over time

Fishermen mentioned four times as many extreme events in the last four decades compared to the first four decades discussed in the interviews. In addition, when asked to discuss their perception of red tide trends, fishermen overwhelmingly perceived an increase in the frequency of major and extreme red tide events. Brand and Compton's (2007) research also indicated that the abundance of *K. brevis* increased in recent decades. The interviews with the fishermen in this study provide additional observations on how the increase in *K. brevis* abundance has been experienced in the marine environment and how it affected fishing businesses.

Early red tides were often described as natural occurrences that were easy to avoid and did not have a major impact on their business operations. In contrast, more recent events, especially since the early 2000s, are perceived to be of a more extreme nature, and are described as "unnatural" events. Most interviewees agree that red tide events in the past were more commonly minor events; these events were described as having a patchy, rather than continuous spatial pattern and interviewees perceived that most fish were able to avoid them. In addition, interviewees noted that the habitat was rarely affected by most past red tide events and sometimes even described red tides having a restorative effect on the habitat, equating it to a forest fire that would result in a lush and more abundant habitat once the red tide had cleared up.

The hypothesis that red tides can act similarly to forest fires had been advanced before (Steidinger, 1983), and related research showed that *K. brevis* blooms can make significant contributions to the annual production of the shelf (Vargo et al. 1987). However, definitive proof on whether red tides may act as a revitalizing force does not exist. Further research on the long term impacts of red tides would show how the environment recovers in relation to different red tide severity levels.

A few interviewees noted that the first time that they noticed an uptick in the frequency of more severe red tide events was in the late 90s, but it wasn't until the 2000s that these became significant enough to be questioned as 'unnatural' or 'unusual'. Two interviewees discussed the red tides' 'unusual' nature in terms of toxicity. Interviewees tended to describe toxicity as the rapidity with which fish were killed. "*In the past, fish would become ill and take a few days to die*", one interviewee explained. However, the recent events killed fish almost instantaneously, which could in part explain why larger fish species were not able to escape the waves of more recent red tides. For example, a retired fisherman from the Naples area notes: *"I've seen them swimming around trying to get air for a day or two before they die, but you don't see that now...you just find them dead."*

In comparison to past events, interviewees characterize the last few red tide events (the 2004-2005, 2014, and especially the 2017-2019 event), as lasting longer, having wider spatial distribution and even affecting areas that had consistently been spared from red tides in the past. In addition, interviewees noted that traditionally red tides dissipate with colder weather, but that was not the case in the most recent (2017-2019) red tide event. Overall, there is a perception that red tide events have not necessarily become more frequent over time *per se* but that major and extreme red tide events with their associated negative socio-economic and environmental impacts have become more frequent in the last 15 to 20 years.

3.1.3 Severity and Environmental Recovery Times

Environmental recovery relates to the time a particular ecosystem takes to go back to pre-red tide conditions in terms of fish species abundance, spawning patterns and general habitat conditions. Fishermen tended to describe certain species as recovering more slowly than others or to discuss the way the habitat has changed for better or worse after the red tide. The general perception was that the environment recovers in less than a year most of the time (Figure 7), with some differences based on the severity of the event. For example, red tide occurrences classified as minor were described as having relatively short recovery times (e.g., 2 weeks to 4 months). Oftentimes interviewees said that the recovery was immediate. Most interviewees indicated that the impacts on the ecosystem were relatively insignificant and sometimes even viewed these minor events as acting as a revitalizing force. In contrast, extreme red tide events generally were reported as having environmental recovery times lasting from a couple of months to many years or even as making permanent changes to the ecosystem. For example, four interviewees said that the ecosystem was still recovering after the 2005, 2014 and 2016 red tide events (the 2017-2019 event was still ongoing at the time of interviews). Two early studies (Smith 1975; Dauer & Simon 1976) conducted after the 1971 red tide on the reef systems in Sarasota, found that it takes approximately two years for the habitat and fish abundance and diversity to return to pre-red tide levels. Further research is needed to understand what specific conditions affect recovery times, and whether there is a change in the duration of recovery in recent years.

In many instances, red tide events were ranked in all three categories of severity in relation to environmental recovery (extreme, major and minor). For example, one interviewee noted that the 1985 red tide was so devastating that it completely wiped out the fish population for an area of five to ten miles off of Cedar Key, and that the fish population did not return until 2013 – a total of 27 years: *"That's the longest that I have seen. You could put a camera down there, and there would be nothing – no bait, no nothing. It was a real green color. And then, in 2013, you put a camera down there, and it was just like a whole different world. It was like magic. It recouped so fast. But until then, there was nothing."* Other interviewees described recovery of the environment after this event as immediate. The difference in experiences could be explained by the location of the two fishermen with the first from Steinhatchee and the second in Sarasota, more than 200 miles away.

Interviewees often noted that the impact of major or extreme red tide events on the fish populations lasts well beyond the red tide period and that fish mortality can continue after the red tide has dissipated. As one fisherman in the Naples area noted on the 2014 red tide event, *"It is still killing things. I promise it's still killing the larvae. It's still killing the baby whatever was trying to come back."* In comparison, regarding the effects of the same event in Steinhatchee, which is some 350 miles north of Naples, some fishermen noted that they were starting to see a slow recovery in their area: *"You might go down and shoot one or two nice red groupers on a spot, but you might have seen ten small ones. There's hope… When we went a couple of years [ago], we didn't even see one. So they are coming back."* Some interviewees felt that major or extreme red tides change the reproductive or migratory cycle of fish. One commercial fisherman from the Sarasota area noted with regard to the 2004-2005 red tide event that certain fish species take a long time to reestablish their reproductive cycle: *"we didn't have a trout in our bay for over a year before you could finally catch one."*

The long-term impacts on the ecosystem result from the changes that occur in the fish habitat. Interviewees discussed habitat impacts particularly in relation to the 2014-2015 and 2017-2019 events. Both of these events were experienced primarily as extreme or major. Interviewees in Steinhatchee describe bleached corals, depleted of any signs of fish, which persisted into 2016 when they last dived in the area. In relation to the 2018 event, interviewees in Naples, Madeira Beach, and Pine Island talked about swaths of seabeds being replaced by sand or a "black blanket" covering the bottom. The impacts red tides have on the fish habitat should be further explored, as habitat changes may have long lasting effects on fish abundance and result in changes in the behavior of fishermen. One interviewee's comment exemplified the need for attention to long-term impacts, noting that fish will not return to a barren bottom to spawn and as a result fishermen have to find something else to do: *"We literally left and went into a hundred-foot and tried to do some different stuff."*(Commercial fisherman from Steinhatchee on the 2014 Red Tide event).

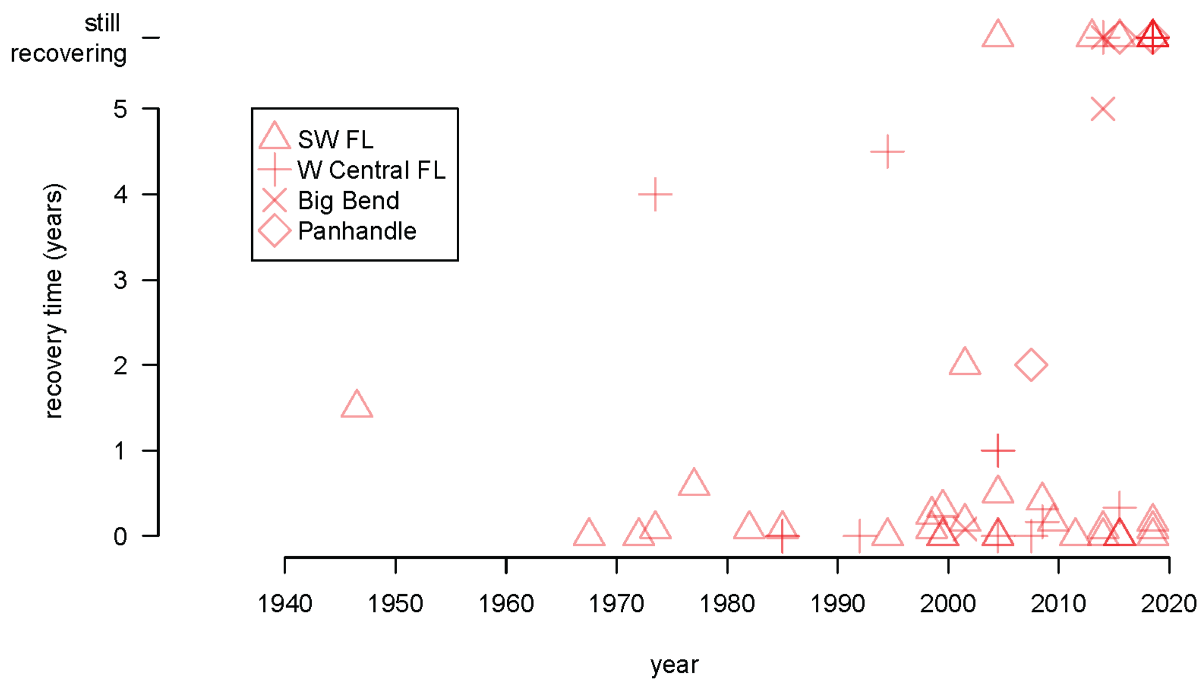

Figure 7. Plotted red tide environmental recovery times for the four regions analyzed. The plot shows that the majority of interviewees note that the environment generally recovers in less than a year after a red tide event.

3.1.4 Red Tide Severity and Proximity to Shore

Most of the fishermen interviewed fish exclusively offshore (50%); smaller percentages fish inshore (21%) or both inshore and offshore (29%). The area where interviewees frequently fish likely influences the red tide observations discussed. Interviewees described red tide events occurring only inshore, only offshore or in both areas. Inshore areas included bayous, bays, estuaries and areas described by interviewees as "nearshore", or "close to shore". Offshore areas are generally perceived as the areas far away from shore. Fishermen reported the occurrence of minor, major and extreme red tide events in both areas with almost equal frequency (Figure 8). Major and extreme red tides are more likely to affect both inshore and offshore areas at the same time perhaps because these events also tend to have a wider spatial extent. The general research consensus is that *K. brevis* blooms that are conducive to major events initiate offshore, and can expand to the inshore areas.

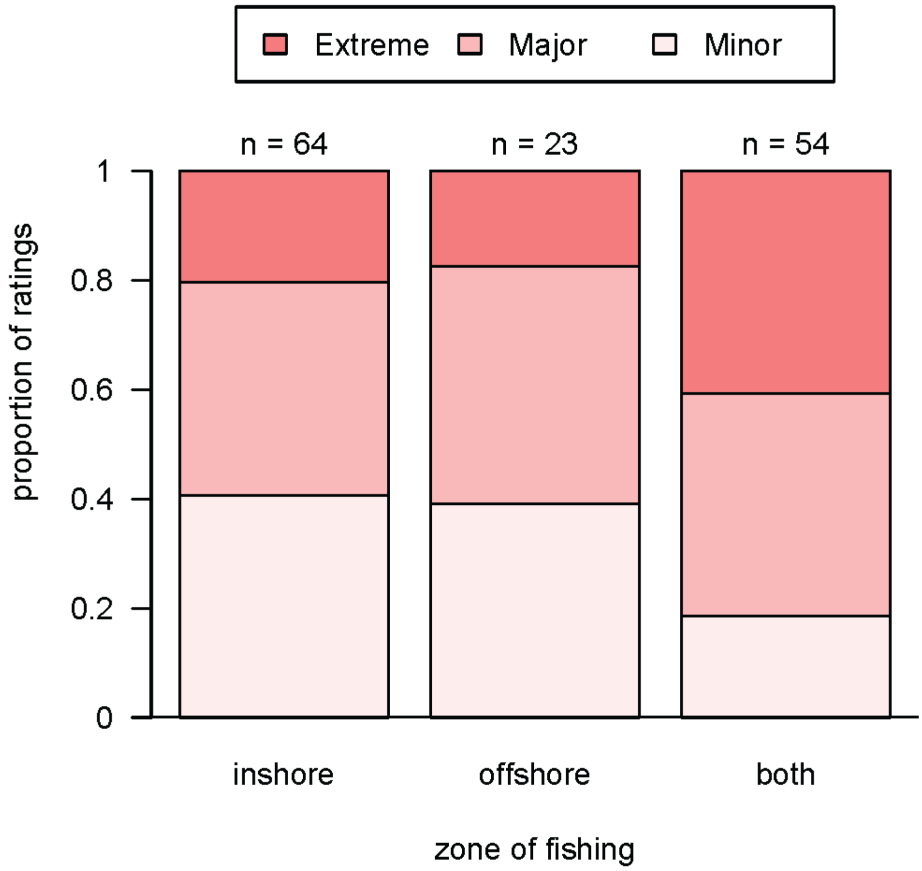

Figure 8. Red Tide severity by proximity to shore. The plot shows the frequency with which extreme, major and minor red tides are observed only inshore, only offshore or both inshore and offshore.

3.1.5 Severity and Impacts on Fish Abundance

Interviewees often noted that smaller fish, such as baitfish and pinfish (*Lagodon rhomboides*), are among the first species to show stress and high mortality in the early stages of red tide events. Mortality of grouper (Serranidae), drum (Sciaenidae), mullet (Mugilidae), and crabs, and to a lesser degree species such as catfish (Ariidae), snook (Centropomidae) and grunt (Haemulidae), are associated with red tide occurrences of all severity levels (Figure 9). Shark kills were only associated with major and extreme occurrences. The death of marine mammals including manatees (*Trichechus manatus*), dolphins (Delphinidae) and even some whales are only associated with extreme red tide events. Fishermen described witnessing fish kills involving these larger species as highly unusual. Despite the fact that the species affected by red tide events are largely the same, the overall mortality rates are perceived as increasing significantly in major and extreme events in comparison to minor events (Figure 8).

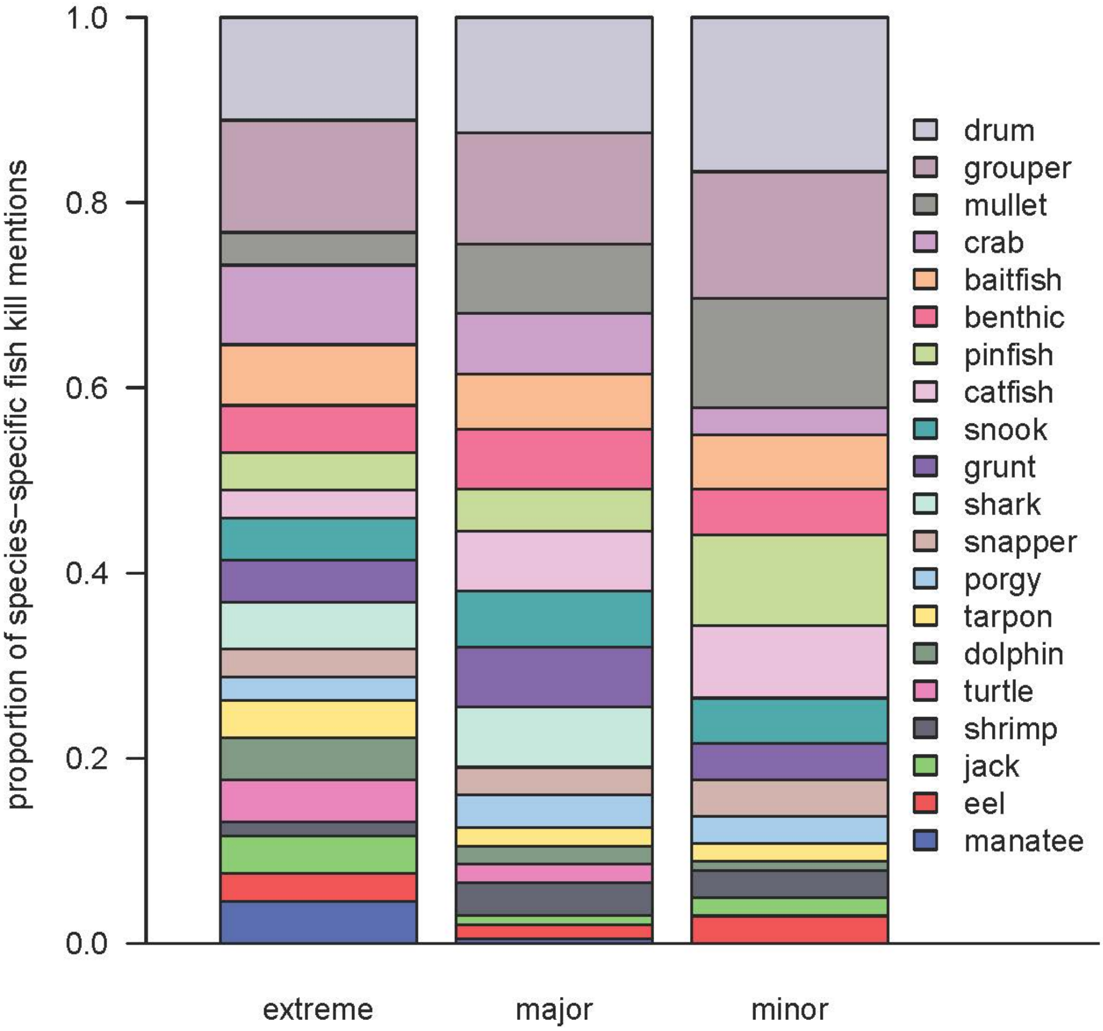

Figure 9. Species affected by red tides. The plot describes the proportion of mentions of species killed in relation to the severity of a red tide event. The category benthic includes taxa such as barnacles (Balanidae), clam (Bivalvia), conch (Strombidae), coral (Anthozoa), mussels (Mytilidae), sponge (Porifera), whelk (Buccinidae), sea fan (Gorgoniidae), and seagrass (Angiospermae). The category baitfish includes taxa such as threadfin herring (*Opisthonema oglinum*), Spanish sardine (*Sardinella aurita*), needlefish (Belonidae), and pilchard (*Harengula jaguana*). Dolphin refers to the mammal, not the fish (mahi mahi). Since LEK relies on the colloquial names provided by fishermen, not scientific names, the taxonomic resolution may not be exact. For more details see Supplementary Materials, Table 2.

Fishermen also described witnessing changes in fish behavior, particularly in relation to major and extreme events, that are likely avoidance behaviors associated with the toxicity of the blooms. A commercial fisherman from Steinhatchee noted: *"the bait would be just swimming around. All of a sudden,* [when the red tide reaches them] *they're wanting to jump out of the water.*" Red tide occurrences are frequently described as acting like a wall that pushes and traps fish in inshore canals and bays; in the words of another interviewee: *"In the canals, there are all manner of sharks, rays, sharks giving birth…. You've got these tiny little sharks just being born trying to get away from it."* (Commercial fisherman from Pine Island, discussing the 2017-2019 red tide event)

Finally, in response to certain (mostly minor) events, some fishermen perceive that red tides can have a rejuvenating effect on the fish populations and the habitat. A fisherman from Pine Island noted: *"Now, the interesting thing about that event is… I want to say about five to six months later, water had cleaned up. It wasn't a long period. Let's say that water was turned for maybe a week, week and a half. It stayed in one area. It did its devastation so I'm thinking top to bottom because obviously the bottom was just gone. The regrowth that happened five months later, six months later was pretty incredible. Again going to compare it to a forest fire you burn everything out it looks like: oh my god! We got a black lifeless area! Within six months … fish over 10 pounds and seeing shots of gags a little more stacked up like they used to be."* (Charter and commercial fisherman from Pine Island). Similarly, a retired commercial fisherman from Sarasota argued that shrimping and crabbing used to be very successful because the red tide tends to negatively affect its predators: *"We had a phenomenal shrimping and crabbing season after that, because it kills a lot of pinfish, the – pinfish is your main little predator fish. I mean they eat everything when it's little. So it eats all the little baby shrimp, eats all little baby crabs. So you have a red tide that kills them all off, and that next year in the spring you'll have a phenomenal shrimp and crab. I mean we went out two weeks ago with my grandkids and great-grandkids and we started hanging it up in the pass and we got almost a 5-gallon bucket full of shrimps and they were like this (makes hand gesture to show how large the shrimp were)."*

3.1.6 Severity and Fishermen's Resilience

The interviewees suggested minor and major red tide events may be disruptive in the short term but generally do not have a significant impact on the ability of fishermen to continue business as usual. Interviewees report that in response to many minor and major events, they were able to simply sail through or avoid red tides and fish in unaffected areas. Some fishermen also report being able to take advantage of red tide occurrences by concentrating their fishing efforts in boundary zones along the edge of blooms or in areas where fish have been trapped and concentrated. As one commercial fisherman from Steinhatchee noted: "*Yes, those fish just bunched up out there. I don't know which way they were going or what. But one of the local fishermen found them and then we all worked together. The best trip was twenty-six-hundred pounds of red grouper in one physical location and in one twenty-four hour period. So that is unusual."* (Comment on the 2014 red tide event)

In the face of extreme events, in some areas simply avoiding the red tide affected areas was impossible. *"Usually, with red tides, they are pronounced in a certain area, so you can move - not like this last one - you can move to another area and find fish. But this last one was so big we had to move completely out of the area"* (Commercial fisherman from Steinhatchee). In some of these extreme cases, fishermen decided to leave the industry permanently. Some interviewees discussed how fellow fishermen had to sell their boats and their permits and leave the business or leave their homes in search of new job opportunities: *"We starved. We literally starved. I almost lost everything and I know several other fishermen that did. I know some that packed their bags and left"* (Commercial fisherman in Fort Myers Beach). The comments from the interviews provide considerable evidence that extreme red tides place a lot of pressure on the ability of fisherman to maintain their livelihoods: *"I used to have 10,400 trap certificates. I had to sell. Last year was bad so I sold 1,000 certificates. This year, just so we could keep going to begin with, I sold 1,000 of them…just so we could keep having money to pay these guys … and all that money is gone now. I don't know what to do"* (Commercial fishermen in Naples). Coping with extreme red tides is particularly difficult if there are other pressures that fishermen experience in a short period of time. One fisherman noted: "*and I'm about to throw in the towel because between paperwork and the regulations and the weather … I'm not that young as I used to be and it's getting to be that the effort is starting to exceed the rewards."* (Charter fisherman from Cape Haze)

More common, however, are stories of resilience. Fishermen adapt by switching to different business models, learning and cooperating with other fishermen, using social media to promote new business models, expanding their fishing or chartering portfolios or simply waiting for better days by doing odd jobs to supplement their income while they wait for the red tide to dissipate. For example, fishermen from Steinahatchee talk about moving south, during the 2014 red tide event: *"I'd never been there before. Just worked my way down there, did real well, and said, 'Well, this is where we need to be!' We went back; we traveled a hundred-and-sixty miles each way. Did a couple of trips traveling back and forth. … Then, after a couple of trips like that, we went down and leased the spot and got settled in with the fish house. Decided that was what we were going to do. We did well!"*

Particularly important for charter fishermen was the emphasis on risk communication: *"I ramped up the social media information. (I would) Let people know when red tide wasn't here and that we didn't have red tide offshore, and we ran farther offshore, and (we would tell them that) all the fish offshore are in good shape, they aren't going to hurt you.*" An analysis of revenue losses during the 2017-2019 red tide event shows that indeed fishermen are generally resilient and were able to mitigate for losses in red tide affected fisheries (Estes & Travis 2020).

While stories of resilience are prevalent in the interviews, this should not diminish the fact that in the face of major and extreme red tide events, the "bottom line" of fishermen is often significantly affected and it may take many years for fishermen and fishing communities to recover economically from the impacts of extreme red tide events.

3.3. Implications for fisheries science and management

Ecosystem-level insights from fishermen LEK can provide additional information and hypotheses useful for stock assessment and to inform management decision making under environmental uncertainty. Importantly, these information sources can assist with developing time series of environmental changes. Stock assessments require long-term datasets to track how fish populations respond to different environmental stressors or episodic mortality events. The time series of red tide severity developed herein, particularly for the historical years, could be used to identify severe red tide events capable of mass mortality for vulnerable species such as Gulf groupers. While considerable efforts have been spent recently to develop satellite-derived indices of red tide severity (Walter et al. 2013; Sagarese et al. 2018) or red tide mortality (Chagaris and Sinnickson 2018; Vilas et al. 2021), these quantitative time series are restricted to more recent years when satellite data were available (1998 for SeaWIFS or 2002 for MODIS). In addition to incorporation into stock assessment modeling, more immediate needs for decision makers also exist such as setting catch advice, which often lags a few years after the completion of a stock assessment. Information from stakeholders on red tide severity could be very helpful in determining how red tides could impact short-term abundance and therefore catch advice (Sagarese et al. 2021).

A major information gap from the stock assessment perspective is understanding the species and size- or age-composition of red tide-induced mortality. Our findings suggest that coastal species such as snook and drums may also be vulnerable to red tide mortality, which could be considered during their state stock assessments. Although other federally assessed species such as gray snapper (*Lutjanus griseus*) could be impacted by red tides, our findings suggest less of an impact on snappers overall. Currently, federal stock assessments for Gulf red grouper (SEDAR 2019; Sagarese et al. 2021) and Gulf gag grouper (SEDAR 2021) account for red tide mortality during severe red tide events, but data gaps remain regarding the size and/or age of groupers affected by red tides. Generally, interviewees conveyed the perception that red tide impacts on grouper populations are not discriminatory and that all age classes of the stocks are affected equally. The LEK insights helped validate the current assumption and methods employed for the Gulf red grouper stock assessment, in which episodic mortality is applied equally to all age classes (Sagarese et al. 2021). However, to date, red tide mortality has been modeled in stock assessments as an immediate effect (i.e., mortality is assumed to occur in the year of the red tide event with no lagged effects). Yet local observations point toward potential habitat loss and long recovery rates of populations subsequent to red tide events sometimes lasting five years or more, which has potential implications for assessment and rebuilding plans.

In addition to information that can directly improve the stock assessment, fishermen also discussed how certain management actions could increase the ability of the fishing community to cope with extreme red tides. The solutions proposed by fishermen show a resilient mindset that acknowledges, rather than resists change (Johnson et al. 2014). The interviewees suggest that managers may be able to increase the resilience of the fishing industry by facilitating access to appropriate substitute species, making legal allowances for fishing without a cap when red tide fish kills become inevitable, and employing fishermen in clean-up efforts. Moreover, allowing for flexibility in the use of gear and permits, and making provisions for the year following an extreme red tide, with certain permit dues being waived to allow for economic recovery, could also significantly increase the resiliency of the fishing industry. Another important policy and management suggestion that interviewees discussed was related to a desire to be a part of the solution. Fishermen often offered their boats and seafaring expertise to collect water samples and other important research data: *"We are willing to do whatever we can for testing or taking samples."* (Charter and commercial fisherman from Pine Island) Research shows that designing institutional structures that promote participatory processes, and integrate local governments, local users and scientists can better respond to current pressures caused by environmental change (Gadgil et al. 2011).

4.0 Conclusions

The present research highlights that the frequency of extreme red tides has increased in recent decades. This research shows that even long, extensive red tide events can be experienced by fishermen as having different levels of severity depending on where they dock their vessels and fish. The socio-economic impacts of red tide events can be severe at a localized scale, even when fishermen experiencing the same event in other areas are able to adapt and mitigate the negative impacts to their businesses. Fishermen's most often expressed concern is that the increase in the frequency of extreme red tides is not random, but rather something to be expected in the future, as a result of environmental degradation. A cluster of extreme events could significantly affect the resiliency of fishing communities all along the western coast of Florida.

Bibliography

Adams, C. (2017). *Red Tide Causes Economic Losses to Southwest Florida Industry.* Retrieved from http://shellfish.ifas.ufl.edu/news/red-tide-causes-economic-losses-sw-florida-industry/.

Anderson, C., Berdalet , E., Kudela , R., Cusack, C., Silke, J., O'Rourke, E., . . . Morell, J. (2019). Scaling up from regional case studies to a global harmful algal bloom observing system. *Frontiers in Marine Science,* 6, 250. https://doi.org/10.3389/fmars.2019.00250

Berkes, F. (2000). Cross-scale institutional linkages: perspectives from bottom up. *IASCP 2000 Conference* (p. 31). Indiana University. Retrieved Jan. 25, 2022, from http://dlc.dlib.indiana.edu/dlc/bitstream/handle/10535/2387/berkesf041200.pdf?sequence=1&isAllowed=y

Bernard, R. (2017). Research methods in Anthropology. Qualitative and Quantitative Approaches (6th Edition). Rowman and Littlefield Publishers.

Brand, L., & Compton, A. (2007). Long-term increase in *Karenia brevis* abundance along the Southwest Florida Coast. *Harmful Algae, 6*, 232-252. https://doi.org/10.1016/j.hal.2006.08.005

Bunce, M., Rodwell, L., Gibb, R., & Mee, L. (2008). Shifting baselines in fishers' perceptions of island reef fishery degradation. *Ocean Coast. Manag., 51*, 285-302. https://doi.org/10.1016/j.ocecoaman.2007.09.006

Chagaris, D., & Sinnickson, D. (2018). *An Index of Red Tide Mortality on red grouper in the Eastern Gulf of Mexico*. North Charleston, SC: SEDAR61-WP-06. SEDAR. Retrieved

Apr. 8, 2022, from http://sedarweb.org/docs/wpapers/S61_WP_06_red_tide_mortality_index.pdf

Christman, M., & Young. (n.d.). *HAB Monitoring Database - Executive Report.* Florida Fish and Wildlife Conservation Commission. Retrieved Nov. 25, 2021, from https://myfwc.com/media/13075/executive-summary-for-database.pdf

Dauer, D., & Simon, J. (1976). Repopulation of the polychaete fauna of an intertidal habitat following natural defaunation: species equilibrium. *Oecologia*, *22*(2), 99-117. https://doi.org/10.1007/BF00344711

des Clers, S., Lewin, S., Edward, D., Searle, S., Liberknecht, L., & Murphy, D. (2008). *Fishermap. Mapping the Grounds: recording fishermen's use of the seas.* A report published for the Finding Sanctuary project. Retrieved April 25th, 2022 from https://docplayer.net/49737396-Fishermap-mapping-the-grounds-recording-fishermen-s-use-of-the-seas-final-report.html

Drew, J. (2005). Use of Traditional Ecological Knowledge in Marine Conservation. *Conservation Biology, 19*(4), 1286-1293. https://doi.org/10.1111/j.1523-1739.2005.00158.x

Driggers, W., Campbell, M., Debose, A., Hannan, K., Hendon, M., Martin, M., & Nichols, C. (2016). Environmental conditions and catch rates of predatory fishes associated with a mass mortality on the West Florida Shelf. *Estuarine, Coastal and Shelf Science, 168*(5), 40-49. https://doi.org/10.1016/j.ecss.2015.11.009

Estes, J., & Travis, M. (2020). *Analysis of the 2017-2018 Red Tide Event in Southwest Florida.* St. Petersburg: SERO. Available upon request from Mike Travis.

Florida Fish and Wildlife Conservation Commission. (n.d.). *HAB Monitoring Database*. Retrieved Nov. 22, 2021, from https://myfwc.com/research/redtide/monitoring/database/

Florida Fish and Wildlife Research Institute. (n.d.). *Karenia brevis* archived status maps. Retrieved Jan. 26, 2022, from www.flickr.com/photos/myfwc/albums/72157635398013168/with/15593857666/

Gadgil, M., Olsson, P., Berkes, F., & Folke, C. (2011). Exploring the role of local ecological knowledge in ecosystem management: three case studies. In F. Berkes, J. Colding, & C. Folke, *Navigating Social-Ecological Systems Building Resilience for Complexity and Change* (pp. 189-209). Cambridge: University Press Cambridge, UK.

Gravinese, P., Munley, M., Kahmann, K., Cole, C., Lovko, V., Blum, P., & Pierce, R. (2020). The effects of prolonged exposure to hypoxia and Florida red tide (*Karenia brevis*) on the survival and activity of stone crabs. *Harmful Algae, 98*, 101897. https://doi.org/10.1016/j.hal.2020.101897

Hanna, S. (1998). Managing for human and ecological context in the Maine soft shell clam fishery. In F. Berkes, & C. Folke, *Linking Social and Ecological Systems: Management*

Practices and Social Mechanisms for Building Social Resilience (pp. 190-211). Cambridge, New York, UK, US: Cambridge University Press.

Hind, E. (2015). A review of the past, the present, and the future of fishers knowledge research: a challange to established fisheries science. *ICES Journal of Marine Science, 72*(2), 341-358. https://doi.org/10.1093/icesjms/fsu169

Hoffman, A., & Hoffman, H. (1994). Reliability and Validity in Oral History: The Case for Memory. In J. Jeffrey, & G. Edwall, *Essays on Recalling and interpreting Experience* (pp. 107-130). Landham, MD: University Press of America.

Huntington, H. (2000). Traditional ecological knowledge in science: methods and applications. *Ecological Applications, 10*(5), 1270-1274. https://doi.org/10.1890/1051-0761(2000)010[1270:UTEKIS]2.0.CO;2

Johannes, R., & Neis, B. (2007). The value of anecdote. In N. Hagan, B. Neis, & I. Baird, *Fishers' Knowledge in Fisheries Science and Management.* Paris: UNESCO.

Johannes, R., Freeman , M., & Hamilton, R. (2000). Ignore fishers' knowledge and miss the boat. *Fish and Fisheries, 1*(3), 257-271. https://doi.org/10.1111/j.1467-2979.2000.00019.x

Johnson, T., Henry, A., & Thompson, C. (2014). *In their own words: fishermen's perspectives of community resilience.* Maine: University of Maine, School of Marine Sciences.

Karnauskas, M., McPherson, M., Sagarese, S., Rios, A., Jepson, M., Stoltz, A., & Blake, S. (2019). *Timeline of severe red tide events on the West Florida Shelf: insights from oral histories.* SEDAR61-WP-20. Retrieved Feb. 9, 2022, from https://sedarweb.org/docs/wpapers/S61_WP_20_Karnauskasetal_red_tide.pdf

Kempton, W., Falk, J., (2000). *Cultural Models of Pfiesteria: Toward Cultivating More Appropriate Risk Perceptions*, Coastal Management, 28:4, 273-285, DOI: 10.1080/08920750050133548

Kuckartz, U., & Radiker, S. (2019). *Analyzing Qualitative Data with MaxQDA.* Berlin, Germany: Springer.

Kusek, K., Vargo, G., & Steidinger, K. (1999). Gymnodinium Breve in the field, in the lab, and in the newspaper - a scientific and journalistic analysis of Florida red tides. *Contributions in Marine Science, 34*, 1-228.

Lopes, P., Begossi, A., Pennino, M., & Verba, J. (2018). Predicting species distribution from fishers' local ecological knowledge: an alternative for data-poor management. *Canadian Journal of Fisheries and Aquatic Sciences*, *76*(8), 1423-1431. https://doi.org/10.1139/cjfas-2018-0148

Maustard, A. (2000). Trapped in biology: an interdisciplinary attempt to integrate fish harvesters' knowledge into Norwegian fisheries management. In B. Neis & L. Felt, *Finding our Sea Legs: Linking Fishery People and their Knowledge with Science and Management* (pp. 133-152). St. John's, Canada: ISER Books.

Maze, G., Olasxoaga, M., & Brand, L. (2015). Historical analysis of environmental conditions during Florida Red Tide. *Harmful algae, 50*, 1-7. https://doi.org/10.1016/j.hal.2015.10.003

McCay, B., Teresa, J., Martin, K., & Douglas Clyde, W. (2006). Gearing up for Improved Collaboration; the potentials and limits of cooperative research for incorporating fishermen's knowledge. *Proceedings of the American Fisheries Society/Sea Grant Symposium: partnership for a common purpose - Cooperative Fisheries Research and Management.* American Fisheries Society. Retrieved March 3, 2022, from, https://vbn.aau.dk/ws/portalfiles/portal/13562566/Gearing_up_for_Improved_Collaboration.pdf

Neis, B., Schneider, D., Felt, L., Haedrich, R., Hutchings, F., & Hutchings, J. (1999). Fisheries assessment: what can be learned from interviewing resource users. *Canadian Journal of Fisheries and Aquatic Sciences, 56*(10), 1949-1963. https://doi.org/10.1139/f99-115

Nenadovic, M., Johnson, T., & Wilson, J. (2012). Implementing the Western Gulf of Maine Area Closure: the Role and Perception of Fishers' Ecological Knowledge. *Ecology and Society, 17*(1). http://dx.doi.org/10.5751/ES-04431-170120

NewsBank, inc. (n.d.). *USA-Florida*. Retrieved from NewsBank Full-Text Newspapers.

National Oceanic and Atmospheric Administration (NOAA) (n.d.). Fisheries One Stop Shop. Retrieved March 7, 2018 from, https://www.fisheries.noaa.gov/foss/f?p=215:200:31958200288653::NO

Paolisso, M., & Chambers, E. (2001). Culture, Politics, and Toxic Dinoflagellate Blooms: The Anthropology of Pfiesteria. *Human Organization, 60*, 1-12.

Saenz-Arroyo, A., & Revollo-Fernandez, D. (2016). Local ecological knowledge concurs with fishing statistics: an example from the abalone fishery in Baja California, Mexico. *Marine Policy, 71*, 217-221. https://doi.org/10.1016/j.marpol.2016.06.006

Sagarese, S., Vaughan, N., Walter III, J., & Karnauskas, M. (2021). Enhancing single-species stock assessments with diverse ecosystem perspectives: a case study for Gulf of Mexico red grouper (*Epinephelus morio*) and red tides. *Canadian Journal of Fisheries and Aquatic Sciences*, *78*(8), 1168-1180. https://doi.org/10.1139/cjfas-2020-0257

Sagarese, S., Walter III, J., Harford, W., Grüss, A., Stumpf, R. & Christman, M. (2018). *Updating indices of red tide severity for incorporation into stock assessments for the shallow-water grouper complex in the Gulf of Mexico*. North Charleston, SC: SEDAR61-WP-07. SEDAR. Retrieved Apr. 8, 2022, from http://sedarweb.org/docs/wpapers/S61_WP_07_Red%20Tide%20Severity_SWG.pdf

Schlacher, T., LLoyd, S., & Wiegand, A. (2010). Use of Local Ecological Knowledge and management of algal blooms. *Environmental Conservation, 37*(2), 210-221. https://doi.org/10.1017/S0376892910000305

SEDAR, Southeast Data, Assessment, and Review. (2006). *SEDAR 12 - Stock Assessment Report: Gulf of Mexico Red Grouper.* Charleston, SC: SEDAR. Retrieved Nov. 23, 2021, from http://sedarweb.org/docs/sar/S12SAR1%20Gulf%20Red%20Grouper%20Completev2.pdf

SEDAR, Southeast Data, Assessment, and Review. (2019). *SEDAR 61 - Stock Assessment Report: Gulf of Mexico Red Grouper.* Charleston, SC: SEDAR. Retrieved Apr. 8, 2022, from http://sedarweb.org/docs/sar/S61_Final_SAR.pdf

SEDAR, Southeast Data, Assessment, and Review. (2021). *SEDAR 72 - Stock Assessment Report: Gulf of Mexico Gag Grouper.* Charleston, SC: SEDAR. Retrieved Apr. 8, 2022, from http://sedarweb.org/docs/sar/S72_SAR_FINAL_v2.pdf

Shephard, S., Connolly, P., Hareide, P., & Rogan, E. (2007). Establishing stakeholder connections for management of the Irish orange roughy fishery. *ICES Journal of Marine Science: Journal du Conseil, 64*, 841-845. https://doi.org/10.1093/icesjms/fsl034

Smith, G. (1975). The 1971 red tide and its impact on certain reef communities in the mid-eastern Gulf of Mexico. *Environmental Letters*, *9*(2), 141-152. https://doi.org/10.1080/00139307509435843

Spooner, E., Karnauskas, M., Harvey, C., Kelble, C., Rossellon-Druker, J., Kasperski, S., . . . Lynch, P. (2021). Using Integrated Ecosystem Assessments to Build Resilient Ecosystems, Communities, and Economies. *Coastal Management, 49*(1), 26-45. https://doi.org/10.1080/08920753.2021.1846152

Stanley, R., & Rice, J. (2007). Fishers' knowledge? Why not add their scientific skills while you're at it? In N. Haggan, B. Neis, & G. Gaird, *Fishers' Knowledge in Fisheries Science and Management.* Paris: UNESCO Publishing.

Stauffer, B., Bowers, H., Buckley, E., Davis, T., Johengen, T., Kudela, R., . . . Tamburn, M. (2019). Considerations in Harmful Algal Bloom Research and Monitoring: Perspectives from a Consensus-Building Workshop and Technology Testing. *Frontiers in Marine Science, 6*, 399. https://doi.org/10.3389/fmars.2019.00399

Steidinger , K. (1983). A re-evaluation of toxic dinoflagellate biology and ecology. In F. Round, & D. Chapman, eds. *Progress in Phycological Research,* 2, 170-182. Elsevier North Holland, New York

Stephenson , R., Stacey, P., Pastoors, M., Kraan, M., Holm, P., Wiber, M., . . . Benson, A. (2016). Integrating fishers' knowledge research in science and management. *Journal of Marine Science*, *73*(6), 1459-1465. https://doi.org/10.1093/icesjms/fsw025

Tibby, J., Lane, M., & Gell, P. (2007). Local knowledge and environmental management: a cautionary tale from Lake Ainsworth, New South Wales, Australia. *Environmental Conservation, 34*(4), 334-341. https://doi.org/10.1017/S037689290700433X

Van Dolah ER, Paolisso M, Sellner K, Place A. (2016). *Employing a socio-ecological systems approach to engage harmful algal bloom stakeholders.* Aquat Ecol. 50(3):577-594. doi: 10.1007/s10452-015-9562-z.

Vargo, G., Carder, K., Gregg, W., Shanley, E., & Heil, C. (1987). The potential contribution of primary production by red tides to the west Florida shelf ecosystem. *Limnol. Oceanogr., 32*, 762-767. https://doi.org/10.4319/lo.1987.32.3.0762

Vilas, D., Chagaris, D., & Buczkowski, J. (2021). *Red tide mortality on gag grouper from 2002-2018 generated by an Ecospace model of the West Florida Shelf.* North Charleston, SC: SEDAR72-WP-01. SEDAR. Retrieved Apr. 8, 2022, from http://sedarweb.org/docs/wpapers/S72_WP_01_red_tide_Mortality_Ecospace_v3.pdf

Voiland, A. (2018). *How scientists are tracking Florida's Red Tide with Satellites and Smartphones. NASA Earth Observatory.* Retrieved Nov. 3, 2021, from https://earthobservatory.nasa.gov/blogs/earthmatters/2018/08/24/how-scientists-are-tracking-red-tides-with-satellites-and-smartphones/

Walter, J., Christman, M., Landsberg, J., Linton , B., Steidinger, K., Stumpf, R., & Tustison, J. (2013). *Satellite derived indices of red tide severity for input for Gulf of Mexico Gag grouper.* North Charleston, SC: SEDAR33-DW08. SEDAR. Retrieved Apr. 8, 2022, from http://sedarweb.org/docs/wpapers/SEDAR33-DW08-%20Walter%20et%20al.%202013%20red%20tide%20indices%20for%20Gag.pdf