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Abstract

As part of the NOAA-Fisheries Climate Science Strategy, fisheries climate vulnerability analyses are being conducted for all NOAA-Fisheries regions to assess the potential vulnerability or resilience of fishes and invertebrates to projected climate change. This document provides a summary of the climate vulnerability analysis conducted for the Gulf of Mexico. The domain for the analysis is the Gulf of Mexico Large Marine Ecosystem. A total of 75 species of fishes and invertebrates, selected from those that are actively exploited and managed, play a significant role in the ecosystem, and/or have protected status, were included in the analysis. Environmental factors considered were temperature, dissolved oxygen and hypoxia, salinity, integrated total primary productivity, ocean acidification, and sea level rise. Most of these environmental factors were derived from an ensemble of models constructed for the Fifth Coupled Model Intercomparison Project using the Representative Concentration Pathway 8.5 scenario (i.e., high greenhouse gas emissions). Non-modeled factors were derived using literature and other publicly available data. Various aspects of species' life histories were used to assess biological sensitivity to climate change. These include habitat specificity, prey specificity, adult mobility, dispersal of early life stages, early-life survival and recruitment requirements, complexity in reproductive strategy, spawning cycle, sensitivity to temperature, sensitivity to ocean acidification, population growth rate, stock size status, and other stressors. The project used a categorical (low, moderate, high, very high) scoring mechanism to assess both environmental and biological factors. Biological factors were scored via expert elicitation from a group of regional fisheries scientists. Environmental factors were scored objectively using climate model output.

The key findings of the climate vulnerability assessment are:

- All species in the Gulf of Mexico are projected to experience high or very high exposure to climate-driven change in environmental variables.
- The primary environmental factors of concern include temperature, salinity, ocean acidification, and dissolved oxygen.
- Biological sensitivities are variable and range from low to very high, with most species (~63%) falling into the low sensitivity category.
- The dominant biological aspects include population growth rate, other stressors, early life stage survival and settlement, spawning cycle, complexity in reproductive strategy, and spawning stock size/status.
- Twenty percent of the species, representing groupers, elasmobranchs, snappers, diadromous fishes, invertebrates, and coastal species, had high or very high *overall vulnerability* to climate change. Twenty-eight percent of all species were moderately vulnerable, and 52% were low-vulnerability species.

In summary, all assessed species in the Gulf of Mexico are projected to face significant exposure to climate-driven environmental changes. However, life-history traits are such that some species are expected to be susceptible and many others resilient to these changes.

Introduction

For more than 100 days in 2023, the daily, global average sea surface temperature was much above the maximums observed during the satellite era. In the North Atlantic, the sea surface temperature often exceeded the mean of that era by 3-, and even 4-sigma. The entry into the series of daily record temperatures occurred before the initiation of the year's El Nino. In addition to the newly developed El Nino, some of the observed temperature increase is likely due to a decrease in sulfur dioxide emissions from the maritime industry, a reduction in dust transport from the Sahara, the North Atlantic Oscillation, the Atlantic Multidecadal Oscillation, and perhaps the Pacific Decadal Oscillation. However, those contributions would be in addition to a robust pattern of increasing sea surface temperature, an important indicator of climate change, observed over decades.

Climate-driven changes in sea surface temperature, the pH of the oceans, stratification, wind stress, sea level height, and more can have profound ramifications for the life cycles, distributions, and population dynamics of living marine resources. These kinds of changes can have direct impacts on ecosystem function, recovery of threatened or endangered species, and the sustainability of fisheries. These effects can have both negative and positive consequences, benefiting some species while putting others at greater risk.

Because these issues are significant, there is a recognized need within fisheries management to identify both at-risk resources and new opportunities (Busch *et al.* 2016, Morrison *et al.* 2016, Karp *et al.* 2019). In order to address this need, NOAA-Fisheries embarked on a series of climate vulnerability assessments for various living marine resources and habitats across all regions in which it has responsibilities. The fisheries assessments begin with a standard methodology (Morrison *et al.* 2015) and then tailor the methodology for regionally specific application (e.g., Hare *et al.* 2016, Crozier *et al.* 2019, Spencer *et al.* 2019). Here we present a brief overview of the methods, the results, and a discussion of those results for the Gulf of Mexico climate vulnerability assessment. The region considered here is the Gulf of Mexico Large Marine Ecosystem (Fig. 1).

Methods

This climate vulnerability assessment largely follows the original methodology set out by Morrison *et al.* (2015) and is most similar to that of Hare *et al.* (2016) for the northeast Atlantic continental shelf. There are, however, important differences, particularly in the consideration of environmental factors.

Climate vulnerability assessments are multi-step exercises that move through 1) defining the study area, 2) selecting species for inclusion in the assessment, 3) recruiting scientists for

scoring, 4) creating species profiles, 5) specifying trait-based biological sensitivity attributes, 6) creating climate/environmental exposure factors, 7) developing species distribution maps, 8) scoring sensitivity attributes, 9) scoring climate exposures, 10) calculating summary statistics, and 11) performing bootstrap analyses.

At the core of the assessment is a scoring process to categorize aspects of both the ecology/life history (biological sensitivity attributes) of individual species and their environment (exposure factors) as projected into the future.

The ecological/life history aspects considered were habitat specificity, prey specificity, adult mobility, dispersal of early life stages, early-life survival and recruitment requirements, complexity in reproductive strategy, spawning cycle, sensitivity to temperature, sensitivity to ocean acidification, population growth rate, stock size status, and other stressors (Appendix A). The environmental factors were temperature, dissolved oxygen and hypoxia, salinity, integrated total primary productivity, ocean acidification, and sea level rise. Note that the dissolved oxygen exposure factor intersects with hypoxia and so, while tracked throughout the study, did not enter into the vulnerability estimates directly.

For the species' ecology/life history, scientist scoring assigns a categorical score (low, medium, high, very high) to each aspect, or attribute, depending on where that attribute falls across a spectrum of possible conditions. For instance, the 'prey specificity' attribute has as endpoints 'prey generalist' (a score of low) and 'prey specialist' (a score of very high). A given species' life-history trait for diet could fall into any one of four bins constructed (inclusively) between those endpoints. The scoring was guided by a standard rubric found in Morrison *et al.* (2015).

The same categorical scores were also used to assess environmental factors. However, here scores were either assigned objectively (for modeled factors) or by scientists (for sea level rise and hypoxia) as above. The climate models produced output on a regular grid. These data were then transformed into standard deviates or standardized anomalies ($(\text{mean}_{2006-2055} - \text{mean}_{1956-2005}) / \text{standard deviation}_{1956-2005}$), and that information was categorized for use in the assessment. Details of these two categorization methods will follow.

Species Selection and Functional Groups

While the primary objective was to examine the vulnerability of marine fishes and invertebrates that occur across the Large Marine Ecosystem (LME), a heavy focus was placed on those species found within state waters and the United States Exclusive Economic Zone (EEZ, out to 200 nautical miles) in the Gulf of Mexico. Thus, the selection process first identified a broad group of candidate species that were subject to United States federal or state fisheries stock assessments and fisheries management plans, those identified by state or federal documents as serving important ecological functions (e.g., forage species), and those listed as threatened or endangered (e.g., Gulf sturgeon). The candidate list was then screened by a group of fishery scientists from the NOAA-Fisheries Southeast Fisheries Science Center to arrive at the final list of species for inclusion in the assessment. These scientists had an opportunity to add or remove species from the candidate list, and ultimately 75 species were selected for assessment (Table 1). Of the 75

species, 69 (92%) had ranges extending beyond state waters and the United States EEZ in the Gulf of Mexico (i.e., into Mexico's territorial waters).

Each of the 75 species was allocated to one of ten 'functional groups' (Table 1; Hare *et al.* 2016) based on life history, phylogeny, and spatial distribution characteristics. The ten functional groups used in this study were snappers (8 species), groupers (11 species), elasmobranchs (16 species), invertebrates (8 species), diadromous (1 species), offshore bottomfish (3 species), other reef fish (2 species), pelagics (3 species), coastal pelagics (9 species), and coastal fishes (14 species). These functional groupings, following Hare *et al.* (2016), were used to both assign species to scientists for scoring and to characterize the vulnerability of broadly similar species to climate change.

The Gulf of Mexico is considered 'data-limited' (Sagarese *et al.* 2018). This means that basic biological information on some species included in this assessment may be absent or poorly known. In these cases, information was gleaned from similar species or based on scoring scientists' knowledge.

Scoring Scientists

Scientists were recruited for scoring species' vulnerability based upon biological sensitivity attributes. A total of 46 scientists were involved in the project, 27 of whom participated in scoring. These scientists were drawn from the Southeast Fisheries Science Center and partner academic and state management institutions. Each person was asked to score one or more of the functional groups such that there were five individuals scoring each species. The number of species scored per scientist ranged from 8 to 24, with most scientists scoring 14 species. The additional scientists assisted with other aspects of the assessment, such as writing species narratives.

Species Profiles

Species profiles were developed for each of the 75 species included in the study (Appendix A). These profiles provided life history information on various aspects (33 different topics covered) of the set of 12 trait-based, biological sensitivity attributes. The species profiles were constructed by examining primary and secondary literature, stock assessment documents, and life history summaries. Following the initial construction of the species profiles, each was then reviewed by a scientist familiar with the species and improved where possible. The species profiles were then given to the project's scoring team as a way to ensure that each individual had access to an initial set of factual information for each species to serve as the basis for scoring along with their own knowledge about the species and/or similar species.

Climate Exposure Factors

As mentioned above, a set of environmental variables was selected to serve as climate exposure factors for the climate vulnerability assessment. Clearly, a wide variety of environmental variables, often interacting in complex ways, combine to structure the population dynamics and

distributions of marine organisms. The climate exposure factors in a climate vulnerability assessment are necessarily a simplified subset of the complete suite of environmental variables influencing a population, and these factors are studied in isolation here. Regional climate exposure factors for this study were selected on the basis of relevance to the Gulf of Mexico study area. The climate exposure factors used were air temperature (as a proxy for estuarine and freshwater temperature), dissolved oxygen, integrated total primary productivity, ocean acidification, sea surface salinity, sea surface temperature, sea level rise, and hypoxia. All of these, except hypoxia and sea level rise, were available from the climate models.

All climate data, except for sea level rise and hypoxia, were obtained from the NOAA-Physical Sciences Laboratory's Climate Change Portal (<https://www.esrl.noaa.gov/psd/ipcc/>). The data sets used were the average of an ensemble of models from the Fifth Coupled Model Intercomparison Project using the Representative Concentration Pathway 8.5 (RCP 8.5) scenario (i.e., high greenhouse gas emissions). The number of models contributing to the average varied with the climate exposure factor under consideration. For instance, 35 models were used to produce data on air temperature and precipitation, 25 models were used to produce information on sea surface temperature and salinity, and 11 models were used to produce information on ocean acidity. The climate data from the Physical Sciences Laboratory's Climate Change Portal were available to the project as 1° gridded arrays containing mean fields and standard deviations for the periods of 1956-2005 (reference time frame) and 2006-2055 (objective time frame). Data for the 2056-2099 time frame were also available but were only used to explore long-term conditions and were not used to assess species vulnerability. For use as climate exposure factors, all climate data, except hypoxia and sea level rise, were transformed from native units to standard deviates (standardized anomaly) using $(\text{mean}_{2006-2055} - \text{mean}_{1956-2005}) / \text{standard deviation}_{1956-2005}$. An example of the sea surface temperature climate exposure factor for the Gulf of Mexico LME is shown in Figure 2, with additional plots for other exposure factors in Appendix B. Although not carried into the full climate vulnerability assessment, standard anomalies were also developed and explored for the 2050-2099 time block.

The sea level rise climate exposure factor (Appendix C) was developed by examining contemporary rates of sea level rise and those projected for the Gulf of Mexico through 2050 (<https://tidesandcurrents.noaa.gov/sltrends/sltrends.html>, Sweet *et al.* 2017a, 2017b). The projections take into account a number of climate and non-climate factors such as crust rebound due to melting of land ice, vertical land movement due to global isostatic adjustment, sediment compaction, and fossil fuel and groundwater withdrawals. The net result of these analyses is that sea levels are rising across the entire Gulf of Mexico with the highest rise rates found along the coasts of Louisiana and Texas.

The hypoxia climate exposure factor (Appendix C) was developed by examining both the climate-modeled precipitation projections across the Mississippi watershed and reviewing the results of high-resolution modeling exercises projecting into the future (Laurent *et al.* 2018). Precipitation in the Mississippi watershed was examined because there is a link between Mississippi River discharge and hypoxia (Rabalais *et al.* 2002a, 2002b). Climate model-based projections of precipitation in the Mississippi watershed are spatially variable with small local

increases (Biasutti *et al.* 2011), but no substantial signal (i.e., the projected changes are generally small and indicate a small shift toward increased precipitation in some areas; Pan *et al.* 2016). Using a high-resolution ROMS hydrodynamic-biogeochemical model, Laurent *et al.* (2018) projected that, owing to temperature-dependent reduced oxygen solubility and increased stratification, there will be a modest expansion in the size of the Gulf of Mexico hypoxic area, but that hypoxia will be more severe and prolonged. In addition, this northern Gulf of Mexico hypoxic area will also experience increased acidification (Laurent *et al.* 2018).

Species Distribution Maps

To carry out the climate exposure analyses, estimates of the spatial distributions of the species included in the assessment were required. The spatial distributions were obtained from two primary sources. For most fishes, the International Union for Conservation of Nature (IUCN) Redlist distribution maps (IUCN 2019) provided a consistent source of vetted information. The IUCN distribution maps were available as ArcGIS shapefiles and imported into MATLAB (2015) for analyses.

Invertebrate distributions and the distributions for smalltooth sawfish and Gulf sturgeon were not available from IUCN. Therefore, these were secured by consulting the Gulf of Mexico Coastal and Ocean Zones Strategic Assessment: Data Atlas (SEFC 1985, NODC Accession 0126646). Full Gulf of Mexico ArcGIS shapefiles were not available from the Atlas, and so the species distribution maps for the LME were manually constructed using the Atlas' maps and maps of the grid node locations for the climate data. The Atlas' graphical distribution maps were scrutinized, and the grid nodes for the climate data that fell within the boundaries of the graphical distribution for each species map were selected. Almaco jack (*Seriola rivoliana*) distribution maps were not available from either source. Almaco jack life history descriptions suggested a distribution ranging from inshore to offshore with an association with sargassum. Dolphin (*Coryphaena hippurus*) appeared to have similar distributional requirements, and so the IUCN Redlist distribution map for dolphin was used for almaco jack. This distribution map is broad and encompasses the whole of the Gulf of Mexico LME.

The primary use of the distribution maps was to identify the climate data relevant for each species. An example of a distribution map for gag grouper (*Mycteroperca microlepis*) is provided in the left panel of Figure 3.

Scoring Biological Sensitivity Attributes, Data Quality, Distributional Shift, and Directional Effects

Biological sensitivity attribute scoring took place in two phases. Following training on how to conduct the scoring, species scientists were first asked to independently score each of the 12 sensitivity attributes for each species in their assigned functional group(s) using a rubric (Table 1, Appendix A, Morrison *et al.* 2015). Scoring sensitivity attributes involved identifying where a species fell across a gradient of four categorical vulnerability bins (low, moderate, high, and very high) for each of the 12 trait-based sensitivity attributes. Generally, a categorical score of low indicated that a particular attribute (e.g., a species with a broad diet) was relatively resilient to

changes that might arise from climate change. A score of very high (e.g., a species that is a dietary specialist) would indicate an attribute that was sensitive to climate change. As sources of uncertainty, complexity, and variability across a species distribution can make it difficult to provide a single score for an attribute, scientists were given five tallies that they could distribute across the four bins. If uncertainty was not a concern, a scientist could allocate all five tallies to a single vulnerability bin (e.g., all five tallies placed in the moderate bin); conversely if uncertainty or variability was a concern, a scientist could split their five tallies across multiple bins (e.g., two tallies in the high bin and three tallies in the moderate bin). By using five tallies and four bins, the scoring mechanism also ensured that a central tendency in attribute scoring was defined, as at least one bin would contain two or more tallies.

Scoring scientists also ranked the quality of data used to assess each sensitivity attribute using an integer scale that spanned from zero to three. A score of zero indicated that no reliable information was available for that sensitivity attribute. A score of one indicated that scientist judgment was the primary information source on which scores were based. A score of two indicated that data exist, but that there is significant uncertainty. This quality ranking may indicate that information came from a similar stock or population and not the stock in question. A score of three indicated that adequate data are well established for the stock. The final data quality score was calculated as the average of the data quality scores across scoring scientists for each species and sensitivity attribute.

Once the results of the independent scoring effort were available, a series of workshops were held to review scores and, following group discussions, offer each scientist an opportunity to independently revise their scores if they deemed it necessary. Prior to the workshops, scientists were given all of the results from the independent scoring and could see how their scores compared to others scoring the same species. Thus, these review workshops were another method of ensuring scientist certainty. The review workshops were arranged by functional group (e.g., groupers, elasmobranchs, snappers) and were held via video conferencing over the course of several weeks.

Another aspect of a species' response to climate change is its propensity to shift in distribution. Assessment of the potential for species to shift distributions considered the biological sensitivity attributes related to temperature sensitivity, dispersal of early life stages, and adult mobility and habitat requirements. Species with highly mobile adults, extensive early life stage dispersal, broad habitat requirements, and low sensitivity to ocean temperatures were assumed to have a large potential to shift distributions under climate change. To calculate the potential for distributional change, the scores for adult mobility, early life stage dispersal, and habitat specificity were reversed. If three or more attributes had an average of ≥ 3.5 then the propensity to shift distribution score was considered to be very high with a value of 4; if 2 or more attributes had an average ≥ 3.0 then the score was considered to be high with a value of 3; if 2 or more attributes had an average ≥ 2.5 then the score was considered to be moderate with a value of 2; otherwise, the score was considered to be low with a value of 1.

Climate change may have general negative, neutral, or positive effects on any given species. A species might become more productive in response to climate change, and this would be viewed

as a positive effect. The result of this exploration is called the ‘directional effect score,’ and it was accomplished in a manner similar to the earlier scoring process, but here scientists independently assigned four tallies to three categorical bins (negative, neutral, positive). For each species, the proportion of tallies cast in each bin was calculated by dividing the number of tallies in each bin by the total number of tallies cast across all scorers. A metric was derived (Hare *et al.* 2016) whereby the proportion of tallies in the negative bin was multiplied by -1.0, the proportion in the neutral bin was multiplied by zero, and the proportion in the positive bin was multiplied by 1.0, and then these products were summed. A sum that was ≤ -0.33 was considered negative, one that was ≥ 0.33 was considered positive, and otherwise, the directional effect score was considered neutral.

Scoring Climate Exposure Factors

All climate exposure factors, except sea level rise and hypoxia, were scored objectively by overlaying the species’ distribution maps on a map of the climate model grid nodes and then selecting those grid nodes that fell within the boundaries of the species’ distributions. These sets of grid nodes were then used to interrogate the climate exposure factor data to extract the standardized anomalies of the climate data that was pertinent to each species. For each species, the absolute value of the standardized anomaly for each grid node falling within the species distribution boundary was placed into one of four bins denoted low, moderate, high, and very high (per Morrison *et al.* 2015). Grid node absolute standardized anomalies > 2.0 were considered to be very high, those between 1.5 and 2.0 were high, those between 0.5 and < 1.5 were moderate, and those less than 0.5 were low. Raw grid node standardized anomalies were also placed into smaller 0.25 standard deviate bins ranging from -5.5 to 5.5. The 0 to 5.5 range was coded (low, moderate, high, very high) as above, and the -5.5 to 0 range was the mirror image ranging into negative standard deviates. This binning gave an indication of the direction of the change as well as the fine-scale distribution of the anomalies.

Figure 3 shows an example of the results of this process for gag grouper and sea surface temperature. The left panel shows the Gulf of Mexico with the absolute value of the standardized anomaly contoured according to the color bar at the top of the panel. The color bar maps to standardized anomalies ranging from 0 to 5.5. The boundary of the species’ distribution is shown by the white polygon. Climate model grid nodes falling inside the boundary are shown as dark gray dots. The top-right panel shows the percentage of model grid nodes falling into 0.25 standardized anomaly bins. The x-axis on this panel runs from -5.5 to 5.5 standardized anomalies and cooling temperatures, in this case, would appear as negative values. The bottom-right panel shows the coarser categorical binning (low, moderate, high, very high) of absolute standardized anomalies described in the above paragraph. Categorical bin colors in both left-hand panels for low, moderate, high, and very high are green, yellow, orange, and red, respectively.

Hypoxia and sea level rise exposure factors were scored by the scientist via prepared rubrics. The scoring method was the same as that used for the biological sensitivity scoring (i.e., five tallies and four bins ranging from low to very high). Both of the rubrics are in Appendix C.

Calculation of Summary Statistics

Three summary values were calculated to assess overall vulnerability: an overall climate vulnerability score, an overall biological sensitivity score, and an overall climate exposure factor score. These scores were assessed by first recasting the categorical scores (low, moderate, high, very high) for the biological sensitivity attributes and climate exposure factors as integers (1, 2, 3, 4). A weighted average score was then calculated for each biological sensitivity attribute and climate exposure factor for each species. Overall sensitivity and exposure scores were then calculated as follows: if three or more attributes or factors had an average of ≥ 3.5 then the sensitivity or exposure score was considered to be very high with a value of 4; if 2 or more attributes or factors had an average ≥ 3.0 then the score was considered to be high with a value of 3; if 2 or more attributes or factors had an average ≥ 2.5 then the score was considered to be moderate with a value of 2; otherwise, the score was considered to be low with a value of 1 (following Morrison *et al.* 2015 and Hare *et al.* 2016).

To calculate the overall climate vulnerability score, the overall sensitivity and exposure scores were multiplied together, thus returning values ranging from 1 to 16, inclusively. The overall climate vulnerability score was low if the product ranged from 1 to 3, moderate if from 4 to 6, high if from 7 to 9, and very high if from 10 to 16 (as in Morrison *et al.* 2015, Hare *et al.* 2016).

Bootstrap Analyses

The certainty of overall climate vulnerability scores was assessed via bootstrap analyses. The scores across all scientists were drawn randomly with replacement 10,000 times and the composite scores were recalculated and recorded at each iteration. When the bootstrap sampling was completed, the proportion of the 10,000 iterations that fell into each categorical bin was calculated. These data were then examined to identify which species might change rankings (i.e., moving to higher or lower categories).

Principal Component Analysis

A Principal Component Analysis (PCA) was conducted on the species-level sensitivity attribute scores and then each species in the biplot was color-coded according to its functional group. The PCA helped identify the primary sensitivity factors accounting for the majority of the variance in sensitivity scores. The analysis was conducted using the MATLAB (2015) function ‘pca’.

Results

General Climate Patterns

In comparison to mean conditions that existed during the fifty-year reference time period (1956 to 2005), the Gulf of Mexico is projected under the RCP 8.5 scenario to become everywhere warmer, saltier, more acidic, and less oxygenated during the current fifty years (2006-2055) (Fig.

2 and Appendix B). Viewed through the lens of standardized anomalies, these changes represent generally large shifts in mean conditions. Temperature (surface air temperature, a proxy for estuarine and freshwater temperatures, and sea surface temperature follow the same pattern) changes in the current time block are projected to be 2.75 to 5 standard deviations larger than the 1956-2005 mean. This places temperature in the very high exposure category. Dissolved oxygen projections are 2 to 5 standard deviations lower than the historical mean, placing it in the very high category. Salinity is projected to be 0.5 to 3.25 standard deviations higher than the historical mean and ranges across the low to very high categories with most observations in the very high bin. Ocean acidity, pH, is projected to be between 10.5 and 30 standard deviations lower than the historical mean placing it well within the very high exposure category. Other environmental variables show less pronounced change. Integrated primary productivity and precipitation were projected to be relatively stable with small declines that are generally within 1 to 2 standard deviations of the 1956-2005 historical mean (precipitation in the Mississippi River watershed is projected to increase modestly).

The projected changes during 2006-2055 have a spatial patterning, and the pattern for each exposure factor is unique. Projected sea surface temperature changes are greatest in the southeastern, central/western, and the northeastern Gulf of Mexico. Sea surface salinity changes are projected to be the largest in the central Gulf. Dissolved oxygen changes are projected to be the largest in the southeastern, central, and northeastern Gulf. Ocean acidity changes are expected to be the largest in the southeastern and central Gulf of Mexico. Note that lesser, but still large, shifts in environmental conditions are projected across the Gulf for all of these exposure factors beyond those areas just highlighted.

Projected climate change during the next fifty years (2050-2099) is shown in Appendix D. The spatial pattern of projected climate change is similar to 2005-2055, but with an amplified environmental signal. For instance, sea surface temperature standardized anomalies range from about 6.5 to 11 (up from 2.75 to 5 in the 2006-2055 period), salinity standardized anomalies range from about 2.6 to 8 (up from 0.5 to 3.25), and pH standardized anomalies range from about 30.5 to 65 (up from 10.5 to 30).

There is evidence that Gulf of Mexico environmental changes may accelerate under the RCP 8.5 scenario. Figure 4 of Appendix D shows temperature plotted against salinity for the CMIP5 climate model data for the three time blocks examined in this study: 1956-2005, 2006-2055, and 2050-2099. The distribution of points and the mean are translated further (toward warmer and saltier) between 2050-2099 and 2006-2055 than they are between 2006-2055 and 1956-2005, thus indicating that the changes in these two critically important environmental variables are projected to be of greater magnitude in the last half of this century under the RCP 8.5 scenario.

General Biological Sensitivity and Exposure Scores

The distributions of trait-based sensitivity attribute scores across species are shown in Figure 4. With respect to median scores, population growth rate (2.3) had the highest scores across species, followed by other stressors (2.2), and then early life stage survival and settlement (2.1), spawning cycle (2.1), complexity in reproductive strategy (2.0), and spawning stock size/status

(2.0). The lowest median scores were prey specificity (1.6) and sensitivity to temperature (1.7). The highest single scores went to adult mobility (4.0), followed by population growth rate (3.8), spawning cycle (3.7), sensitivity to ocean acidification (3.7), spawning stock size/status (3.7), early life stage dispersal (3.6), and other stressors (3.6).

Figure 5 shows the distribution of climate exposure scores across species. Air temperature, ocean acidification, and sea surface temperature all scored 4.0. Dissolved oxygen (Appendix B) was also valued at 4.0. Note that either air temperature or sea surface temperature was used for a given species depending on how much of the life history occurred in fresh, estuarine, or ocean environments. This was to avoid ‘double counting’ the temperature effect in this assessment. Following temperature and ocean acidification were salinity (3.4 median value), sea level rise (2.2), hypoxia (1.8), primary productivity (1.7), and precipitation (1.0).

The relative contribution of each sensitivity attribute for each species is depicted in the glyph plots in Figure 6. In this plot, attribute scores are arranged along the spokes of each subplot. The longer the spoke, the higher the score. The least vulnerable species in the assessment were southern flounder, Gulf menhaden, butterflyfish, spotted seatrout, red drum, and lesser amberjack. These species had low scores for all attributes. The most vulnerable species were Gulf sturgeon, Nassau grouper, black grouper, yellowmouth grouper, and eastern oyster. All of these vulnerable species have large sensitivities across most sensitivity attributes. Gulf sturgeon had very high scores in population growth rate, stock size/status, spawning cycle, and early life stage dispersal. The lowest attribute scores for Gulf sturgeon were prey specificity and sensitivity to ocean acidification. Nassau grouper also had very high scores in population growth rate, stock size/status, and spawning cycle. The lowest scores were in prey specificity and early life stage dispersal. Eastern oyster had very high scores in adult mobility (i.e., sessile), sensitivity to ocean acidification, and other stressors.

Similarly, the relative contribution of each climate exposure factor for each species is shown in Figure 7. Here, the importance of temperature (air and sea surface are depicted as the spokes pointing right, and to the bottom right, respectively), ocean acidification (spoke pointing directly up), and salinity (spoke pointing to the bottom left) are again identified as important. Hypoxia (spoke pointing to the upper right) also played a role in all but three species. Interestingly, the glyph plots for blue crab, brown shrimp, eastern oyster, pink shrimp, and white shrimp are all very similar and reflect the importance of air temperature (a proxy for estuarine and freshwater temperatures), hypoxia, ocean acidification, sea level rise (spoke pointing directly down), and, to a small extent, precipitation (spoke pointing to the upper left), primary productivity (spoke pointing directly left), and salinity (spoke pointing to the bottom right). Gulf sturgeon, the most vulnerable species in the assessment, had a similar glyph plot to those species just mentioned, but was not as subject to primary productivity or salinity. Nassau grouper, the second most vulnerable species, was most exposed to sea surface temperature, ocean acidification, and salinity, with some exposure to primary productivity and other exposure factors.

Overall Vulnerability Scores

The scope of climate change and the susceptibility of marine organisms to it are reflected in the overall vulnerability plot shown in Figure 8, which is set up such that the rankings for climate exposure factors are read along the x-axis, while the rankings for the trait-based biological sensitivities are read along the y-axis. Each axis is divided into categorical scores (low, moderate, high, very high). The overall climate vulnerability is given by the colors green, yellow, orange, and red representing low, moderate, high, and very high, respectively.

Climate factor exposures (x-axis in Fig. 8) were in the high or very high categories for all species. Sixty-four species were in the high exposure category and eleven species were in the very high exposure category. This is driven by temperature, salinity and pH, all of which are in the very high exposure category for the Gulf of Mexico. Dissolved oxygen could be added to this list. Species were much more dispersed across trait-based biological sensitivity categories (y-axis in Fig. 8). The majority of species were located in the low sensitivity category (46 species), followed by the moderate (15 species), high (13 species), and very high (one species) categories.

As mentioned, the overall climate vulnerability score is given by the color of the boxes in Figure 8 (low, moderate, high, and very high are colored green, yellow, orange, and red, respectively). Gulf sturgeon and three groupers (Nassau grouper, black grouper, and yellowmouth grouper) were all in the very high overall vulnerability category. Note that Gulf sturgeon and Nassau grouper are both considered threatened under the Endangered Species Act.

The high overall vulnerability category (orange) was dominated by elasmobranchs and grouper and contained eleven species (scalped hammerhead shark, great hammerhead shark, goliath grouper, dusky shark, yellowedge grouper, eastern oyster, Warsaw grouper, speckled hind, smalltooth sawfish, gag grouper, and snook). Smalltooth sawfish is an Endangered Species Act endangered species. These rankings were largely driven by population growth rates, stock size/status, and some subset of three major climate exposure factors (i.e., temperature, salinity, pH).

The moderate (21 species) and low (31 species) overall climate vulnerabilities (yellow and green, respectively) each contained a mix of species, including all invertebrates except Eastern oyster. Interestingly, four shrimp species as well as stone and blue crab were all in the low overall exposure category, while spiny lobster was in the moderate category. All of the low and moderate overall vulnerability species had one or two climate exposures in the very high category and biological sensitivity attributes that were in the moderate and low categories.

Several species that support important fisheries in the Gulf of Mexico (e.g., Gulf menhaden, brown shrimp, pink shrimp, white shrimp, vermillion snapper, cobia, Spanish mackerel, speckled sea trout, and amberjack) were in the low overall vulnerability category indicating that these species may have some resilience to climate change despite large environmental exposures. Red snapper, red grouper, snowy grouper, golden tilefish, king mackerel, and dolphin, which are additional important fishery species, were in the moderate overall vulnerability category, suggesting somewhat lessened resilience.

A number of important fishery species also had high or very high overall vulnerabilities. These included black grouper, yellowmouth grouper, goliath grouper, yellowedge grouper, Warsaw grouper, speckled hind, and gag grouper.

Overall, twenty percent of the assessed species in the Gulf of Mexico had high or very high overall climate vulnerability. The remaining eighty percent were in the moderate (28% of the total) and low (52% of the total) overall vulnerability categories (Fig. 8).

Overall Vulnerability Bootstrap

Results from the bootstrap analysis conducted to assess the probability that overall vulnerability rankings could change are also shown in Figure 8. Thirty-three of the species (denoted by bold text in Fig. 8) had a ≥ 0.25 to < 0.5 probability of moving one category higher (e.g., moderate to high), while just one species (denoted by italics in Fig. 8) had a ≥ 0.25 to < 0.5 probability of moving one category lower. Similarly, twelve species had a ≥ 0.5 probability of moving one rank higher (denoted by bold text and an asterisk in Fig. 8) while none had a ≥ 0.5 probability of moving one rank lower (would be denoted by italicized text and a double asterisk in Fig. 8). This suggests that small differences in individual species scores could have shifted a large portion of species (45%) into a higher overall risk category. Eighteen percent of high vulnerability species had a ≥ 0.5 probability of moving from high to very high, 14% of the moderate category species had a ≥ 0.5 probability of moving to high, and 15% of low category species had a ≥ 0.5 probability of moving to moderate. This, in combination with the data-limited nature of many Gulf fishery stocks (Sagarese *et al.* 2018), leads to some uncertainty in the proportion of species that fall into the higher risk categories and suggests that additional species may be at risk. This is especially the case for those that could have moved from high to very high (i.e., scalloped hammerhead shark, great hammerhead shark, goliath grouper, and yellowedge grouper) or from moderate to high (sandbar shark, hogfish, red grouper, lemon shark, tiger shark, snowy grouper, tarpon, southern stingray, and mutton snapper).

Functional Group Scores

The functional groups of the species were examined to identify the risk category of the groups (Table 3). There was only one diadromous fish (Gulf sturgeon) included in the analyses and it had a very high overall vulnerability. The eleven grouper species were spread across three vulnerability categories (moderate, high, and very high having 3, 5, and 3 species in each category, respectively). Sixteen elasmobranchs were included in the analyses and these fell into the low, moderate, and high (7, 5, and 4 species respectively) vulnerability categories. The eight invertebrates and 14 coastal fishes were all distributed in a similar manner across low to high vulnerabilities, with a greater number of species in the low category. The pelagics, offshore bottomfish, snappers, and coastal pelagics functional groups were all distributed in the low and moderate vulnerability categories with a greater number of species in the low category, except for pelagics, which had one species in the low and two species in the moderate category.

Principal Component Analysis

A principal component analysis (PCA) was conducted on the sensitivity attribute scores at the species level (Fig. 9). The first principal component (PC1) accounted for 43.7% of the variance, and the main loadings were population growth rate (0.51), stock status/size (0.42), and complexity in reproductive strategy (0.35). The second principal component (PC2) accounted for 26.9% of the variance, and the main loadings were population growth rate (0.55), early life history survival and settlement (-0.49), and adult mobility (-0.36). After running the PCA, the species on the biplot were color-coded according to functional group. Species in functional groups were distributed near each other in the PCA biplot suggesting that there were similar sensitivity scores within functional groups. Generally, functional groups were separated most along the PC1 axis, but elasmobranch and invertebrates were separated from the others along the PC2 axis. Eastern oyster (shown in brown) and Gulf sturgeon (red) were located by themselves in the fourth quadrant of the biplot.

Propensity of Distributional Change

The species' propensity for distributional change was assessed and the results are shown in Figure 10. Note that the colors (red to green and their corresponding categories (low to very high, respectively) are reversed from those in Figure 8, as a higher propensity for distributional change was assumed to confer greater resilience to climate change. For example, a low propensity for distributional change is viewed as an increased vulnerability to climate change and is color-coded red. Three species (tiger shark, scalloped hammerhead shark, and sandbar shark) had a very high (green) propensity for distributional change indicating a movement-related resilience to climate change. Fifty-one species had a high (yellow) propensity, fourteen had a moderate (orange) propensity, and seven (speckled hind, black grouper, red grouper, gag grouper, goliath grouper, Gulf sturgeon, and eastern oyster) had a low (red) propensity for distributional change. Overall, 68% of species in the assessment had a high or very high propensity for distributional change, while 9.3% had a low propensity. While a high or very high propensity for distributional shift may convey resilience, it may also mean that the species has a chance of moving out of the region and perhaps into areas that make them more or less vulnerable to exploitation as conditions change.

In Figure 11, the propensity for distributional change was plotted against the overall climate vulnerability. These data indicate that some species, such as black grouper and Gulf sturgeon, have both very high overall climate vulnerability and low potential to change distributions. These species may be unlikely to have the capacity to move despite their very high vulnerability to climate change. Species such as tiger shark and sandbar shark have moderate overall climate vulnerability and a very high propensity for distributional change, thus possibly affording them a means to offset the effects of climate change via movement. Note that overall climate vulnerability and propensity for distributional change are not completely independent. The four trait-based sensitivity attributes (i.e., temperature sensitivity, dispersal of early life stages, and adult mobility and habitat requirements) that are used to construct the propensity for

distributional change are found among the twenty sensitivity attributes and exposure factors used to construct the overall climate vulnerability.

Species Information Sheets and Species Narratives

A summary graphic, referred to as a species information sheet, was developed for each species in the climate vulnerability assessment. An example for gag grouper is provided in Figure 12 (other species available in Appendix E). In the case of gag grouper, the overall climate vulnerability, trait-based sensitivity, and climate exposure were all classified as high (orange). The overall data quality score was calculated to be ≥ 2 , indicating that there were limited data.

Below the summaries for overall vulnerability and data quality in Figure 12 are the scores for specific trait-based sensitivity attributes and climate exposure factors. In this gag grouper example, the mean scores for sensitivity attributes range from 1.8 for prey specificity to 3.2 for population growth rate. Data quality scores for the sensitivity attributes range from 2 to 3. The bar charts suggest that the central tendencies for gag grouper across all of the sensitivity attributes were generally in the high and moderate categories. The overall trait-based sensitivity score was high. Below the sensitivity attribute scores are the climate exposure factor scores. Mean scores for climate exposure factors ranged from 1.6 to 2.9 with data quality scores ranging from 1.6 to 3. Note that a data quality score of zero here indicates that the climate exposure factor was not used for this species. Neither air temperature nor precipitation were used for gag grouper. The bar charts to the right of the exposure factors score highlight the importance of ocean acidification and sea surface temperature for gag grouper, both of which are very high. The overall climate exposure factor score was high, as was the overall climate vulnerability score.

Species information sheets shed light on the details underpinning the exposure, sensitivity, and overall vulnerability rankings. For instance, Gulf sturgeon was clearly an outlier with very high scores in nearly all sensitivity attributes, as well as very high exposures to temperature and ocean acidification. Nassau grouper had very high ocean acidification, salinity, and sea surface temperature exposure factors and had high or very high biological sensitivity attributes in all areas except prey specificity, adult mobility, and early life stage dispersal. Black grouper was vulnerable to ocean acidification, salinity, and sea surface temperature, and also had generally high biological sensitivities. Yellowmouth grouper was subject to the same three exposure factors, but had a few more moderate sensitivity attribute scores, especially for early life stage dispersal and spawning cycle.

The species information sheets also revealed the importance of the population growth rate and stock size/status sensitivity attributes. Eight of the eleven grouper species in the assessment had very high dominant modes in the population growth rate sensitivity attribute; five also had very high scores in the stock size/status attribute. These species tend to be long-lived, with slow population growth rates and relatively small stock sizes. Six species in the elasmobranch functional group (lemon shark, dusky shark, great hammerhead shark, nurse shark, sandbar shark, and smalltooth sawfish) had very high scores in the population growth rate sensitivity attribute. Smalltooth sawfish, which is a protected resource, also had very high sensitivities in

stock size/status. Similarly, Gulf sturgeon, another protected resource, had very high scores in growth rate and stock size/status. Because of their life history strategies and vulnerabilities, these species may warrant close attention.

Directional Effects

Based on scientist judgment, the analyses of the directional effects (Fig. 13) assessed whether a given species would be influenced by climate change in a negative, neutral, or positive manner. Twenty-one species (28%) were expected to experience negative climate effects, fifty-one (68%) neutral effects, and three (4%) were expected to experience positive effects. The ranking itself is skewed towards negative effects overall with fifty-eight species possessing negative scores ranging from -0.85 to -0.05 and fourteen having positive scores ranging from 0.05 to 0.35. A perfectly neutral score of 0.0 was ascribed to king mackerel, greater amberjack, and flyingfishes. The species that had the most negative rankings were Gulf sturgeon (-0.85), smalltooth sawfish (-0.80), and eastern oyster (-0.70). Those with the most positive rankings were banded rudderfish, Atlantic croaker, and ballyhoo, all of which were ascribed a score of 0.35.

Given the relatively large number of species with a low overall climate vulnerability score, it is interesting that scorers expected only three species to experience overall beneficial effects from climate change in the future. However, there were important similarities between the directional effects scores (Fig. 13) and the overall vulnerability scores (Fig. 8). The two approaches (species scoring and directional effect scoring) both identified Gulf sturgeon, Nassau grouper, black grouper, yellowmouth grouper (all very high overall vulnerabilities), scalloped hammerhead shark, great hammerhead shark, eastern oyster, Warsaw grouper, speckled hind, smalltooth sawfish, gag grouper, and snook (all high overall vulnerabilities) as species that may be challenged by climate change. Similarly, both approaches identified banded rudderfish and Atlantic croaker as species that had low vulnerability or may experience positive effects from climate change.

Discussion

The RCP8.5 scenario used here projects substantial climate-related change in several important environmental variables for the Gulf of Mexico LME. Specifically, the projections indicate that the Gulf will become warmer, saltier, more acidic, and less oxygenated during the 2006 to 2055 period, relative to baseline conditions estimated for 1956-2005. Projections for the next fifty years (2050-2099) indicate further divergence from that baseline.

The expected shifts in these key environmental variables (Manderson 2016, Deutsch *et al.* 2020), which may shift along different trajectories (Mora *et al.* 2013, Schlunegger *et al.* 2020), suggests that a dynamic set of environmental stressors (Bopp *et al.* 2013, Breitburg *et al.* 2018, Sampio and Rosa 2019) may be operating chronically in the Gulf as the climate changes. This may have

important implications for living marine resources (Manderson 2016). Because of this, biotic and abiotic conditions should be carefully monitored as conditions change.

Note that because north-central hypoxia has long been a significant regional concern (Malakof 1998, Rabalais *et al.* 2002a, 2002b), hypoxia was carried through the full assessment instead of Gulf-wide dissolved oxygen. If dissolved oxygen were carried through the full assessment instead of hypoxia, it would have resulted in very high climate exposure for most species and more species moving up in overall vulnerability categories, even to the very high category, as dissolved oxygen is ranked very high across the Gulf of Mexico. It is interesting that, while the climate models produced a ranking of very high for dissolved oxygen, scientist elicitation produced a median score of 1.8 (near moderate) for hypoxia (Fig. 5). This may have arisen because most species' distributions extended well beyond the region of the Dead Zone, and so were presumed by the scorers to not be impacted by hypoxia throughout their entire ranges in the Gulf LME.

The projected patterns of climate change in the Gulf and its unique geography may limit the ability of species to move latitudinally or longitudinally to avoid the effects of climate change. The northern Gulf of Mexico might thus be viewed as an 'ecological trap' under climate change. However, there are indications of species moving deeper in the Gulf of Mexico (Pinsky *et al.* 2013) and this may be a mechanism by which climate effects are reduced for some species. However, such changes may present key physiological challenges (Manderson 2016, Caves and Johnson 2021) and therefore warrant careful consideration in assessing the effects of climate change on living marine resources.

While many species seem to have life-history traits that make them susceptible to climate change, more in the region appear to have traits that may lend resilience against climate change. However, many species in the Gulf of Mexico are considered data-limited and this led to greater uncertainty in scores, with scientists assigning tallies to three and sometimes all four categorical bins (low to very high) rather than one or two. The bootstrap analyses also highlighted a dynamic in which many more species could have been assigned to higher-risk categories with small changes in scoring. This, in combination with the data-limited nature of the Gulf, leads to some uncertainty in the proportion of species that fall into the higher-risk categories.

The top-ranked life-history traits across species were population growth rate, other stressors, early life stage survival and settlement requirements, spawning cycle, stock size/status, and spawning complexity (Fig. 4). However, the across-species median scores for these life-history traits are not different at the 5% significance level, suggesting that all are equally important. Aside from other stressors, which included consideration of factors such as harmful algal blooms, habitat loss, and pollutants, the top-ranked sensitivities at this level of analysis are all related to population size, successful reproduction, and settlement/recruitment.

A lower level of analysis was provided and generally upholds these findings, but adds other traits depending on particular species' life-history strategies. The general results are bolstered by the PCA which found the main loadings of the first principal component to be population growth rate, stock size/status, and spawning complexity, and the main loadings of the second principal

component to be population growth rate, early life stage survival and settlement, and adult mobility.

The CMIP6-class models became available during the course of this study, but the CMIP5 models were used. This was done to provide common ground between this work and that of Hare *et al.* (2016). Additionally, the RCP 8.5 scenario was used which expresses a ‘business as usual’ scenario. This scenario was chosen because it was used in other climate vulnerability assessments, seemed the most likely to take place, and because current and near-future emissions seem to track RCP 8.5 (Schwain *et al.* 2020a, 2020b, but see Hausfather and Peters 2020). Other, less aggressive scenarios might also be considered if societal adaptation to and mitigation of climate change ensues. There is not, however, much difference in the temperature outcomes between representative concentration pathways in the early part of the CMIP5 projections (20052055) covered by this climate vulnerability assessment.

Climate vulnerability assessments are intended to help inform the management of living marine resources. They can be used to support biological opinions for endangered species, risk assessments, and integrated ecosystem assessments. The results of a climate vulnerability assessment can be used to help identify management actions, such as protecting spawning biomass, that might increase stock resilience, and they can be used by social scientists in assessing the vulnerability of fishing communities to climate change. Environmental variables can be identified that might be studied independently and/or included in improved stock assessments. In addition, the results can be used to set research agendas for the region, such as prioritizing work to fill gaps in biological data or examining how particular environmental processes affect species’ physiology or ecology.

Effective management in a changing climate will require continued information on the risks posed to individual species. As in Hare *et al.* (2016), we recommend repeating the Gulf of Mexico climate vulnerability assessment periodically, and several improvements could be made. A new assessment could take advantage of changes in ecological knowledge of the species, stock size/status updates, and the development of new climate modeling products such as the CMIP6 modeling effort or work done to downscale climate models for regional applications (Spencer *et al.* 2019). Better information on species distributions and environmental tolerances could also be used. Following the introduction of this assessment to the management arena, better linkages to that enterprise will help ensure an improved positioning of the results. Future assessments could also include a greater number of diadromous species such as striped bass, that may be dependent on spring-fed cool water sources in the summer (Van Den Avyke and Evans 1990), and alosines like Alabama shad and skipjack herring (Mettee and O’Neil 2003). Corals, seagrasses, and mangroves are exceptionally important in the Gulf of Mexico, but were not included in this assessment. These were omitted intentionally as new techniques in habitat climate vulnerability were in development (Farr *et al.* 2021). We anticipate the application of these habitat assessment techniques to address Gulf of Mexico coral, seagrass, mangroves, and other habitats.

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Figures

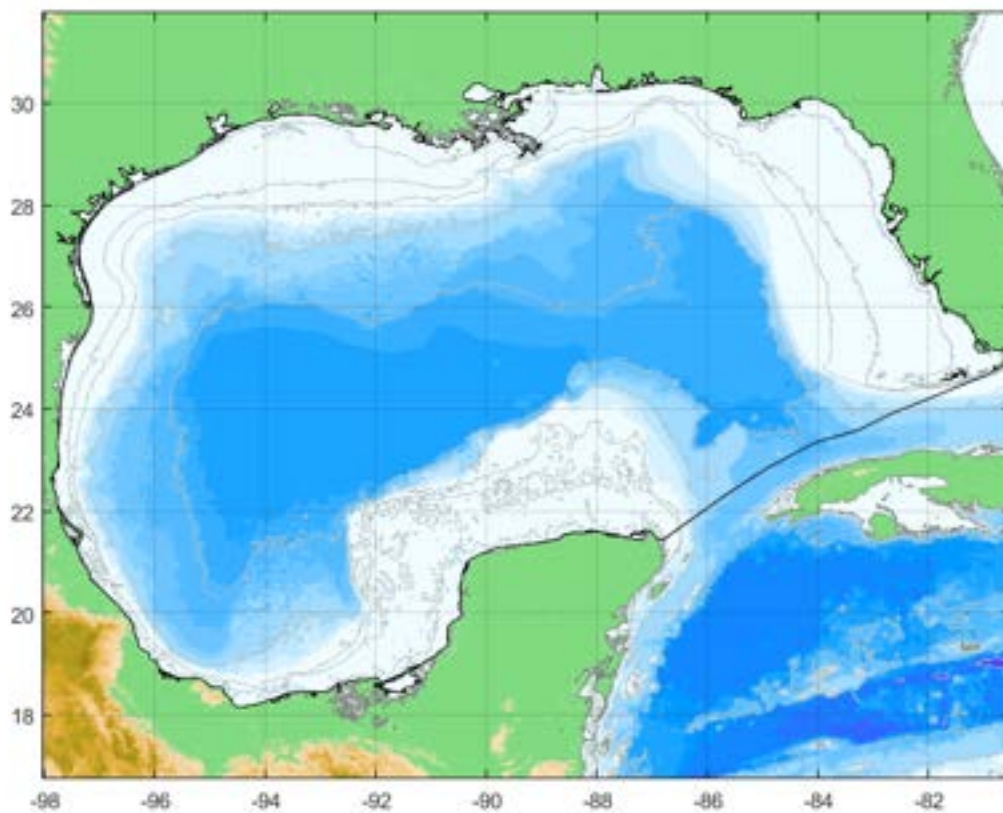


Figure 1 - Gulf of Mexico Large Marine Ecosystem. The Gulf of Mexico Large Marine Ecosystem, outlined in black, is the study area for this Climate Vulnerability Analysis. Estuarine and adjacent freshwater systems were included where required by species life history requirements.

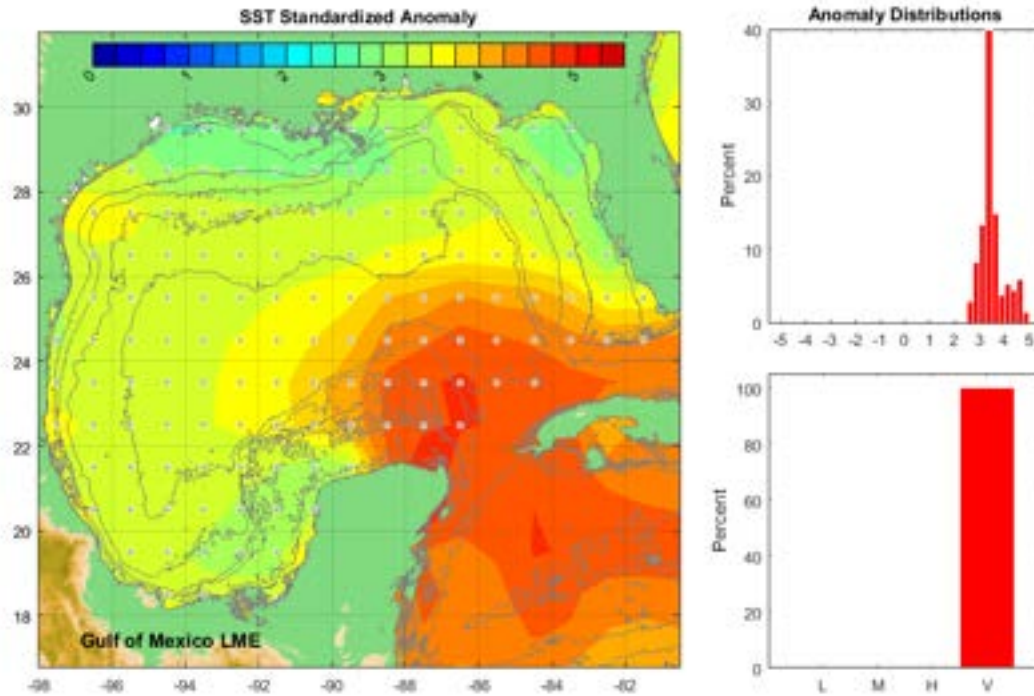


Figure 2 - Standardized anomaly for 2006-2055 sea surface temperature in the Gulf of Mexico Large Marine Ecosystem. Left hand panel shows the absolute value of the standardized anomaly (difference is SST between 2006-2055 and 1956-2005 divided by the standard deviation of the 1956-2005 SST). Units are in standard deviates. The 10, 50, 100, 1000, 3000, and 6000 m depth contours are shown in gray. Small circular markers indicate climate-model data grid points inside the Gulf LME. The top right panel shows the frequency distribution of the 0.25-sigma binned standardized anomaly values (standard deviations) at the grid points. Negative values indicate cooling; positive values indicate warming. Bar color indicates Low (green), Moderate (yellow), High (orange), and Very High (red) values for the SST exposure attribute. The bottom right panel shows the frequency distribution of the absolute value of the standardized anomaly data binned into Low (green), Moderate (yellow), High (orange), and Very High (red) categories for use in scoring exposure attributes as per Morrison *et al.* 2015. All SST standardized anomaly values across the Gulf LME between about 2.5 and 5 standard deviations (top right panel) and are in the Very High exposure category (bottom right panel).

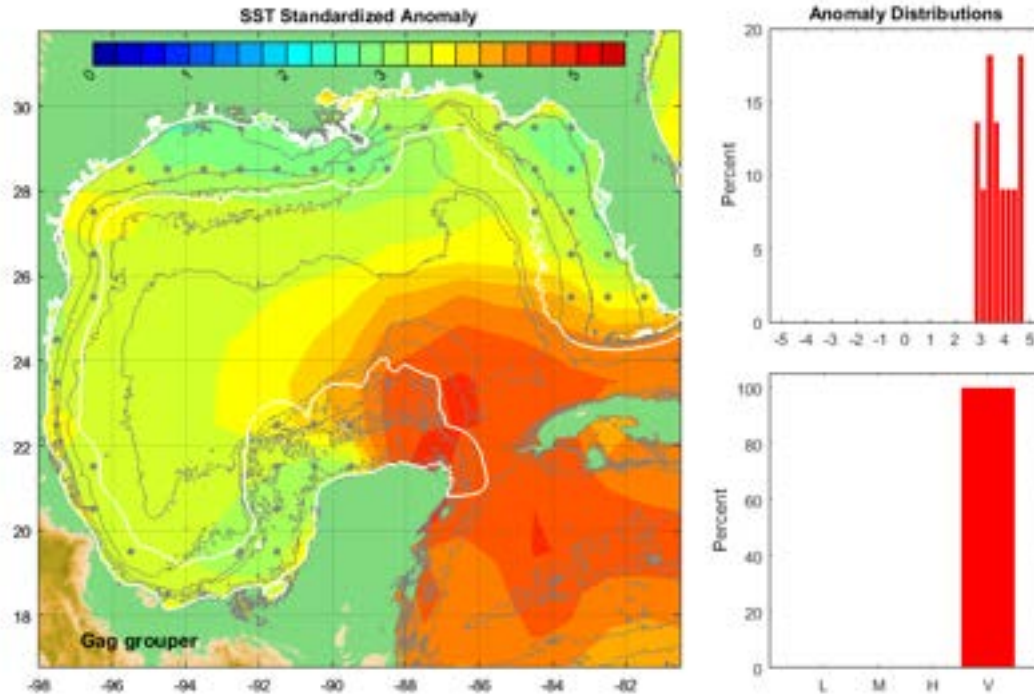


Figure 3 - Gag grouper distribution plotted on sea surface temperature standardized anomaly. Left hand panel shows the absolute value of the standardized anomaly (difference is SST between 2006-2055 and 1956-2005 divided by the standard deviation of the 1956-2005 SST). Units are in standard deviates. The 10, 50, 100, 1000, 3000, and 6000 m depth contours are shown in gray. Small circular markers indicate climate-model data grid points inside the polygon representing the distribution of gag grouper, the boundary of which is shown as a white polygon. The top right panel shows the frequency distribution of the 0.25-sigma binned standardized anomaly values at the grid points for gag grouper. Negative values indicate cooling; positive values indicate warming. Bar color indicates Low (green), Moderate (yellow), High (orange), and Very High (red) values for the SST exposure attribute. The bottom right panel shows the frequency distribution of the absolute value of the standardized anomaly data binned into binned Low (green), Moderate (yellow), High (orange), and Very High (red) classes for use in scoring exposure attributes as per Morrison *et al.* 2015. All SST standardized anomaly values for gag grouper are in the Very High exposure category.

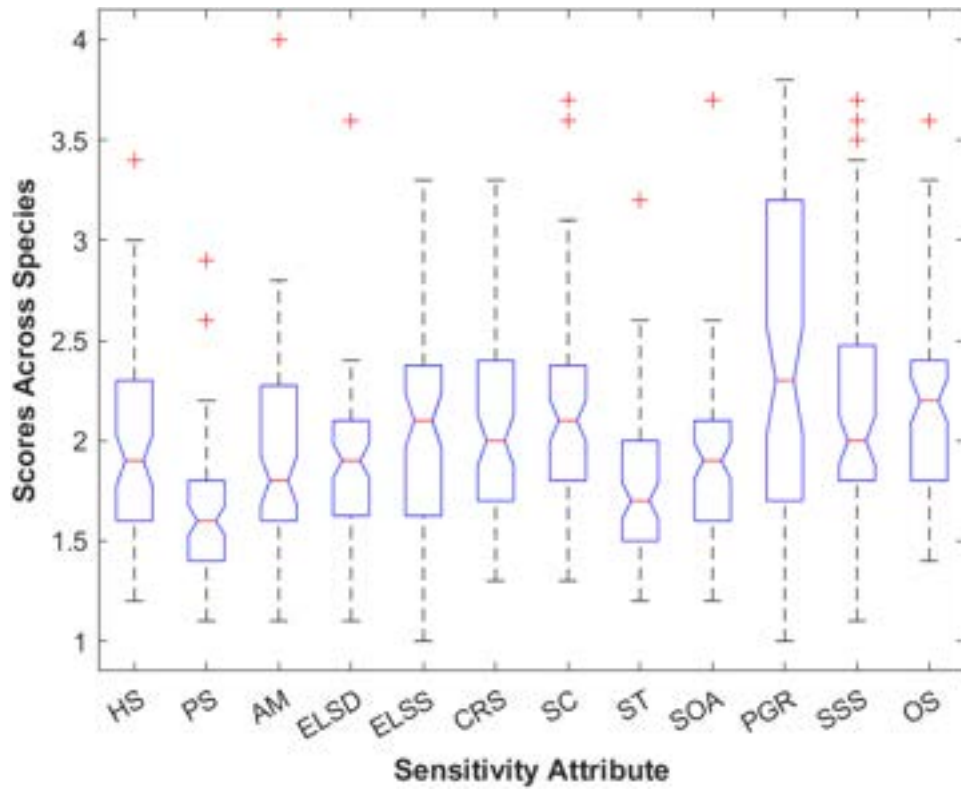


Figure 4 - Sensitivity attribute scores across species. The sensitivity attributes are along the x-axis, and the scores across species are shown along the y-axis. The red horizontal lines indicate the median score. The notches are used to identify which medians are different from others. Notches that do not overlap have different medians at the 5% significance level. The box represents the interquartile range. The whiskers extend to the most extreme value not considered an outlier. Individual scores beyond the whiskers are shown as red crosses. Along the x-axis, HS represents habitat specificity, PS is prey specificity, AM is adult mobility, ELSD is early life stage dispersal, ELSS is early life stage survival and settlement requirements, CRS is complexity is reproductive strategy, SC is spawning cycle, ST is sensitivity to temperature, SOA is sensitivity to ocean acidification, PGR is population growth rate, SSS is stock size/status, and OS is other stressors.

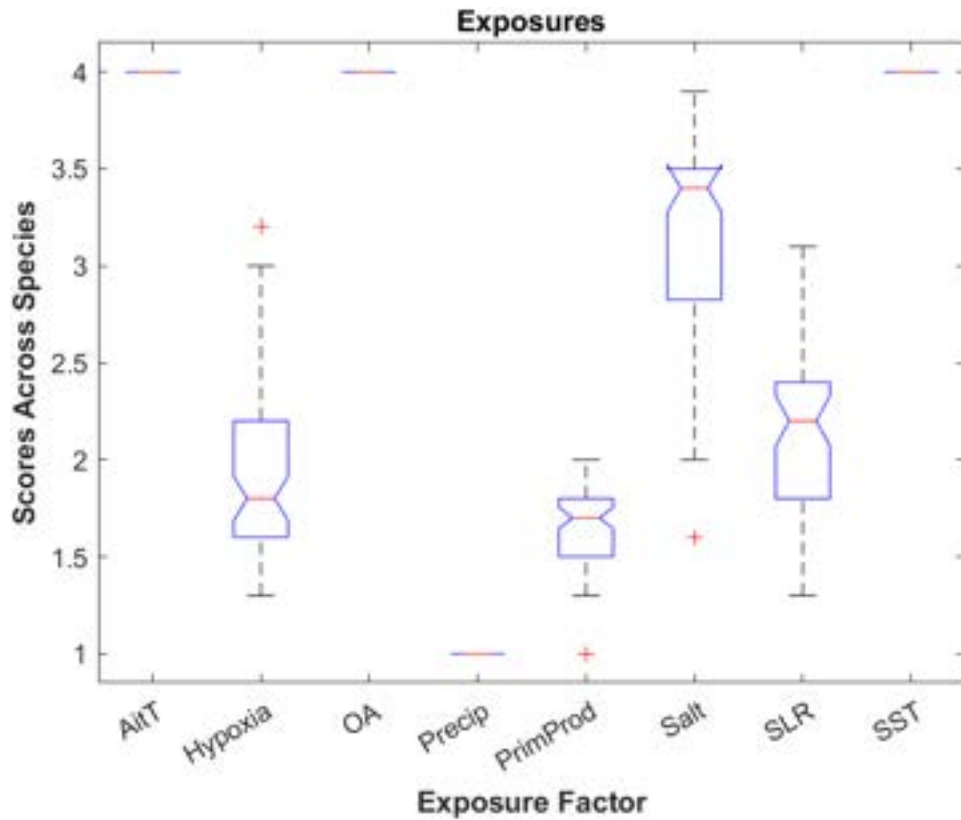


Figure 5 - Climate exposure factor scores across species. The exposure factors are along the x-axis, and the scores across species are shown along the y-axis. The red horizontal lines indicate the median score. The notches are used to identify which medians are different from others. Notches that do not overlap have different medians at the 5% significance level. The box represents the interquartile range. The whiskers extend to the most extreme points not considered outliers. Scores beyond the whiskers are shown as red crosses. Along the x-axis, AirT represents air temperature, Hypoxia is hypoxia, OA is ocean acidification, Precip is precipitation, PrimProd is integrated primary productivity, Salt is salinity, SLR is sea level rise, and SST is sea surface temperature.

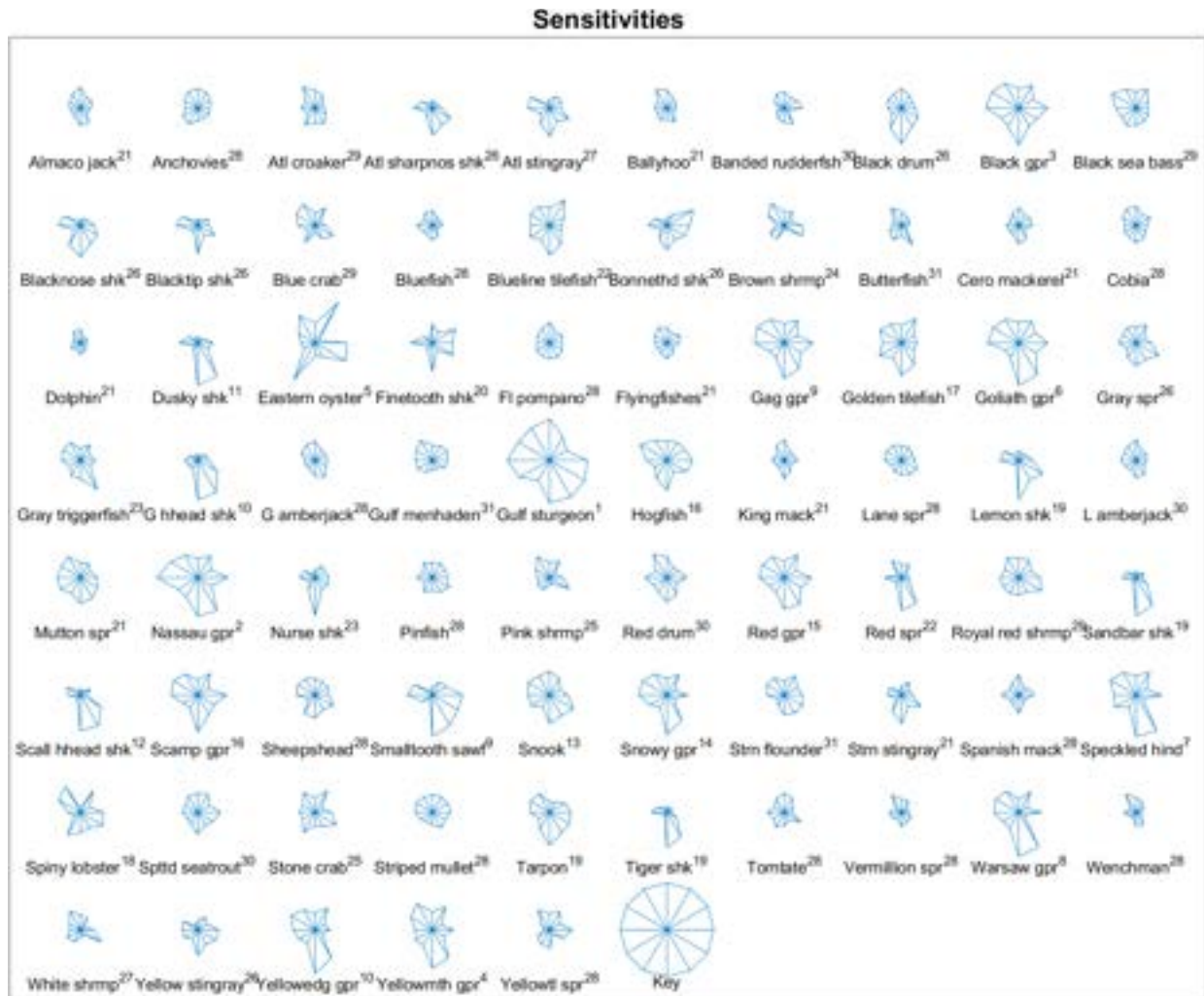


Figure 6 - Biological sensitivity attribute glyph plot. The average trait-based sensitivity attribute scores for each species are shown as spokes. The 'Key' subgraph in the bottom row represents a model in which all 12 attributes have a score of 4.0 (the maximum). The habitat specificity attribute is shown as the spoke pointing directly to the right. Then moving counterclockwise, spoke 2 is prey specificity; spoke 3 is adult mobility; spoke 4 (pointing directly up) is early life stage dispersal; spoke 5 is early life stage survival and recruitment requirements; spoke 6 is complexity in reproductive cycle; spoke 7 (pointing directly left) is spawning cycle; spoke 8 is sensitivity to temperature; spoke 9 is sensitivity to ocean acidification; spoke 10 (pointing directly down) is population growth rate; spoke 11 is stock size/status; and spoke 12 is other stressors. The superscripts after species names represent species' overall climate vulnerability rank ranging from 1 (most vulnerable) to 31 (least vulnerable). Note that the overall vulnerability is comprised of sensitivity attribute and climate exposure scores. Only attribute scores are shown here.

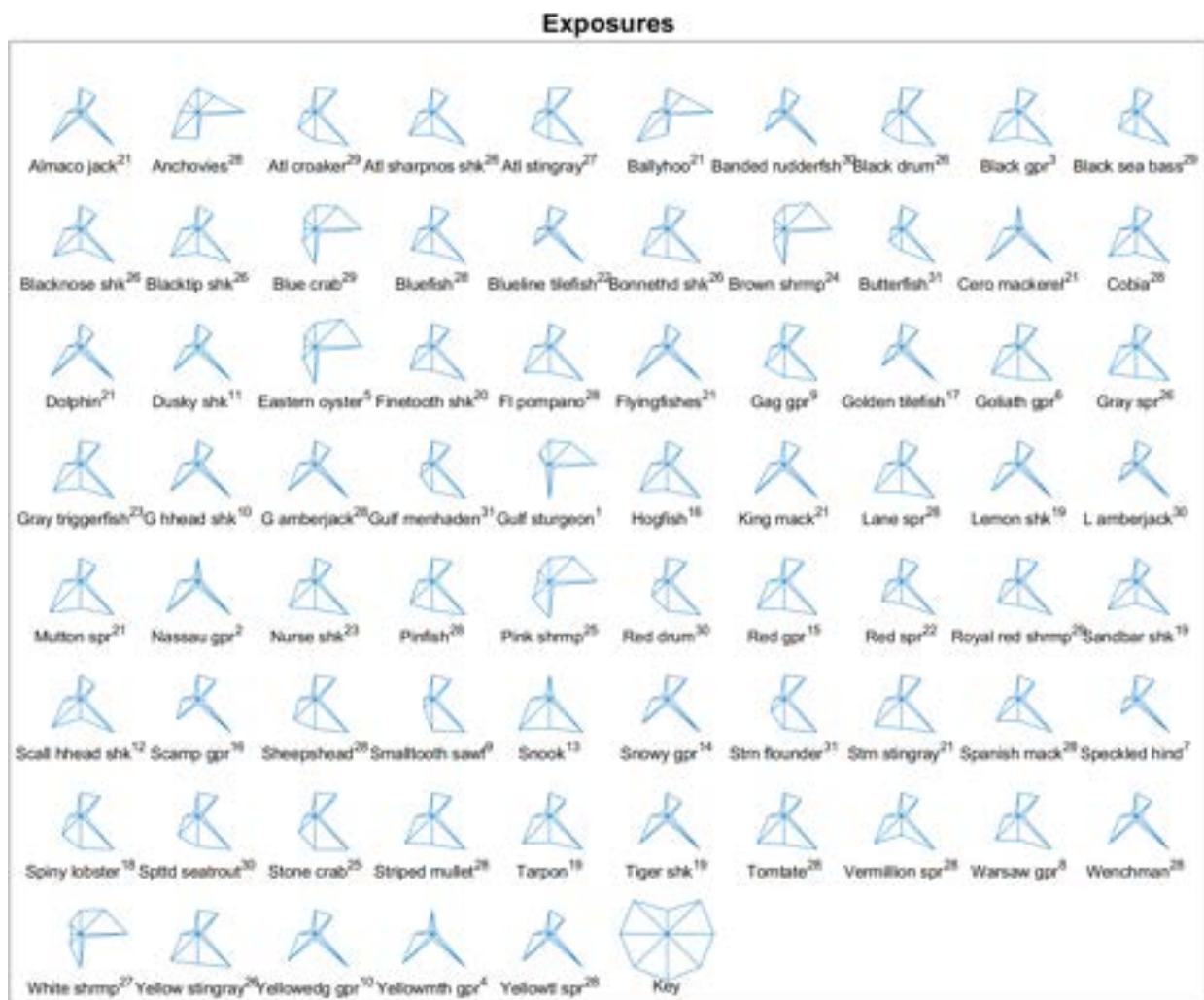


Figure 7 - Climate exposures glyph plot. The average climate exposure scores for each species are shown as spokes. The 'Key' subgraph in the bottom row represents a model in which all eight attributes have a score of 4.0 (the maximum). The air temperature (a proxy for estuarine temperatures) is shown as the spoke pointing directly to the right. Then moving counterclockwise, spoke 2 is hypoxia; spoke 3 (pointing directly up) is ocean acidification; spoke 4 is precipitation; spoke 5 (pointing directly left) is primary productivity; spoke 6 is salinity; spoke 7 (pointing directly down) is sea level rise, and spoke 8 is sea surface temperature. As in Figure 6, the superscripts after species names represent species' overall climate vulnerability rank ranging from 1 (most vulnerable) to 31 (least vulnerable). Note that the overall vulnerability is comprised of sensitivity attribute and climate exposure scores. Only exposure scores are shown here.

Sensitivity	Very High			Gulf sturgeon	
	High		Scalloped hammerhead shark* Great hammerhead shark* Goliath grouper Dusky shark Yellowedge grouper	Eastern oyster Warsaw grouper Speckled hind Smalltooth sawfish Gag grouper	Nassau grouper Black grouper Yellowmouth grouper
	Moderate		Sandbar shark* Hogfish* Red grouper Lemon shark Tiger shark* Snowy grouper Tarpon	Scamp grouper Southern stingray Golden tilefish Spiny lobster Red snapper Blueline tilefish Finetooth shark	Snook
	Low		Blacktip shark* Bonnethead shark* Blacknose shark* Yellow stingray* Gray snapper* Atlantic stingray* Gray triggerfish Greater amberjack Stone crab Yellowtail snapper Wenchman Lane snapper Striped mullet Vermilion snapper Cobia Tomtate Florida pompano Red drum Black drum Anchovies	Nurse shark Royal red shrimp Blue crab Atlantic sharpnose shark Brown shrimp Black sea bass Sheepshead Pink shrimp Spanish mackerel Southern flounder Spotted seatrout Pinfish Bluefish Gulf menhaden White shrimp Atlantic croaker Banded rudderfish Lesser amberjack Butterfish	Mutton snapper* Cero mackerel Flyingfishes Kingmackerel Almaco jack Dolphin Ballyhoo
		Low	Moderate	High	Very High
		Exposure			

Figure 8 - Climate Vulnerability. The x-axis shows species' climate exposure (Low, Moderate, High, Very High). Y-axis shows species' trait-based biological sensitivity (Low, Moderate, High, Very High); Color indicates overall climate vulnerability (green, yellow, orange, and red correspond to Low, Moderate, High, and Very High vulnerability, respectively). Borderline cases from the bootstrap results are indicated with bold and italics. Bold means there is a $\geq 0.25 < 0.50$ probability that the score is one vulnerability rank higher. Italics mean there is a $\geq 0.25 < 0.50$ probability that the score is one vulnerability rank lower. Bold and one asterisk (*) means there is a ≥ 0.50 probability that the score is one vulnerability rank higher.

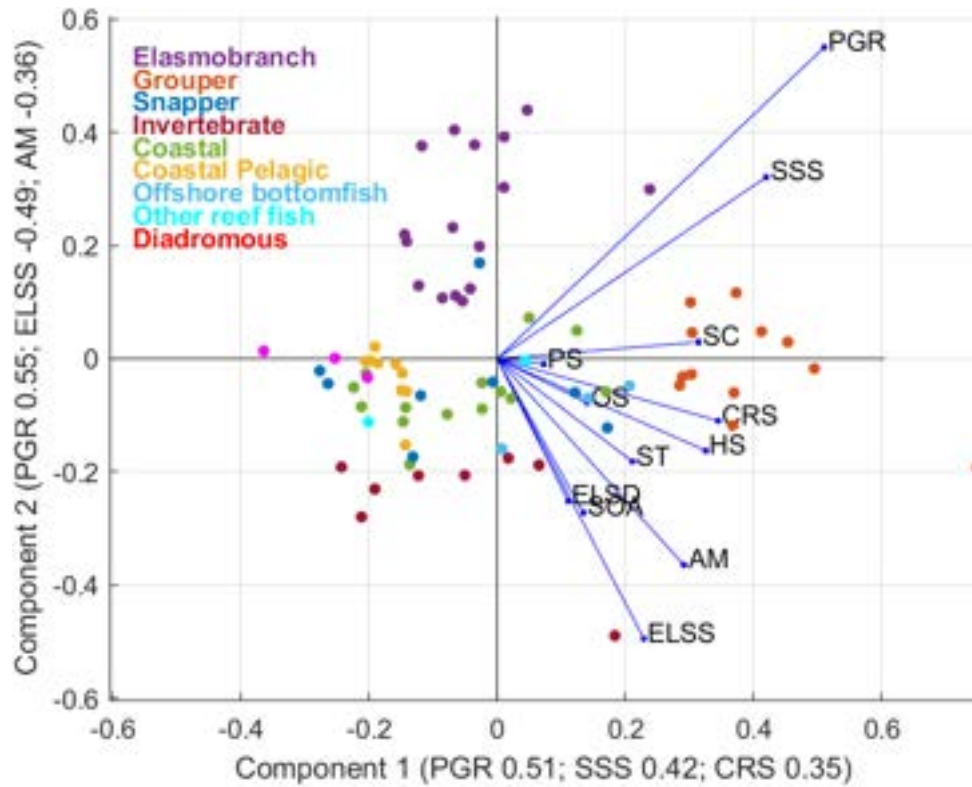


Figure 9 - Principal Components Analysis. Biplot for the species-level principal components analysis. Functional groups are color-coded as per the legend. The first principal component accounted for 43.7% of the variance, and the main loadings were population growth rate, stock size/status, and complexity in reproductive strategy. The second principal component accounted for 26.9% of the variance, and the main loadings were population growth rate, early life stage survival and settlement, and adult mobility. PGR is population growth rate; SSS is stock size/status; SC is spawning cycle; PS is prey specificity; OS is other stressors; CRS is complexity in reproductive strategy; HS is habitat specificity; ST is sensitivity to temperature; ELSD is early life stage dispersal; SOA is sensitivity to ocean acidification; AM is adult mobility; and ELSS is early life stage survival and settlement.

Propensity for Distributional Change				
Low	Moderate	High		Very High
Speckled hind Black grouper Red grouper Gag grouper Goliath grouper Gulf sturgeon Eastern oyster	Anchovies Red drum Snook Snowy grouper Warsaw grouper Royal red shrimp Spiny lobster Southern flounder Yellowmouth grouper Yellowtail snapper Spotted seatrout Scamp grouper Hogfish Nassau grouper	Great hammerhead shark Atlantic sharpnose shark Dolphin Blacktip shark Butterfish Blacknose shark Dusky shark Lemon shark Vermilion snapper Wenchman Atlantic stingray Bluefish Mutton snapper White shrimp Flyingfishes Southern stingray Ballyhoo Nurse shark Yellow stingray Red snapper Cobia Gulf menhaden Lesser amberjack Tarpon Brown shrimp Lane snapper	Florida pompano Cero mackerel Greater amberjack Finetooth shark Tomtate Gray triggerfish Atlantic croaker Spanish mackerel Almaco jack Bonnethhead shark Black sea bass Blue crab Pink shrimp Black drum Golden tilefish Banded rudderfish King mackerel Pinfish Sheepshead Blueline tilefish Yellowedge grouper Striped mullet Smalltooth sawfish Gray snapper Stone crab	Tiger shark Scalloped hammerhead shark Sandbar shark

Figure 10 - Propensity for distributional change. The potential for a species range to change in response to climate change is shown categorically. Red, Orange, yellow, and green are Low, Moderate, High, and Very High distributional change potential, respectively. The order in each category relates to how easy or difficult range change may be for each species.

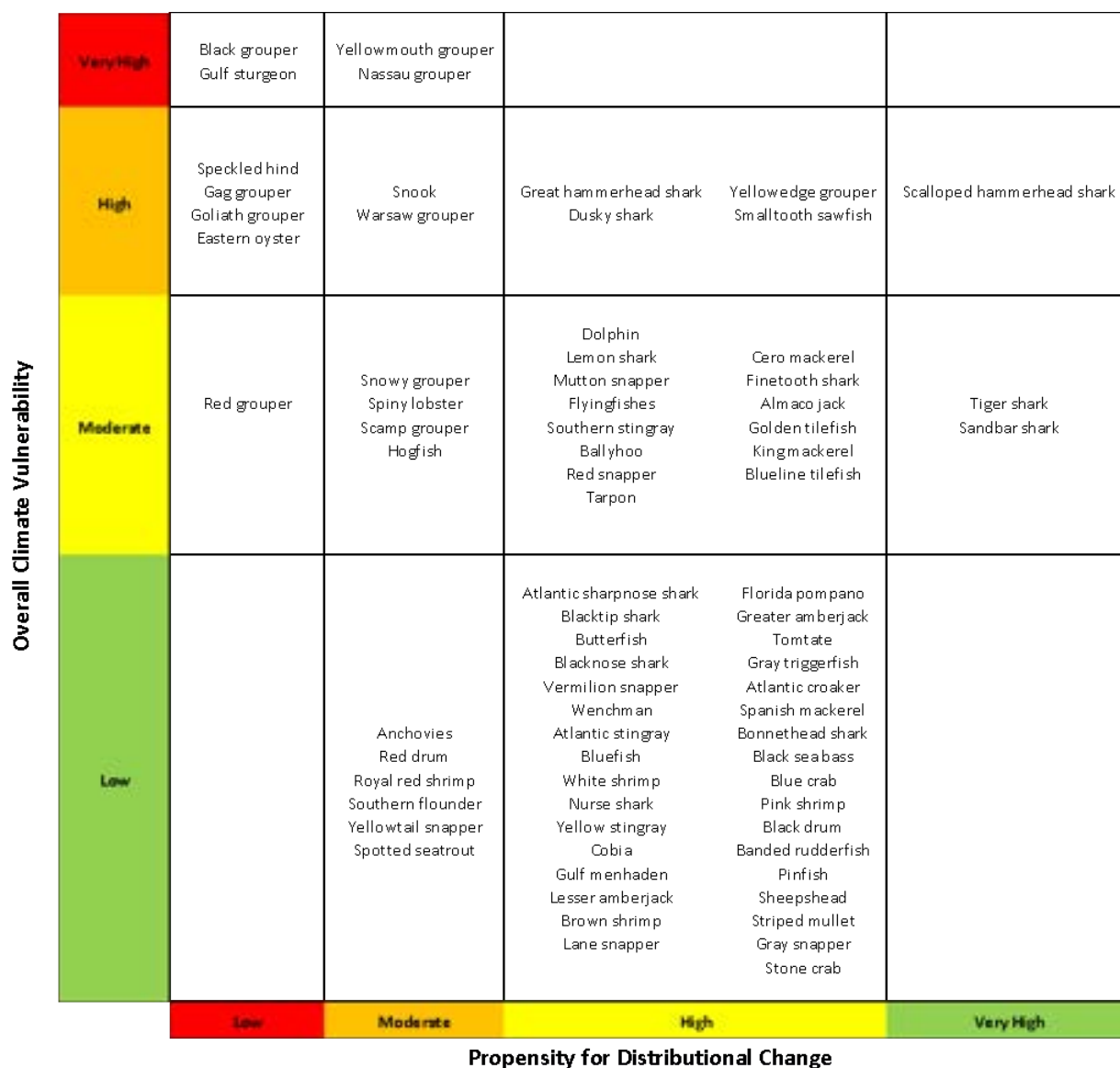


Figure 11 - Propensity for distributional change plotted against overall climate vulnerability. The x-axis is the propensity for distributional change. Low propensity for change means that the species has little capacity for changing its distribution and is viewed as increasing its risk to climate change. The y-axis is the overall climate vulnerability. Here, Very High indicates that the species is extremely vulnerable to climate change.

Gag grouper - *Mycteroperca microlepis*

Overall Vulnerability Rank = High 

Habitat Sensitivity = High 

Climate Exposure = High 

Data Quality = 85% of scores ≥ 2

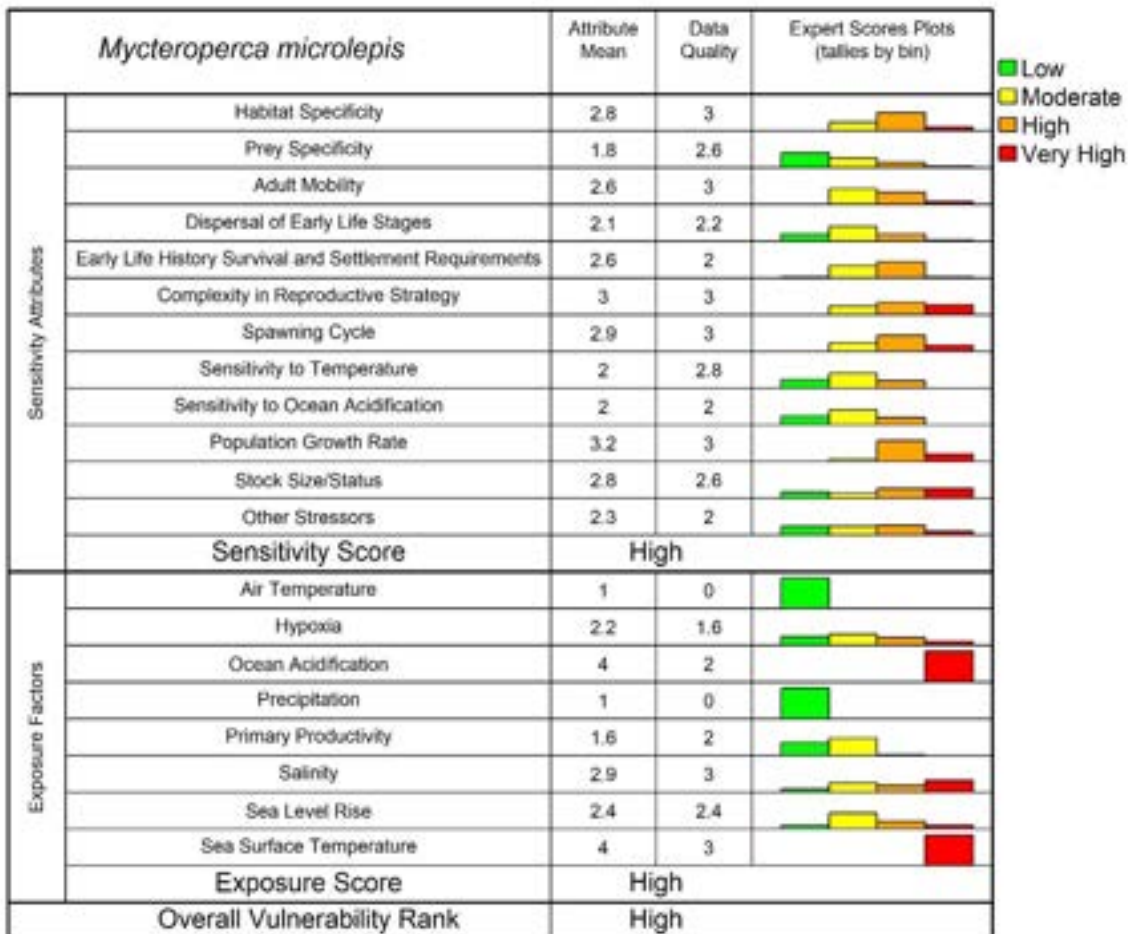


Figure 12 - Species Information Sheet. This is the Species Information Sheet for gag grouper. The overall climate vulnerability, habitat or trait-based sensitivity, and climate exposure were all classified as High (orange). The overall data quality score is calculated to be ≥ 2 . The sensitivity attribute bar charts suggest that the central tendencies across all of the sensitivity attributes were generally in the Moderate and High categories. The exposure factor bar charts to the right of the exposure factors score highlight the importance of ocean acidification and sea surface temperature for gag grouper, both of which are Very High. In the Species Information Sheets, a data quality score of zero in the Exposure Factors indicates that this climate exposure factor was not used. Additional Species Information Sheets are available in Appendix E.

Negative	Neutral	Positive
Gulf sturgeon (-0.85)	Southern stingray (-0.30)	Butterfish (-0.10)
Smalltooth sawfish (-0.80)	Sheepshead (-0.30)	Atlantic stingray (-0.10)
Eastern oyster (-0.70)	Red grouper (-0.30)	Spiny lobster (-0.10)
Snook (-0.60)	Hogfish (-0.30)	Spanish mackerel (-0.10)
Nassau grouper (-0.60)	Dusky shark (-0.30)	Florida pompano (-0.10)
Lemon shark (-0.60)	Yellowedge grouper (-0.30)	Blacknose shark (-0.10)
Great hammerhead shark (-0.60)	Yellow stingray (-0.30)	Atlantic sharpnose shark (-0.10)
Black grouper (-0.60)	Spotted seatrout (-0.25)	Vermilion snapper (-0.05)
Scamp grouper (-0.55)	Nurse shark (-0.25)	Mutton snapper (-0.05)
Southern flounder (-0.45)	Goliath grouper (-0.25)	Lesser amberjack (-0.05)
Kag grouper (-0.45)	Fine tooth shark (-0.25)	Bluefish (-0.05)
Bonnethead shark (-0.45)	Tarpon (-0.25)	King mackerel (0.00)
Black sea bass (-0.45)	Golden tilefish (-0.25)	Greater amberjack (0.00)
Yellowmouth grouper (-0.40)	Blue crab (-0.25)	Flyingfishes (0.00)
Scalloped hammerhead shark (-0.40)	Blacktip shark (-0.25)	Gray triggerfish (0.05)
Black drum (-0.40)	Tomate (-0.20)	Cobia (0.05)
Blueline tilefish (-0.35)	Tiger shark (-0.20)	Striped mullet (0.10)
Warsaw grouper (-0.35)	Sandbar shark (-0.20)	Royal red shrimp (0.10)
Speckled hind (-0.35)	Red drum (-0.20)	Dolphin (0.15)
Snowy grouper (-0.35)	Gulf menhaden (-0.20)	Anchovies (0.15)
Brown shrimp (-0.35)	Yellowtail snapper (-0.15)	Stone crab (0.20)
	White shrimp (-0.15)	Pink shrimp (0.20)
	Weinman (-0.15)	Cero mackerel (0.20)
	Red snapper (-0.15)	Pinfish (0.20)
	Lane snapper (-0.15)	Almaco jack (0.25)
	Gray snapper (-0.15)	

Figure 13 - Directional Effect Scores. Whether climate change will have a negative, neutral, or positive effect on individual species was assessed by species experts. The negative, neutral, and positive directional effects on each species due to climate change are shown in red, yellow, and green respectively. The minimum and maximum values for the directional effect metric are -1.0 (negative) and 1.0 (positive). The species scores across this range are shown parenthetically. This process assigned a -0.85 to Gulf sturgeon, a zero score to king mackerel, greater amberjack, and flyingfishes, and a score of 0.35 to banded rudderfish, Atlantic croaker, and ballyhoo. The data are skewed towards negative effects overall.

Tables

Table 1 - Species list. A listing of the species included in the assessment. The first column provides the common name, second column is the scientific name, and the third column is the assigned functional group.

Common Name	Species	Functional Group
Almaco jack	<i>Seriola rivoliana</i>	Coastal Pelagic
Anchovies	<i>Engraulidae</i>	Coastal Pelagic
Atlantic croaker	<i>Micropogonias undulatus</i>	Coastal
Atlantic sharpnose shark	<i>Rhizoprionodon terraenovae</i>	Elasmobranch
Atlantic stingray	<i>Dasyatis Sabina</i>	Elasmobranch
Ballyhoo	<i>Hemiramphus sp.</i>	Coastal
Banded rudderfish	<i>Seriola zonata</i>	Coastal
Black drum	<i>Pogonias cromis</i>	Coastal
Black grouper	<i>Mycteroperca bonaci</i>	Grouper
Black sea bass	<i>Centropristis striata</i>	Offshore Bottomfish
Blacknose shark	<i>Carcharhinus acronotus</i>	Elasmobranch
Blacktip shark	<i>Carcharhinus limbatus</i>	Elasmobranch
Blue crab	<i>Callinectes sapidus</i>	Invertebrate
Bluefish	<i>Pomatomus saltatrix</i>	Pelagic
Blueline tilefish	<i>Caulolatilus microps</i>	Offshore Bottomfish
Bonnethead shark	<i>Sphyrna tiburo</i>	Elasmobranch
Brown shrimp	<i>Penaeus aztecus</i>	Invertebrate
Butterfish	<i>Peprilus triacanthus</i>	Coastal
Cero mackerel	<i>Scomberomorus regalis</i>	Coastal Pelagic
Cobia	<i>Rachycentron canadum</i>	Coastal Pelagic
Dolphin	<i>Coryphaena hippurus</i>	Pelagics

Dusky shark	<i>Carcharhinus obscurus</i>	Elasmobranch
Eastern oyster	<i>Crassostrea virginica</i>	Invertebrate
Finetooth shark	<i>Carcharhinus isodon</i>	Elasmobranch
Florida pompano	<i>Trachinotus carolinus</i>	Coastal Pelagic
Flyingfishes	<i>Exocoetidae</i>	Pelagics
Gag grouper	<i>Mycteroperca microlepis</i>	Grouper
Golden tilefish	<i>Lopholatilus chamaeleonticeps</i>	Offshore Bottomfish
Goliath grouper	<i>Epinephelus itajara</i>	Grouper
Gray snapper	<i>Lutjanus griseus</i>	Snapper
Gray triggerfish	<i>Balistes capriscus</i>	Other Reef Fish
Great hammerhead shark	<i>Sphyrna mokarran</i>	Elasmobranch
Greater amberjack	<i>Seriola dumerili</i>	Coastal Pelagic
Gulf menhaden	<i>Brevoortia patronus</i>	Coastal
Gulf sturgeon	<i>Acipenser oxyrinchus</i>	Diadromous
Hogfish	<i>Lachnolaimus maximus</i>	Snapper
King mackerel	<i>Scomberomorus cavalla</i>	Coastal Pelagic
Lane snapper	<i>Lutjanus synagris</i>	Snapper
Lemon shark	<i>Negaprion brevirostris</i>	Elasmobranch
Lesser amberjack	<i>Seriola fasciata</i>	Coastal Pelagic
Mutton snapper	<i>Lutjanus analis</i>	Snapper
Nassau grouper	<i>Epinephelus striatus</i>	Grouper
Nurse shark	<i>Ginglymostoma cirratum</i>	Elasmobranch
Pinfish	<i>Lagodon rhomboides</i>	Coastal
Pink shrimp	<i>Penaeus robustus</i>	Invertebrate
Red drum	<i>Sciaenops ocellatus</i>	Coastal
Red grouper	<i>Epinephelus morio</i>	Grouper
Red snapper	<i>Lutjanus campechanus</i>	Snapper

Royal red shrimp	<i>Pleoticus robustus</i>	Invertebrate
Sandbar shark	<i>Carcharhinus plumbeus</i>	Elasmobranch
Scalloped hammerhead shark	<i>Sphyrna lewini</i>	Elasmobranch
Scamp grouper	<i>Mycteroperca phenax</i>	Grouper
Sheepshead	<i>Archosargus probatocephalus</i>	Coastal
Smalltooth sawfish	<i>Pristis pectinata</i>	Elasmobranch
Snook	<i>Centropomus undecimalis</i>	Coastal
Snowy grouper	<i>Epinephelus niveatus</i>	Grouper
Southern flounder	<i>Paralichthys lethostigma</i>	Coastal
Southern stingray	<i>Dasyatis americana</i>	Elasmobranch
Spanish mackerel	<i>Scomberomorus maculatus</i>	Coastal Pelagic
Speckled hind	<i>Epinephelus drummondhayi</i>	Grouper
Spiny lobster	<i>Panulirus argus</i>	Invertebrate
Spotted seatrout	<i>Cynoscion nebulosus</i>	Coastal
Stone crab	<i>Menippe adina</i>	Invertebrate
Striped mullet	<i>Mugil cephalus</i>	Coastal
Tarpon	<i>Megalops atlanticus</i>	Coastal
Tiger shark	<i>Galeocerdo cuvier</i>	Elasmobranch
Tomtate	<i>Haemulon aurolineatum</i>	Other Reef Fish
Vermilion snapper	<i>Rhomboplites aurorubens</i>	Snapper
Warsaw grouper	<i>Epinephelus nigritus</i>	Grouper
Wenchman	<i>Pristipomoides aquilonaris</i>	Snapper
White shrimp	<i>Penaeus setiferus</i>	Invertebrate
Yellow stingray	<i>Urobatis jamaicensis</i>	Elasmobranch
Yellowedge grouper	<i>Epinephelus flavolimbatus</i>	Grouper
Yellowmouth grouper	<i>Mycteroperca interstitialis</i>	Grouper
Yellowtail snapper	<i>Ocyurus chrysurus</i>	Snapper

Table 2 - Biological sensitivity attributes. Trait-based sensitivity attributes are used in this assessment. The middle column lists the attributes. The left (right) column lists the characteristics leading to a low (high) score for each attribute. This table is adapted from Morrison *et al.* 2015).

Low Score (1.0)	Attribute	Very High Score (4.0)
Generalist	Habitat specificity	Specialist
Generalist	Prey specificity	Specialist
Highly mobile	Adult mobility	Sessile
High dispersal	Early life stage dispersal	Low dispersal
Larval requirements are resistant to environmental change	Early life stage survival and settlement	Larval requirements are specific and likely impacted by environmental change
Low complexity likely not disrupted by environmental change	Complexity in reproductive strategy	High complexity likely disrupted by environmental change
Year-round spawner, broadcast spawners	Spawning cycle	Short duration, aggregate spawners
Species found in wide temperature, latitudinal, and/or depth range	Sensitivity to temperature	Species found in limited temperature, latitudinal, and/or depth range
Not sensitive or doesn't rely on sensitive taxa for food or shelter	Sensitivity to ocean acidification	Is sensitive or does rely on sensitive taxa for food or habitat
High productivity	Population growth rate	Low productivity
High abundance	Stock size/status	Low abundance
Low levels of other stressors that could limit response to environmental change	Other stressors	High levels of other stressors

Table 3 - Overall climate vulnerability for functional groups. The number of species from each functional group falling into each climate vulnerability category (Low, Moderate, High, and Very High) are shown as numbers in the table.

	Low	Moderate	High	Very High
Diadromous				1
Groupers		3	5	3
Elasmobranchs	7	5	4	
Invertebrates	6	1	1	
Coastal Fishes	11	2	1	
Pelagics	1	2		
Offshore				
Bottomfish	3	2		
Snappers	5	3		
Coastal Pelagics	6	3		

Appendix A - Biological Sensitivity Attributes and Data Quality Scoring Template

Stock Profile for Vulnerability Assessment to Climate Change			
Common and Scientific Name:			
Stock area:	Gulf of Mexico		
Please read Sensitivity Attribute Definitions Document for full description of attributes and scoring bins.			
ATTRIBUTE	DATA	SOURCE	DATA QUALITY SCORE
Habitat specificity -			
What are the habitat requirements for juveniles? (e.g., What types of habitat does the stock utilize? Is the species a specialist or a generalist? Does it utilize a physical or biological habitat? Is the habitat rare or abundant? Is the habitat disturbed?)			
What are the habitat requirements for adults? (e.g., What types of habitat does the stock utilize? Is the species a specialist or a generalist? Does it utilize a physical or biological habitat? Is the habitat rare or abundant? Is the habitat disturbed?)			
Prey specificity -			

What species/types of food do juveniles of this species eat? (e.g., Is the stock a detritivore, herbivore, or omnivore at this life stage? Does the stock show a strong preference for a particular prey type? If its preferred prey is unavailable, is there evidence that it can expand its diet?)			
Adult mobility -			
Are adults highly mobile?			
Are adults limited in their mobility (either due to physical or behavioral constraints)?			
Are adults sessile?			
Dispersal of early life stages -			
What is the duration of the planktonic eggs and larval life stages?			
During the planktonic stage, how far will the eggs and larvae travel? (e.g., Do currents move them up the coast or out into deeper water? Once they disperse do they settle in the new location or do they follow gyres that bring them back to the original location?)			
Early life history survival and settlement requirements -			
Is the larvae's food present for a limited time? (i.e., Could changes in emergence of food result in mismatch between presence of food and larvae?)			

Are larvae dependent on specific physical conditions to survive? (e.g., Is the larvae dependent on gyres to provide food, calm conditions to allow food to become concentrated, or currents/gyres to provide transport to nurseries?)			
Are the larvae dependent on low predator abundances such that a change in predation pressure could impact persistence of the stock?			
Are there specific environmental cues that stimulate settlement? If so, what are they and is there evidence that those cues may be impacted by climate change?			
Complexity in reproductive strategy -			
Are there known temperature effects on reproduction? (e.g., Temperature dependent sex change, gonadal development or spawning cues?)			
Does the stock utilize large spawning aggregations? (How far does the stock travel to reach spawning grounds? Is there an environmental cue that triggers formation of the aggregation?)			
Are there known depensation/allee effects?			
Is the stock dependent on vulnerable habitats for a critical life stage? (i.e., estuary			

hatcheries or freshwater spawning grounds)			
Spawning cycle -			
What is the stock's temporal time frame for spawning? (e.g., Does the stock spawn year round? Does the stock have seasonal spawning events and if so how long is the season?)			
Sensitivity to temperature -			
What temperatures does the stock occur in? (e.g., What are the latitudinal limits of the stock range? How many regional provinces (Spalding <i>et al.</i> 2007) does the stock or species occur in?)			
Does the stock utilize various depths within the water column? (e.g., Does the stock travel from the benthos to the surface for food or reproduction?)			
Sensitivity to ocean acidification -			
Does the species have a calcium carbonate exoskeleton or shell?			
Is the stock dependent on another species (for food or habitat) that has a calcium carbonate exoskeleton or shell? To what degree is it dependent?			
Population growth rate -			
Intrinsic rate of increase (r)			

Von Bertalanffy K			
Age at Maturity			
Maximum age			
Natural mortality			
Stock size status -			
Do we have an estimate of B _{current} /B _{msy} (or proxy)? Go to http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries/ and click on the most recent link for "FSSI and non FSSI Stocks." Other information on stock status (such as ORCS approaches) may be used but with lower confidence.			
Has the genetic variation for the stock been compromised? (e.g. are there documented cases of large variations in reproductive success, large fluctuations in population size, or frequent local extinctions?)			
Other stressors -			
Is the habitat on which the stock depends degraded? Examples include anthropogenic effects, changes to freshwater input, stratification, storm intensity and hypoxia.			
Is the stock currently exposed to detrimental levels of pollution?			
Has the stock experienced a known increase in parasites,			

disease, or harmful algal bloom exposure?			
Has the stock experienced a detrimental impact due to a change in the food web? Examples include increases in the abundance of predators, competitors, or the introduction of an invasive species. Do not include changes to prey.			
Supporting References:			

Data Quality Score	Description
3	Adequate Data. The score is based on data which have been observed, modeled or empirically measured for the stock in question and comes from a reputable source.
2	Limited Data. The score is based on data which has a higher degree of uncertainty. The data used to score the attribute may be based on related or similar stocks or species, come from outside the study area, or the reliability of the source may be limited.
1	Expert Judgment. The attribute score reflects the expert judgment of the reviewer and is based on their general knowledge of the stock, or other related stocks, and their relative role in the ecosystem.
0	No Data. No information to base an attribute score on. Very little is known about the stock or related stocks and there is no basis for forming an expert opinion (please use judiciously).

Appendix B - Climate Exposure Factors 2006 - 2055

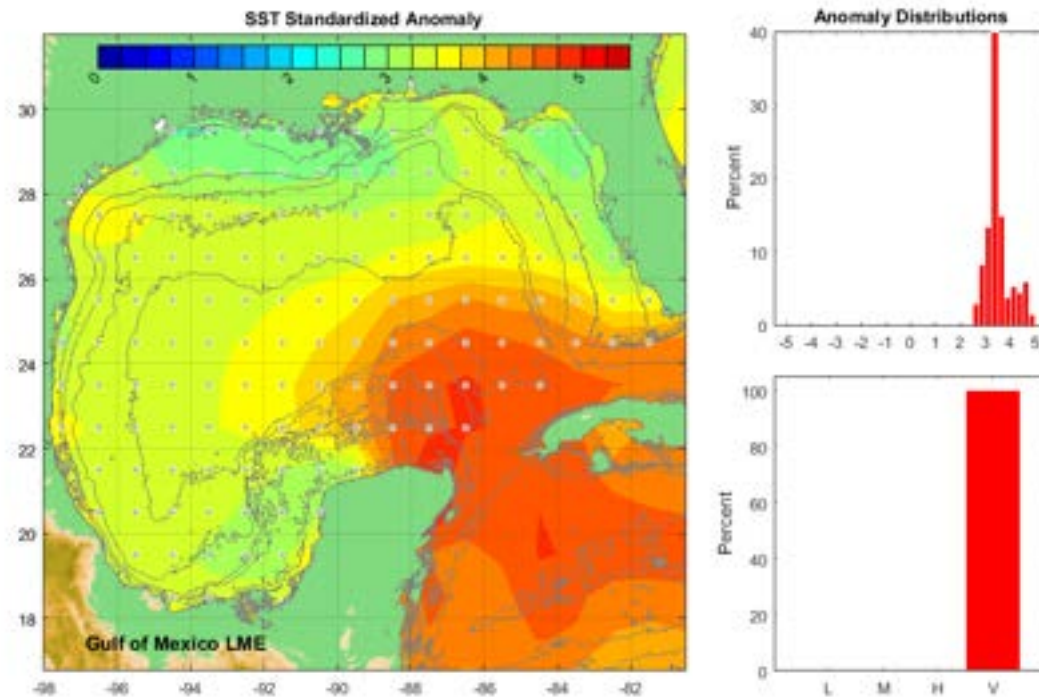


Figure 1 - Standardized anomaly for 2006-2055 sea surface temperature in the Gulf of Mexico Large Marine Ecosystem. **Left hand panel** shows the absolute value of the standardized anomaly (difference is SST between 2006-2055 and 1956-2005 divided by the standard deviation of the 1956-2005 SST). Units are in standard deviates. The 10, 50, 100, 1000, 3000, and 6000 m depth contours are shown in gray. Small circular markers indicate climate-model data grid points inside the Gulf LME. The **top right panel** shows the frequency distribution of the 0.25-sigma binned standardized anomaly values at the grid points. Negative values indicate cooling; positive values indicate warming. Bar color indicates Low (green), Moderate (yellow), High (orange), and Very High (red) values for the SST exposure factor. The **bottom right panel** shows the frequency distribution of the absolute value of the standardized anomaly data binned into binned Low (green), Moderate (yellow), High (orange), and Very High (red) classes for use in scoring exposure attributes as per Morrison *et al.* 2015. All SST standardized anomaly values across the Gulf LME are in the Very High exposure category. SST is projected to increase across the Gulf of Mexico.

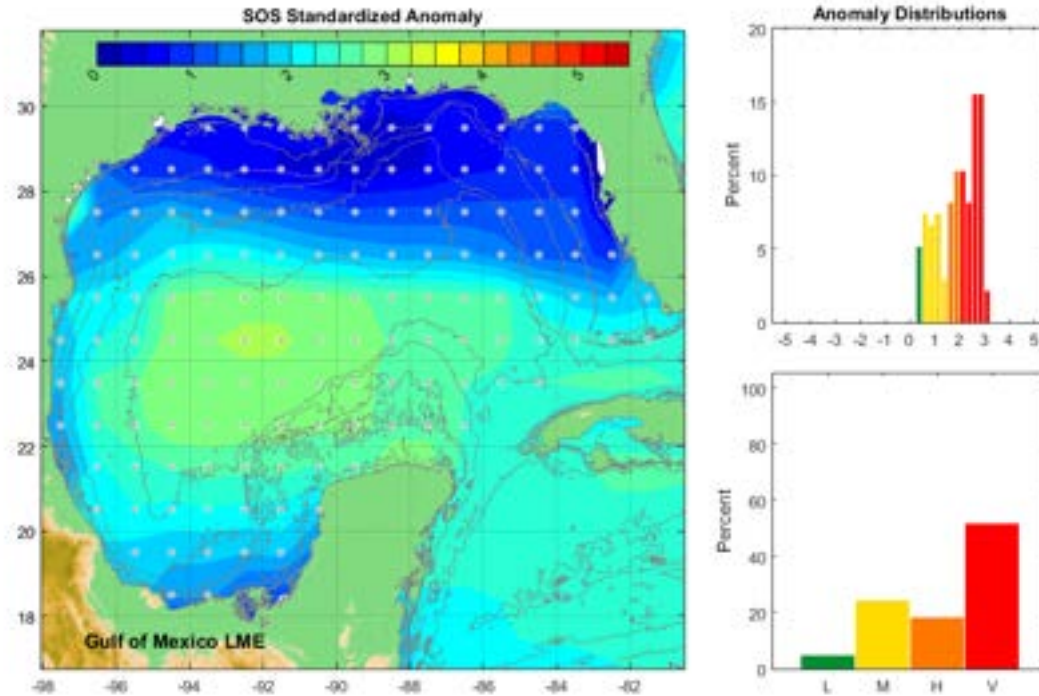


Figure 2 - Standardized anomaly for 2006-2055 sea surface salinity in the Gulf of Mexico Large Marine Ecosystem. As in Figure 1. Sea surface salinity standardize anomaly values range from Low to Very High with most of the area classified as Very High. Sea surface salinity is projected to increase across the Gulf of Mexico with the largest increases found in the central Gulf.

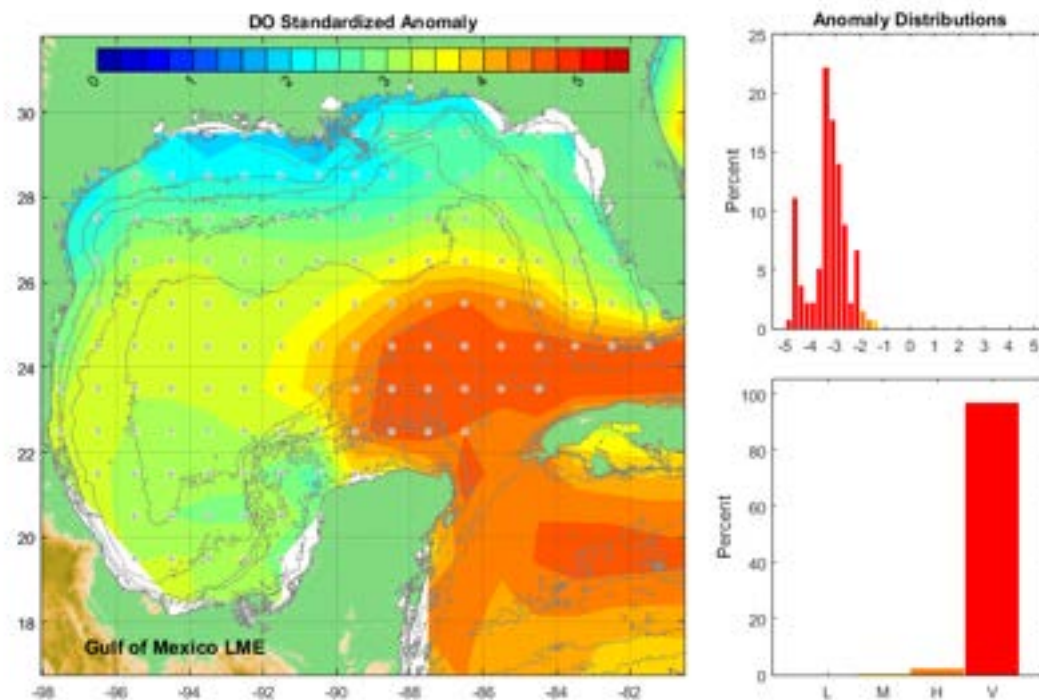


Figure 3 - Standardized anomaly for 2006-2055 dissolved oxygen in the Gulf of Mexico Large Marine Ecosystem. As in Figure 1. Dissolved oxygen standardized anomaly values range from High to Very High with most of the area classified as Very High. Dissolved oxygen is projected to decrease across the Gulf of Mexico with the largest increases found in the Loop Current region.

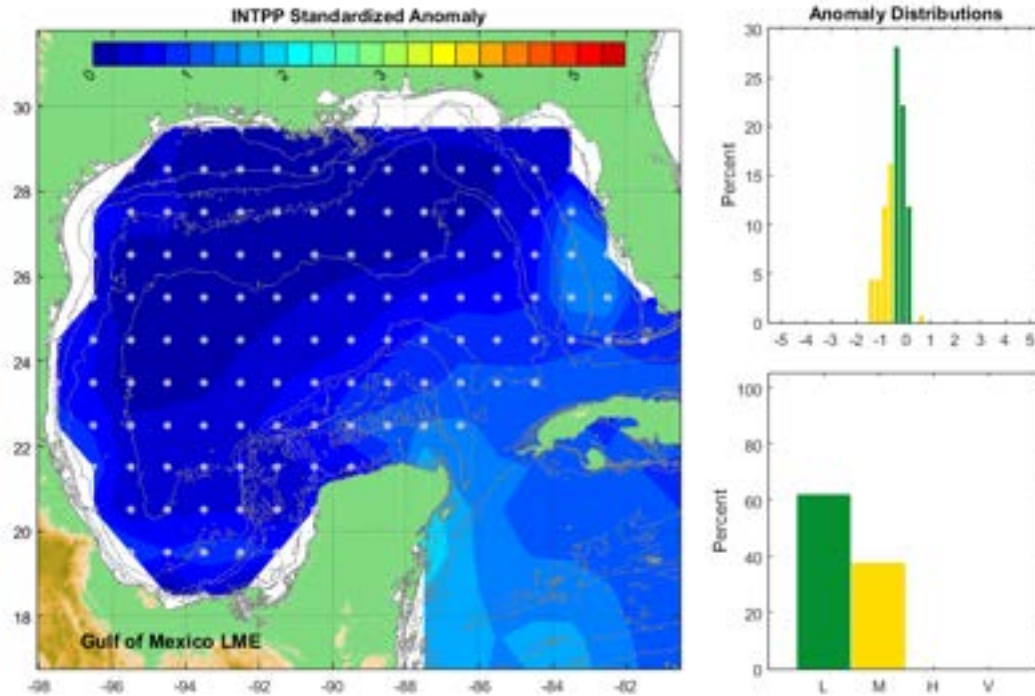


Figure 4 - Standardized anomaly for 2006-2055 integrated primary productivity in the Gulf of Mexico Large Marine Ecosystem. As in Figure 1. Integrated primary productivity anomaly values range from Low to Moderate with most of the area classified as Low. Integrated primary productivity is projected to slightly increase in some areas and decrease in others. The largest change is projected to be on the West Florida Shelf.

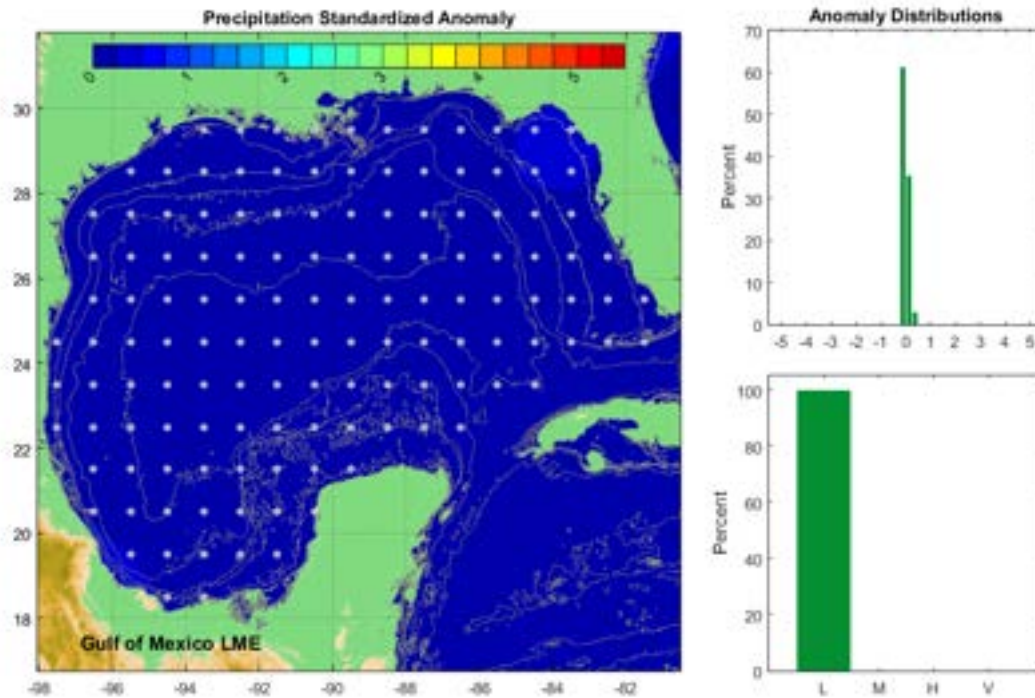


Figure 5 - Standardized anomaly for 2006-2055 precipitation in the Gulf of Mexico Large Marine Ecosystem. As in Figure 1. Precipitation standardize anomaly values are Low across the Gulf of Mexico. Precipitation is projected to increase slightly.

Appendix C - Sea Level Rise and Hypoxia Exposure Factors

Sea Level Rise Exposure

Sea level rise is primarily due to the thermal expansion of seawater as temperatures increase and the melting of ice in glaciers and in the Greenland and Antarctic ice sheets (Sweet *et al.* 2017a, 2017b). Additional factors involve vertical land movement from tectonics, glacio-isostatic adjustments and subsidence, changes in metocean processes that alter sea surface heights (e.g., shifts in ocean currents, winds, air pressure), groundwater use, storage and extraction, and fossil fuel extraction (Sweet *et al.* 2017a, 2017b). Currently, about two thirds of the global sea level rise is due to ice melt and about a third is due to thermal expansion (Sweet *et al.* 2017b).

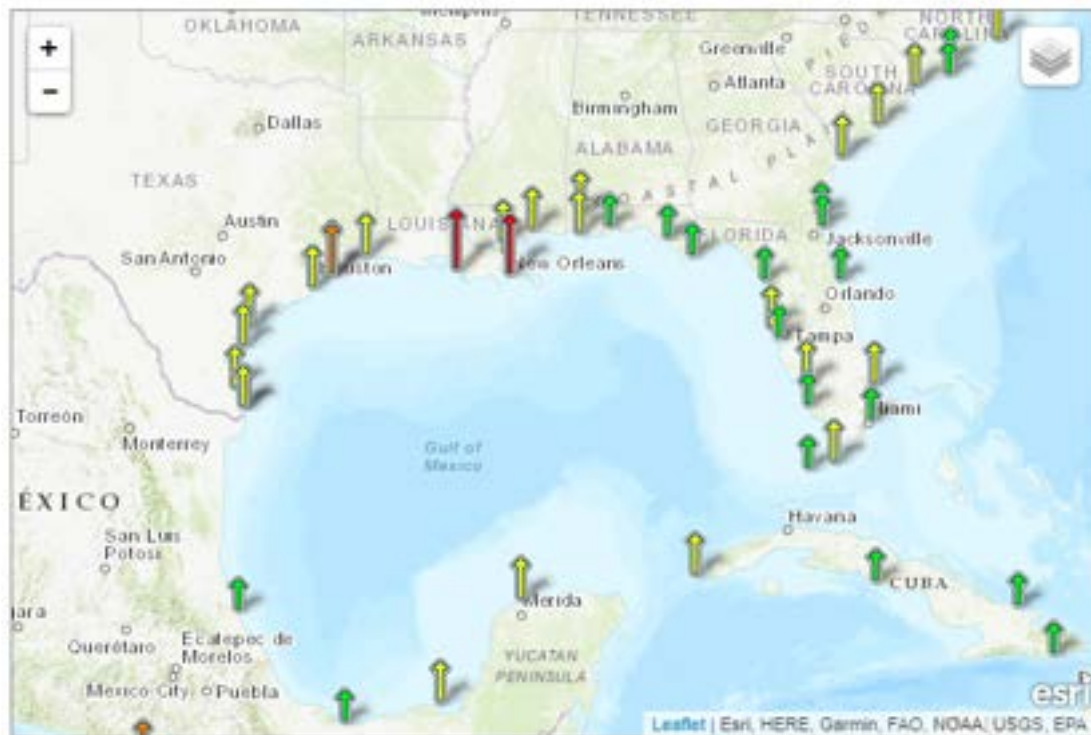
Owing to inertia in the climate system, climate change-related sea level rise will continue to manifest beyond the end of this century (Sweet *et al.* 2017a, 2017b). While sea levels have been relatively stable for the past 6000-7000 years (Blum and Roberts 2009, Donahue 2011), the rate of global sea level rise since 1900 has been faster than at any time in the past 2800 years and now stands at about 3.4 mm/yr (Sweet *et al.* 2017b). Global sea levels have risen between 16 and 21 cm since 1900, with about 50% of that rise occurring since 1993 (Sweet *et al.* 2017a, 2017b). Global sea levels are projected to rise an additional 9 to 18 cm by 2030 and another 15 to 38 cm by 2050 (Sweet *et al.* 2017b) and there is little difference in sea level rise projections between emissions pathways during the first half of this century (Sweet *et al.* 2017a, 2017b). Uncertainty exists, however, and it is plausible that as much as 2.5 m of sea level rise could be experienced by 2100 if Antarctic ice sheet stability is an issue (Sweet *et al.* 2017b). Regional or local sea level rise may be substantially higher than the global average (Figure 1, Table 1) and this is the case especially for the north and western Gulf of Mexico (Louisiana and Texas) which is experiencing high rates of land subsidence (Blum and Roberts 2009, Donoghue 2011, Sweet *et al.* 2017b). It is also important to recognize that paleo records indicate that past global sea level rise rates have been substantially larger (16 - 45 mm/yr) than 3.4 mm/yr and some interglacial sea level rise rates have resulted in sea levels overstepping and drowning river deltas and barrier islands in the Gulf of Mexico (Donoghue 2011).

Sea level rise will likely influence the population dynamics of fishes and invertebrates via alteration of marsh, seagrass, mangrove, coral, and estuary habitats. These habitats all provide important ecosystem services to many fishes and invertebrates and are sensitive to sea level height (Nichols *et al.* 1999, Short and Neckles 1999, Duarte 2001, Morris *et al.* 2002, Craft *et al.* 2009, Krauss *et al.* 2013). Because most of these habitats occur in nearshore zones, the largest sea level rise impacts are expected to occur in nearshore and estuarine habitats.

The Gulf of Mexico is largely characterized by low relief coastlines that typically experience relatively low tidal ranges. One aspect of sea level rise is that it tends to shift the distribution of regional tidal sea levels toward higher stands. This means that high tides may result in larger and more frequent inundation of Gulf habitats that are sensitive to sea level height (e.g., marsh, seagrass, mangrove, coral, and estuary habitats). This inundation may offer opportunities for

habitats to develop in new areas (Craft *et al.* 2009), but it also means that conditions for existing habitats may become suboptimal thereby reducing habitat productivity and ecosystem services provided (Duarte 2002). An additional factor is the extent to which coastlines are or will be developed or armored. Developed or armored coastlines will tend to prevent shoreward movement of these habitat types and thus limit the natural adaptive capacity any given habitat may have to deal with increased sea level height.

Higher sea level stands will reduce the light levels in the water column in ways that are problematic for existing seagrass meadows. Growing seagrasses require irradiance that is at least 11% of the incident light levels at the surface (Duarte 2002). As sea level increases, light is attenuated exponentially by the deeper water column thus resulting in light limitations in the deeper areas of the meadow (Short and Neckles 1999). Furthermore, increased sea level height can be linked to higher coastal erosion rates which can in turn damage nearshore seagrass meadows (Short and Neckles 1999, Duarte 2002). At the same time, higher sea level stands may allow shoreward expansion of a given seagrass meadow by making available to subtidal seagrasses areas that were intertidal.



The map above illustrates relative sea level trends, with arrows representing the direction and magnitude of change. Click on an arrow to access additional information about that station.



Figure 1 - Rates of relative sea level rise across the Gulf of Mexico. Relative sea levels are rising across the Gulf of Mexico with highest rates in the northern and western Gulf of Mexico where land subsidence owing to subsidence and water and fossil fuel extraction occurs. A live version of this map is located at <https://tidesandcurrents.noaa.gov/sltrends/sltrends.html> and can be used as an aid to scoring. Clicking on any tidal station (arrow) will open a window showing the current rate of sea level rise and the time over which it is calculated. Clicking on 'Linear Trend' will open a web page showing the historical monthly sea level record with a linear curve fit. Clicking on 'Regional Scenario' opens a web page showing the projected relative sea level rise through 2100 based on a set of emissions/sea level rise scenarios ranging from Low to Extreme (Sweet *et al.* 2017b).

Table 1 - Relative sea level rise trends for select tide gauge stations in the Gulf of Mexico. Station locations start on the Yucatan and then are located clockwise around the Gulf of Mexico as one moves down the table. The second column corresponds to the current sea level rise rates depicted in Figure 1. The third column represents the projected 2000-2050 sea level rise rates for the High-Intermediate scenario presented in Sweet *et al.* (2017b).

Tide Gauge Station	Relative Historical Sea Level Trend (mm/year)	Future Relative Sea Level Trend (mm/year) 2000-2050
Progreso	3.69	
Ciudad del Carmen	3.60	12.67
Coatzacoalcos	2.86	
Tuxpan	2.64	
Port Isabel	4.00	12.47
Port Mansfield	3.19	
Corpus Christi	4.65	
Rockport	5.62	
Freeport	4.43	
Galveston Pleasure Pier	6.62	15.20
Sabine Pass	5.86	
Eugene Island	9.65	18.60
Grand Isle	9.08	17.60
New Canal	5.35	
Waveland	4.64	
Dauphin Island	3.74	
Mobile State Docks	3.85	
Pensacola	2.40	10.80
Panama City	2.43	10.47
Apalachicola	2.38	

Cedar Key	2.13	10.80
Clearwater Beach	3.68	
St. Petersburg	2.78	11.60
Fort Myers	3.11	
Naples	2.85	
Key West	2.42	11.40
Vaca Key	3.66	

Scoring Exposure to Sea Level Rise

Recent research suggests that sea level rise is increasing across the Gulf of Mexico and particularly in the northwestern Gulf (see Figure 1 and Table 1). Projections indicate that this pattern will continue through at least the remainder of this century with a worst case scenario of 2.5 m of sea level rise by 2100 (Sweet *et al.* 2017b). Current rates of sea level rise range from about 2.1 to 9.6 mm/year (Table 1). Sea level rise rates between 2000 and 2050 are projected to range from 10.5 to 18.6 mm/year (Table 1) for the intermediate-high scenario of Sweet *et al.* (2017b). The realized sea level rise rates could be lower or higher than these projections.

Sea level rise will likely influence the productivity of marine fisheries by altering the productivity and viability of important habitats such as marshes, seagrass meadows, mangroves, corals, and or estuaries. A given habitat's capacity for adaptation to sea level rise appears to be dependent on local conditions and is a function of a host of processes (e.g., sediment supply, vertical accretion, tolerance to inundation and changes in salinity, interspecific competition, light levels), thus making generalities difficult. However, higher rates of sea level rise present greater challenges for all habitat types than do lower sea level rise rates.

The impact of sea level rise on a fish stock is dependent on the usage of habitats that will be impacted by rising sea levels. There is a continuum of relative impact of sea level rise on fish species depending on their use and reliance on vulnerable nearshore habitats. Species which are highly reliant on these vulnerable nearshore habitats throughout their life cycle should receive the highest scores. Offshore, or deepwater species, which will have little spatial overlap, or exposure, to these impacts should receive low scores. Using your expert knowledge of the life history of the species and regarding present and projected sea level rise (Figure 1, Table 1, and <https://tidesandcurrents.noaa.gov/sltrends/sltrends.html>), distribute the five tallies across the four bins (Low, Moderate, High, Very High) according to the following rubric:

1. Low: Score stocks low if they do not rely on marsh, seagrass, mangrove, coral, or estuary habitats.
2. Moderate: Score stocks moderate if they rely on marsh, seagrass, mangrove, coral, or estuary habitats, and the relative sea level trends in their range are 0 to 6 mm/year.
3. High: Score stocks high if they rely on marsh, seagrass, mangrove, coral, or estuary habitats, and the relative sea level trends in their range are 6 to 9 mm/year.

4. Very High: Score stocks very high if they rely on marsh, seagrass, mangrove, coral, or estuary habitats, and the relative sea level trends in their range are 9 or more mm/year.

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Hypoxia Exposure

The Mississippi - Atchafalaya River systems drain a watershed that covers more than 40% of the contiguous United States and discharge $380 \text{ km}^3 \text{ yr}^{-1}$ into the northern Gulf of Mexico (Bianchi *et al.* 2010). Intensive agriculture occurs across a significant portion of this watershed and as a result the river systems receive excess nutrients from agricultural and animal feed lots, as well as from industry and sewage treatment plants (Bianchi *et al.* 2010). These nutrients are transported to the northern Gulf of Mexico and contribute to phytoplankton blooms that eventually result in the establishment of a large hypoxic area (dissolved oxygen $<2 \text{ mg L}^{-1}$) that forms annually in the spring and summer months off the Louisiana and Texas coasts (Rabalais *et al.* 2002, Fennel *et al.* 2013).

Nutrients in the river discharge support phytoplankton growth that is, in places, fast enough to outstrip grazing by zooplankton (Dagg *et al.* 2007). Phytoplankton and zooplankton fecal pellets sink out of the upper mixed and into the colder, saltier bottom waters on the shelf (Dagg *et al.* 2007). These organic materials are then respired which draws down oxygen and results in hypoxia and low dissolved oxygen across large areas of the shelf (Rabalais *et al.* 2002, Dagg *et al.* 2007). There is evidence that hypoxic conditions existed in the region in the early 1900s, but persistent seasonal hypoxia and low oxygen conditions are believed to have begun in the 1950-1970s with a tripling of nitrate loadings in the river systems (Rabalais *et al.* 2002).

While the hypoxic area averages about $14,000 \text{ km}^2$ (Fennel *et al.* 2013, Laurent *et al.* 2018; <https://gulfhypoxia.net/research/shelfwide-cruises/>) significant interannual variability exists (Rabalais *et al.* 2001b). Smaller hypoxic areas occur when river discharge is low, winds are not upwelling favorable, and when there are frequent storm fronts or tropical storms that reduce water column stratification. Hypoxic areas are more extensive when the water column is more intensively stratified by high spring river discharge and upwelling favorable winds exist that move the river plumes seaward over the shelf (Bianchi *et al.* 2010, Fennel and Testa 2019).

Organisms vary in their sensitivity to hypoxia and low oxygen. In a ranking across taxa, Vanquer-Sunyer and Duarte (2008) found that crustaceans were most sensitive (median lethal concentrations) to low oxygen and hypoxia, followed by fishes, bivalves, and gastropods. However, Rabalais *et al.* (2001a) report that motile organisms have the capacity to avoid hypoxic and low dissolved oxygen areas. Purcell *et al.* (2017) also found that shrimp fleets targeted aggregations of shrimp that were located just outside ($<5 \text{ km}$) of hypoxic areas suggesting that shrimp also move away from hypoxic areas. While avoidance behaviors reduce mortality directly associated with hypoxia, hypoxia can introduce ecological costs associated with movement, changes in typical migration pathways, increased respiration, or loss of habitat.

Projections of northern Gulf of Mexico hypoxia under climate change scenarios (Justic *et al.* 1996, Rabalais *et al.* 2009, Laurent *et al.* 2018) generally agree that there will be an expansion of the area and increasing severity and duration. Using a 3D biogeochemical circulation model, Laurent *et al.* (2018) projected a modest expansion in the areal extent of hypoxia with increases in both the severity and duration of hypoxia. Justic *et al.* (1996) used a two-box model to assess

the implications of a doubling of atmospheric CO₂ and found a 30-60% decrease in oxygen below the pycnocline.

Scoring Exposure to Hypoxia

Research suggests that climate change will result in larger hypoxic areas and that both the severity and duration of hypoxia will increase. While most motile organisms appear to move out of hypoxic regions, this avoidance behavior could be associated with ecological costs arising from processes such as forced movement, changes in typical migration pathways, increased respiration, increased predation risk, or loss of habitat.

Using your expert knowledge of the life history and distribution of the species and the above information regarding projected hypoxia, distribute the five tallies across the four bins (Low, Moderate, High, Very High) according to the following rubric:

1. Low: Score stocks low if they do not occur in an area influenced by hypoxia or low dissolved oxygen.
2. Moderate: Score stocks moderate if they occur in an area influenced by hypoxia or low dissolved oxygen, but are pelagic (i.e., life stages are not benthic or demersal and can use the upper mixed portion of the water column) or are highly motile (i.e., motile enough to avoid low dissolved oxygen for weeks to months).
3. High: Score stocks high if they occur in an area influenced by hypoxia, are demersal or benthic, and are moderately motile (i.e., not motile enough to avoid low dissolved oxygen for months).
4. Very High: Score stocks very high if they occur in an area influenced by hypoxia, are demersal or benthic, and are not motile (i.e., not motile enough to avoid low dissolved oxygen for weeks to months).

Maps of the extent of hypoxia between 2006 and 2019 can be found at: LUMCON's Gulf of Mexico Hypoxia website: <https://gulfhypoxia.net/research/shelfwide-cruise/?y=2019> . An example image from 2019 is below.

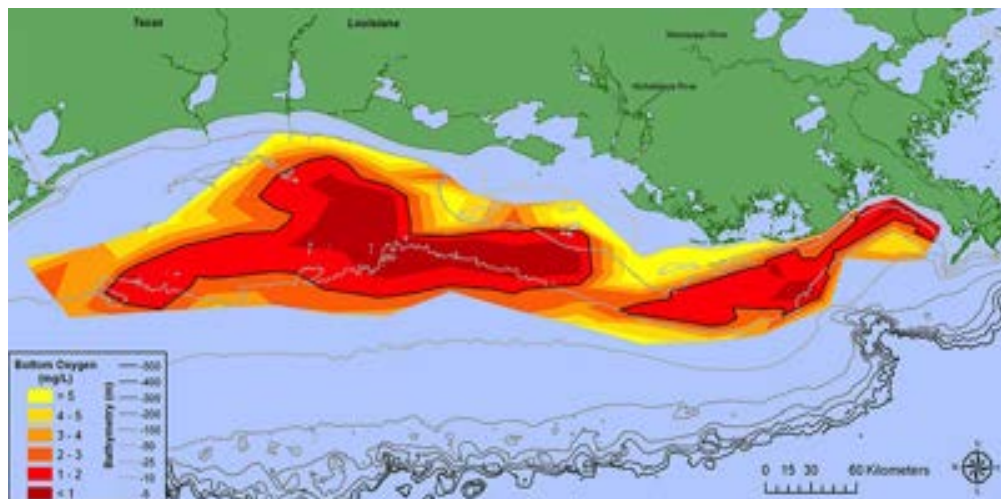


Figure 1. Extent of hypoxia in the Northern Gulf of Mexico in 2019.

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Appendix D - Climate Exposure Factors 2056 - 2099: 1956 - 2005

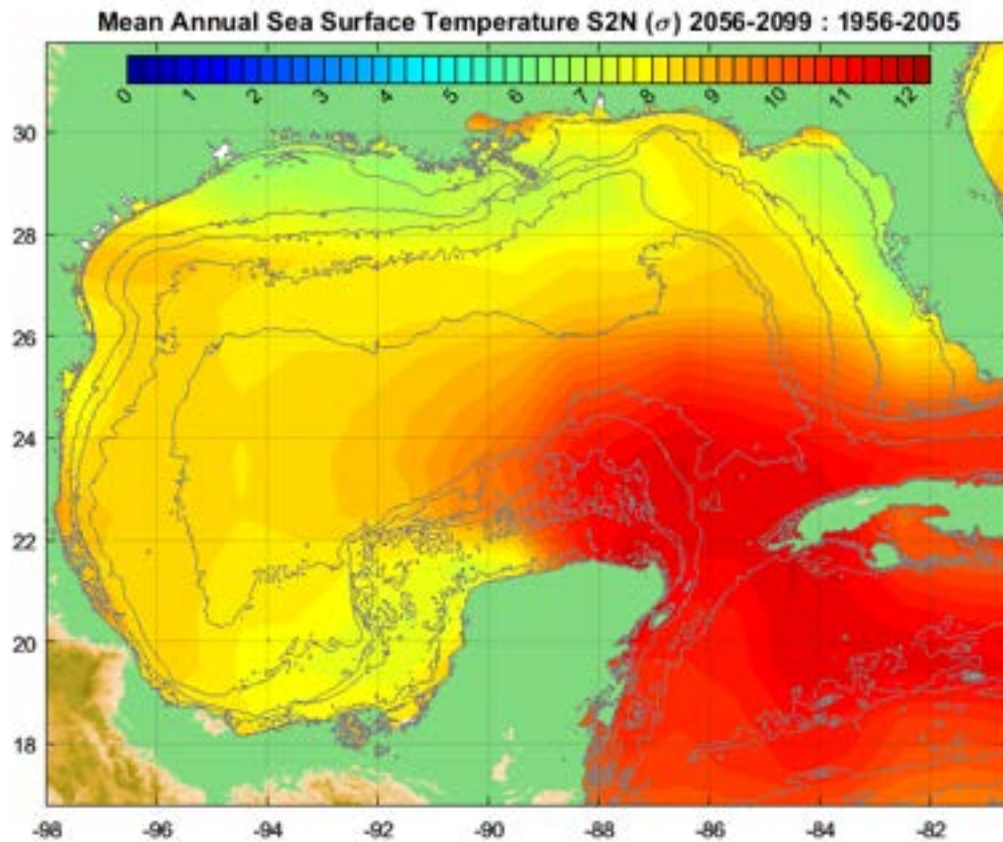


Figure 1 - Standardized anomaly for 2056-2099 sea surface temperature in the Gulf of Mexico Large Marine Ecosystem. Figure shows the absolute value of the standardized anomaly (difference in SST between 2056-2099 and 1956-2005 divided by the standard deviation of the 1956-2005 SST). Units are in standard deviates. The 10, 50, 100, 1000, 3000, and 6000 m depth contours are shown in gray.

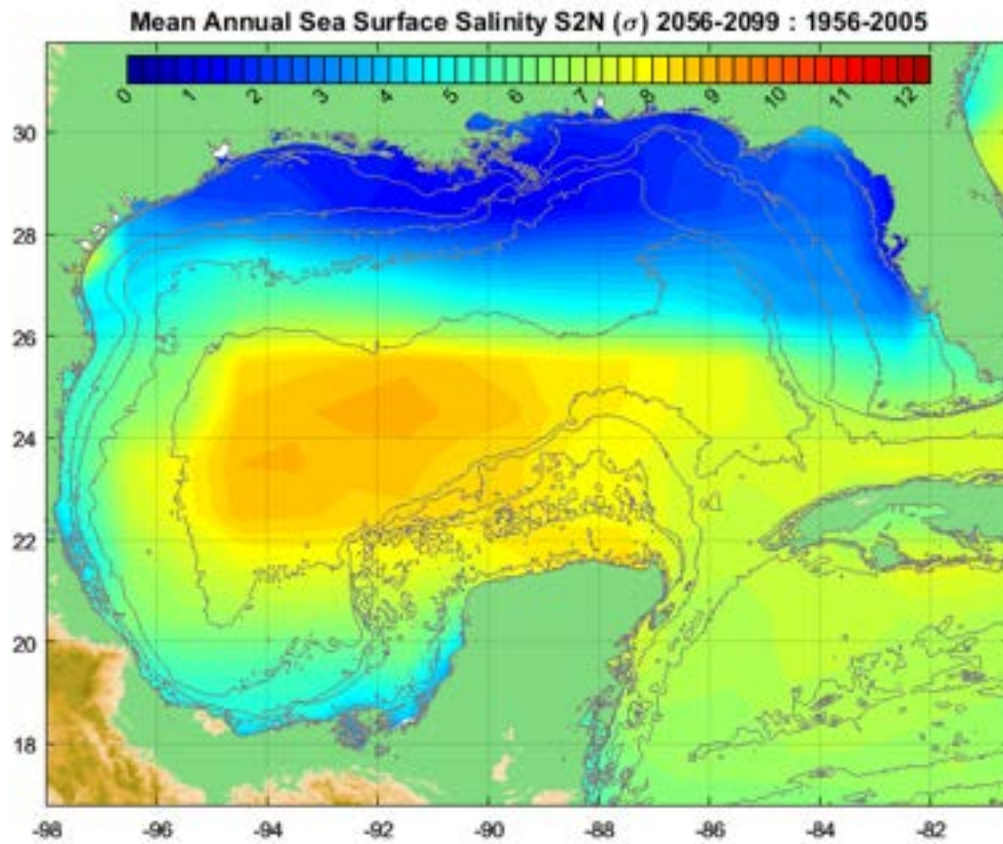


Figure 2 - Standardized anomaly for 2006-2055 sea surface salinity in the Gulf of Mexico Large Marine Ecosystem. Figure shows the absolute value of the standardized anomaly (difference in salinity between 2056-2099 and 1956-2005 divided by the standard deviation of the 1956-2005 salinity). Units are in standard deviates. The 10, 50, 100, 1000, 3000, and 6000 m depth contours are shown in gray.

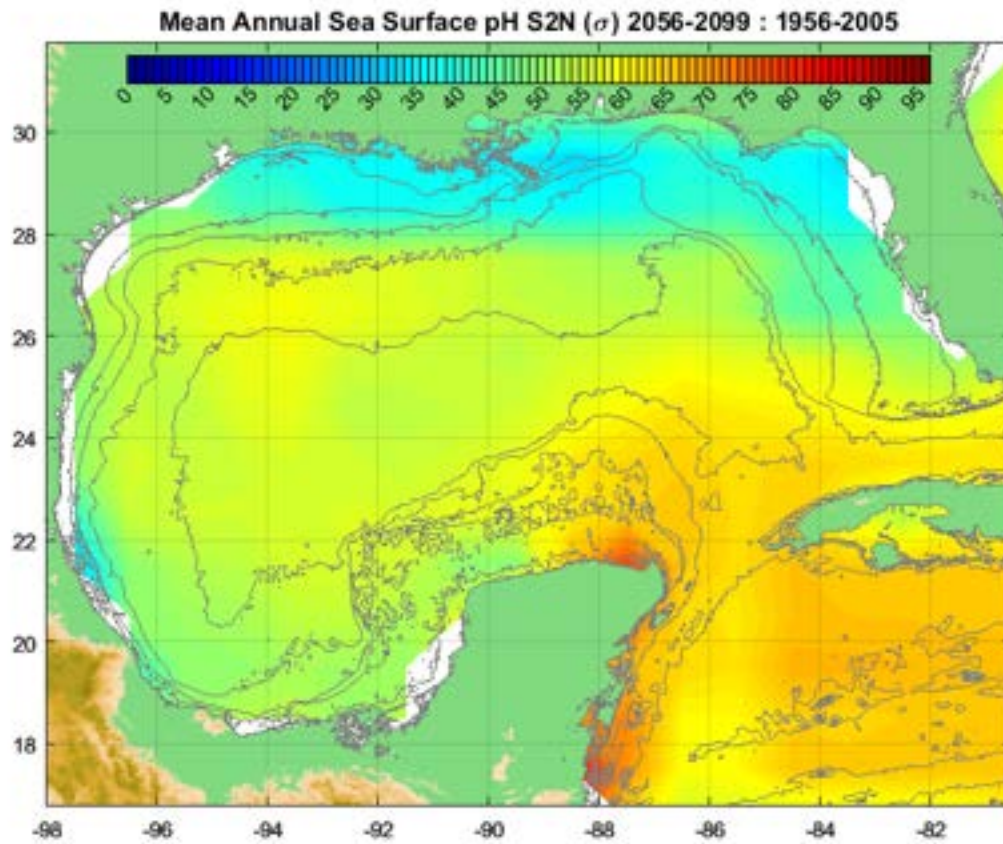


Figure 3 - Standardized anomaly for 2056-2099 pH in the Gulf of Mexico Large Marine Ecosystem. Figure shows the absolute value of the standardized anomaly (difference in pH between 2056-2099 and 1956-2005 divided by the standard deviation of the 1956-2005 pH). Units are in standard deviates. The 10, 50, 100, 1000, 3000, and 6000 m depth contours are shown in gray.

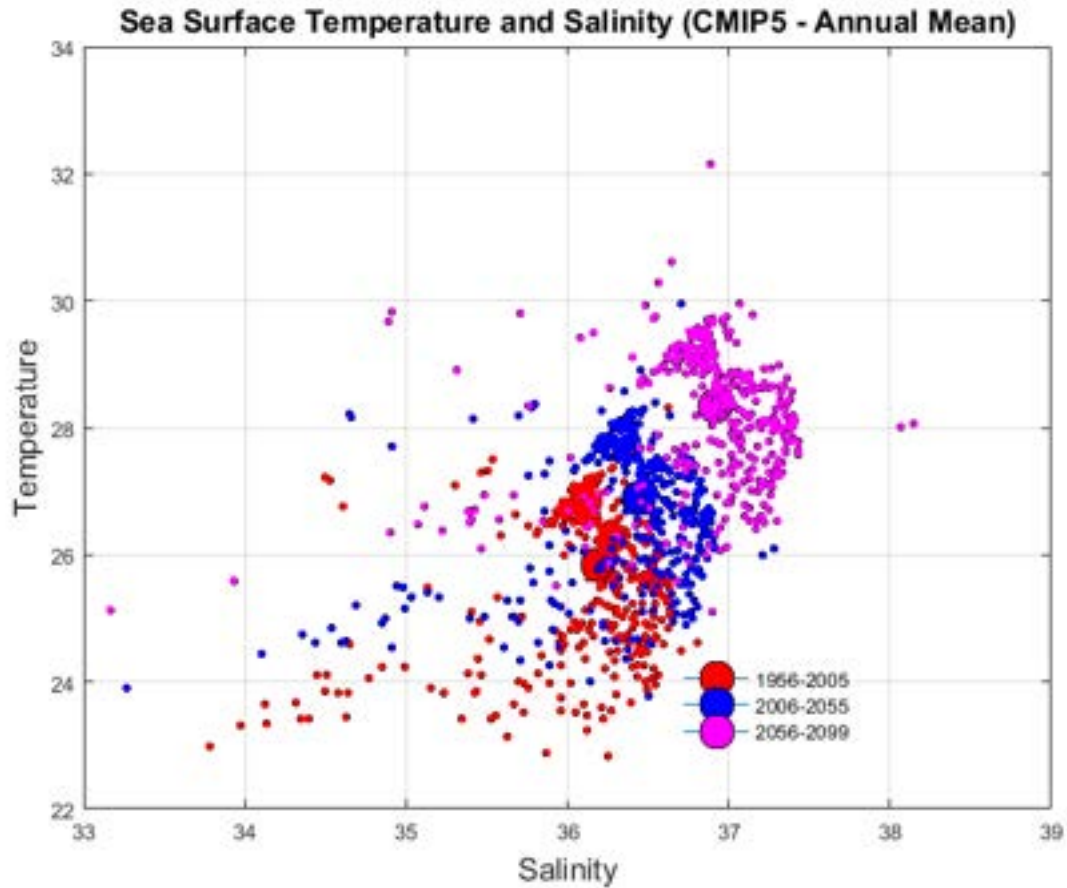


Figure 4 - Projected sea surface temperature and salinity for the Gulf of Mexico Large Marine Ecosystem. Mean annual temperature and salinity from the CMIP5 climate model for the Gulf of Mexico Large Marine Ecosystem. Three time blocks are shown in this plot: red is 1956-2055 reference period, blue is 2006-2055, and magenta is 2056-2099. Mean temperature and salinity are shown by the large markers in the appropriate color.

Appendix E - Species Information Sheets and Species Narratives

Almaco jack - *Seriola rivoliana*

Overall Vulnerability Rank = Moderate ■

Habitat Sensitivity = Low ■

Climate Exposure = Very High ■

Data Quality = 45% of scores ≥ 2

<i>Seriola rivoliana</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	1.6	2		Low Moderate High Very High
	Prey Specificity	1.7	1.8		
	Adult Mobility	1.6	2.4		
	Dispersal of Early Life Stages	2.2	1.6		
	Early Life History Survival and Settlement Requirements	1.8	1		
	Complexity in Reproductive Strategy	1.8	1.4		
	Spawning Cycle	1.7	2		
	Sensitivity to Temperature	1.5	2.2		
	Sensitivity to Ocean Acidification	1.6	2		
	Population Growth Rate	1.9	1.4		
	Stock Size/Status	1.9	1.2		
	Other Stressors	1.6	1.6		
	Sensitivity Score		Low		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	1.6	1.6		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.6	2		
	Salinity	3.7	3		
	Sea Level Rise	1	0		
	Sea Surface Temperature	4	3		
	Exposure Score		Very High		
Overall Vulnerability Rank		Moderate			

Overall Climate Vulnerability Rank: **Moderate.** (93% bootstrap results in Moderate, 7% bootstrap results in Low).

Climate Exposure: **Very High.** The three exposure factors contributing to the very high ranking for almaco jack were sea surface temperature (4.0), ocean acidification (4.0), and salinity (3.7). Primary productivity (1.6) and hypoxia (1.6) were ranked as moderate to low.

Biological Sensitivity: **Low.** The main sensitivity attributes contributing to a low biological sensitivity score for almaco jack were sensitivity to temperature (1.5), habitat specificity (1.6), adult mobility (1.6), sensitivity to ocean acidification (1.6), other stressors (1.6), prey specificity (1.7), and spawning cycle (1.7).

Distributional Vulnerability Rank: **High.** Three attributes indicated high vulnerability to distribution shift:

the species is found across a wide range of temperatures (2.1), is a habitat generalist (1.9), and the adults are highly mobile (2.5).

Data Quality: Almaco jack is a data poor species (Adams *et al.* 2016). Data quality scores for prey specificity, dispersal of early life stages, early life history survival and settlement requirements, complexity in reproductive strategy, population growth rate, stock size/status, other stressors, and hypoxia were all less than 2.0.

Climate Effects on Abundance and Distribution: No studies were found that examined the effect of climate change on the population productivity of almaco jack. Researchers ascribed oceanic warming to an apparent range change into European Atlantic waters (Capdevila -Argüelles and Zilletti. 2008). Additionally, in aquaculture settings, salinity appears to play a role in the survival of yolk-sac larvae (Reinoso *et al.* 2019). In that study, yolk-sac larvae survived between 35 and 40 g/L and perished on either side of that range. Egg and larval buoyancy were also modulated by salinity. This information was used to discuss potential salinities for successful spawning. Because their diets are at least partially composed of portunid crabs, there is some indication that ocean acidification could affect this species. However, they appear to feed as piscivores as well.

Life History Synopsis: The scientific literature on almaco jack (*Seriola rivoliana*) is sparse. Almaco jack are a circumtropical species and, in the western Atlantic, are distributed from Cape Cod to northern Argentina. This species is generally pelagic and epibenthic and inhabits oceanic waters (Smith *et al.* 2015). Larval and juvenile almaco jack are associated with sargassum mats (Dooley 1972, Rooker *et al.* 2006, Wells and Rooker 2004). Spawning is believed to occur offshore from spring to summer in the Gulf of Mexico. Adult almaco jack are associated with hard bottom reefs (Dennis and Bright 1988) and are generally found associated with structure such as reefs and seamounts (Fontes *et al.* 2014). There is some indication from acoustic telemetry that adult almaco jack are year-round, multi-year residents in some areas (Fontes *et al.* 2014), suggesting that individual almaco jack may have relatively small ranges and are not wide ranging predators. Adult diets in the South Atlantic Bight include fishes, shrimp, and portunid crabs (Manooch and Haimovici, 1983). Almaco jack in the Azores were completely piscivorous (Barreiros *et al.* 2003). The species

is considered to be suitable for aquaculture (Simpson 2011, Renshaw *et al.* 2012) and so grows reasonably quickly, however the age at maturity is about four years and the maximum age is 22 years.

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Atlantic croaker - *Micropogonias undulatus*

Overall Vulnerability Rank = Low ■

Habitat Sensitivity = Low ■

Climate Exposure = High ■

Data Quality = 85% of scores ≥ 2

<i>Micropogonias undulatus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	1.5	3		Low Moderate High Very High
	Prey Specificity	1.4	2.8		
	Adult Mobility	1.8	2.6		
	Dispersal of Early Life Stages	2	2.7		
	Early Life History Survival and Settlement Requirements	2.4	2.2		
	Complexity in Reproductive Strategy	1.7	2.2		
	Spawning Cycle	1.9	2.4		
	Sensitivity to Temperature	1.5	2.2		
	Sensitivity to Ocean Acidification	2.2	2.3		
	Population Growth Rate	1.7	2.6		
	Stock Size/Status	2	1.5		
	Other Stressors	1.9	2.2		
	Sensitivity Score		Low		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	2.5	2.6		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.5	2		
	Salinity	2.7	3		
	Sea Level Rise	2.2	2.6		
	Sea Surface Temperature	4	3		
Exposure Score		High			
Overall Vulnerability Rank		Low			

Overall Climate Vulnerability Rank: **Low.** (100% bootstrap results in Low).

Climate Exposure: **High.** The attributes contributing to Atlantic croaker's high climate exposure ranking were sea surface temperature (4.0) and ocean acidification (4.0), while primary productivity had a low to moderate score (1.5). Salinity (2.7) and sea level rise (2.2) had scores ranging from low to very high.

Biological Sensitivity: **Low.** The main sensitivity attributes contributing to a low biological exposure score for Atlantic croaker were prey specificity (1.4), sensitivity to temperature (1.5), and habitat specificity (1.5). Only dispersal of early life stages (2.0), early life history survival and settlement requirements (2.4), and sensitivity to ocean acidification (2.2) had an attribute mean of two or greater.

Distributional Vulnerability Rank: **High.** Three attributes contributed to the species' high vulnerability ranking. Atlantic croaker are habitat generalists (1.7), have highly adult mobility (2.0) and highly dispersive early life stage dispersal (2.1). Additionally, Atlantic croaker occur across a wide range of temperatures (1.5).

Data Quality: 85% of the data quality scores were 2 or greater. (*Identify any interesting data gaps like attributes that have high sensitivity as well as low data quality*)

Climate Effects on Abundance and Distribution: While there have been no studies specific to the Gulf of Mexico, simulations of global climate change in the mid-Atlantic region have shown increases in Atlantic croaker abundance with lower inter-annual variability (Hare *et al.* 2010, Diamond *et al.* 2013). In a sensitivity analysis, Diamond *et al.* (2013) noted that the major positive response was due to warmer temperatures, but negative effects were due to increased variability in salinity, increased offshore transport, and sea level rise. Climate change also has been shown to increase the occupancy probability of Atlantic croaker in the western Gulf of Mexico (Fujiwara *et al.* 2019).

Increases in the size or duration of the hypoxic zone in the Gulf of Mexico could have a negative effect the abundance of Atlantic croaker, as shown in the simulation models from Rose *et al.* (2018a) and Rose *et al.* (2018b) that modeled encounters with hypoxia. Thomas and Rahman (2012) have shown impaired gonadal growth and gamete production and male skewed sex ratios in Atlantic croaker collected within hypoxic areas. When displaced to deeper offshore waters due to hypoxia (Craig and Crowder 2005), there may be bioenergetics implications due to being in areas with temperatures lower than those considered for optimal growth (Craig and Bosman 2013). Finally, ocean acidification may have some effect on Atlantic croaker, as crustaceans and mollusks were the primary diet item found in stomachs in the Gulf of Mexico (Overstreet and Heard 1978).

Life History Synopsis: Atlantic croaker are an estuarine-dependent, coastal species occurring from Cape Cod, Massachusetts through central Florida, and from Tampa Bay north through the Gulf of Mexico around to the Yucatan Peninsula and Cuba (Able and Fahay 2010, Croaker Technical Task Force 2017). Genetic differences have been found between the population in the Atlantic and Gulf of Mexico (Able and Fahay 2010), although Anderson *et al.* (2019) has suggested that some gene flow may be present, albeit limited. While no differences in populations have been found along the Atlantic coast, recent work suggests there may be some minor genetic differences among populations in the Gulf of Mexico (Anderson *et al.* 2019).

Atlantic croaker are found across the continental shelf and in coastal waters and undertake inshore/offshore migrations between nursery grounds and spawning areas. However, their mobility has been found to be limited by hypoxic events (Craig and Crowder 2005). Maturity may be reached by age one and most fish are mature by age three (Barbieri *et al.* 1994, Anderson *et al.* 2018). Atlantic croaker have an extended spawning season that begins in fall and extends into early spring, with peak spawning from October to November (USFWS 1996). A second peak also has been observed in late January to early February (Cowan 1988, Barbieri *et al.* 1994, Kupchik and Shaw 2016).

Atlantic croaker larvae are pelagic and are transported into estuaries by tides, currents and other oceanographic processes (Joyeux 1998), typically in the late winter and early spring and peaked between February and April (Anderson *et al.* 2018). Once in the estuaries, larvae transition to the brackish bottom waters in nursery habitats associated with low-salinity tidal creeks to complete development into juveniles (Norcross 1991, Able and Fahay 1998, Miller *et al.* 2002). Large juveniles and adults migrate offshore during the fall where spawning occurs (Anderson *et al.* 2018).

The major prey of young-of-the-year Atlantic croaker are polychaetes, copepods, mysids, and detritus (Soto *et al.* 1999, Sink 2011). Adult croaker collected in Gulf of Mexico ate primarily crustaceans followed by polychaetes, mollusks, fishes (Overstreet and Heard 1978). Detritus was found in Atlantic croaker stomachs that were collected offshore, but in lower amounts than those collected inshore (Overstreet and Heard 1978).

Atlantic croaker have a moderately fast population growth rate, based on a growth coefficient of 0.12 (± 0.08), a maximum age of 8 years and a relatively small maximum body size (61 cm, average size 30 cm) (Croaker Technical Taskforce 2017). This rate of growth is slower than rates reported in the Atlantic (0.20-0.32 (Foster 2001), but may be due to low number of age-0 fish in the study (Croaker Technical Taskforce 2017).

Currently, no stock assessments have been undertaken in the Gulf of Mexico. A stock assessment (ASMFC 2017) was unable to determine stock status of Atlantic croaker with confidence, but noted the base model and all sensitivity runs evaluated suggested the spawning biomass was increasing.

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Atlantic sharpnose shark - *Rhizoprionodon terraenovae*

Overall Vulnerability Rank = Low ■

Habitat Sensitivity = Low ■

Climate Exposure = High ■

Data Quality = 90% of scores ≥ 2

<i>Rhizoprionodon terraenovae</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	1.5	2.8		Low Moderate High Very High
	Prey Specificity	1.2	2.8		
	Adult Mobility	1.2	3		
	Dispersal of Early Life Stages	1.3	3		
	Early Life History Survival and Settlement Requirements	1	2.6		
	Complexity in Reproductive Strategy	1.8	2.6		
	Spawning Cycle	2.2	3		
	Sensitivity to Temperature	1.4	2.8		
	Sensitivity to Ocean Acidification	1.6	2.6		
	Population Growth Rate	2.6	2.6		
	Stock Size/Status	2.1	2.4		
	Other Stressors	2.4	2.2		
	Sensitivity Score		Low		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	1.6	2.2		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.6	2		
	Salinity	3.2	3		
	Sea Level Rise	1.7	2.8		
	Sea Surface Temperature	4	3		
	Exposure Score		High		
Overall Vulnerability Rank		Low			

Overall Climate Vulnerability Rank: **Low.** (83% bootstrap results in Low, 17% bootstrap results in Moderate).

Climate Exposure: **High.** Three exposure factors contributed to a high ranking for Atlantic sharpnose shark: sea surface temperature (4.0), ocean acidification (4.0) and salinity (3.2), ranging from low to very high. The largest exposure to all three factors occurs in nearshore waters during the juvenile and adult life stages. Atlantic sharpnose sharks use coastal and nearshore habitats during juvenile and adult (only males) stages, and make offshore movements into deep waters during late fall and winter. Adult female Atlantic sharpnose sharks remain in offshore waters year-round once they reach maturity and presumably only move into nearshore waters for parturition. Hypoxia and sea level rise were both low to moderate, while primary productivity was moderate to low.

Biological Sensitivity: **Low.** The sensitivity attributes contributing to a low biological sensitivity score for Atlantic sharpnose shark included early life history survival and settlement requirements (1.0), prey specificity (1.2), adult mobility (1.2), sensitivity to temperature (1.4), and habitat specificity (1.5).

Distributional Vulnerability Rank: **High.** Three attributes contributed to Atlantic sharpnose shark's high vulnerability ranking. The species has highly mobile adults (2), has high early life stage dispersal (1.7), and occurs across a wide range of temperatures (2.0).

Data Quality: 90% of the data quality scores were 2 or greater. (*Identify any interesting data gaps like attributes that have high sensitivity as well as low data quality*)

Climate Effects on Abundance and Distribution: Several studies have described the distribution and abundance of Atlantic sharpnose sharks (*Rhizoprionodon terraenovae*) throughout the northern Gulf of Mexico (Parsons and Hoffmayer 2005, 2007, Drymon *et al.* 2010, 2013); however, none of these studies directly addressed the potential effects of climate change. Atlantic sharpnose sharks have shown extensive movements within the Gulf of Mexico, but there are no examples of this species leaving the region (Kohler and Turner 2019). As such, the timing of their inshore-offshore movements may be shifted with increasing water temperatures.

Life History Synopsis: Atlantic sharpnose shark (*Rhizoprionodon terraenovae*) is relatively small (max. length approx. 120 cm total length) coastal species with a ubiquitous distribution ranging from low salinity waters of estuaries, across the continental shelf, and to offshore depths up to 180 m in the Gulf of Mexico (Bigelow and Schroeder 1948, Branstetter 1981, Compagno 1984, Cortés *et al.* 2009). Nursery and parturition areas are enclosed large bays and sounds, which may offer protection from larger sharks, and residence time by juveniles in these areas is variable (Branstetter 1981, Parsons and Hoffmayer 2005, 2007, Carlson *et al.* 2008); as such, inshore juvenile habitats may be prone to anthropogenic degradation, development, and exploitation.

Adult females remained exclusively in offshore, cooler waters once mature (Parsons and Hoffmayer 2005, Drymon *et al.* 2010). Adult males are highly mobile and undergo a seasonal inshore-offshore migration with their winter habitat being deeper, offshore waters (Compagno

1984, Parsons and Hoffmayer 2005). During summer, adults males tend to move to offshore waters, although the extent of their vertical migrations is unknown (Parsons and Hoffmayer 2005, Hoffmayer *et al.* 2006).

Atlantic sharpnose sharks are opportunistic predators that exhibit an ontogenetic shift in their diet (Hoffmayer and Parsons 2003, Bethea *et al.* 2006). Young-of-the-year consume mostly teleosts (sciaenids) and shrimps (Hoffmayer and Parsons 2003, Bethea *et al.* 2006); adults tend to feed on cephalopods, crustaceans, and teleosts (sciaenids), although diet composition may vary by locale (Hoffmayer and Parsons 2003, Bethea *et al.* 2006, Drymon *et al.* 2012, Higgs *et al.* 2013, Delorenzo *et al.* 2015, Plumlee and Wells 2016). Given that crustaceans are an important component of their diet, Atlantic sharpnose shark may be sensitive to the effects of ocean acidification. However, since the Atlantic sharpnose shark is considered an opportunistic predator (Hoffmayer and Parsons 2003, Bethea *et al.* 2006), feeding on more abundantly available species in the area and may be less susceptible to changes in prey groups in the face of climate change (Viana-Morayta *et al.* 2020).

Atlantic sharpnose sharks are viviparous with a gestation period of 10-12 months; parturition occurs May to July and pups are about 30 cm in total length at birth (Parsons 1983, Loefer and Sedberry 2003, Hoffmayer *et al.* 2013). In addition, it has been documented that a shift in reproductive timing of Atlantic sharpnose sharks in the north central Gulf of Mexico to earlier in the spring occurred and corresponded with a 3.0°C increase in spring sea surface temperature over a 29-year period (Hoffmayer *et al.* 2010). Atlantic sharpnose sharks in the Gulf of Mexico were also shown to exhibit a protracted reproductive cycle, similar to sharpnose species in tropical regions, and it was suggested it may be related to changing environmental conditions (i.e., elevated water temperatures) in the northern Gulf of Mexico (Hoffmayer *et al.* 2013). Atlantic sharpnose sharks exhibit relatively rapid growth with von Bertalanffy growth rates of 0.63 for females and 0.85 for males; females mature between 1.3-2.3 years and males between 1.4-2.3 years; maximum age is reported to be 17 years and natural mortality is relatively low at 0.209-0.256 (Branstetter 1981, Parsons 1985, Carlson and Baremore 2003, Driggers *et al.* 2013, SEDAR 34).

SEDAR 34 found SSF_{2011}/SSF_{MSY} ranged from 1.01 to 2.88 for different model runs, indicating the stock was not overfished and F_{2011}/F_{MSY} ranged from 0.03-0.57, indicating the stock was not currently undergoing overfishing in 2011 (SEDAR 34). International Union for the Conservation of Nature lists the species as least concern to overfishing (Cortés 2009).

Due to their nearshore distribution, Atlantic sharpnose sharks are potentially susceptible to harmful algal blooms, indeed mortalities were documented in the northern Gulf of Mexico during a bloom of *Karenia brevis* (Flewelling *et al.* 2010). Mercury levels in this species of shark were higher than the 0.5ppm threshold deemed safe for human consumption (Adams and McMichael 1999).

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Atlantic stingray - *Dasyatis sabina*

Overall Vulnerability Rank = Low ■

Habitat Sensitivity = Low ■

Climate Exposure = High ■

Data Quality = 80% of scores ≥ 2

<i>Dasyatis sabina</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	1.6	2.8		Low Moderate High Very High
	Prey Specificity	1.7	2.8		
	Adult Mobility	1.7	2.8		
	Dispersal of Early Life Stages	1.4	3		
	Early Life History Survival and Settlement Requirements	1	2.2		
	Complexity in Reproductive Strategy	2.4	2.6		
	Spawning Cycle	2.4	2.6		
	Sensitivity to Temperature	1.6	2.6		
	Sensitivity to Ocean Acidification	2.1	2.6		
	Population Growth Rate	2.7	1.4		
	Stock Size/Status	1.8	0.4		
	Other Stressors	2.5	2.6		
	Sensitivity Score		Low		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	2.6	2.4		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.5	2		
	Salinity	2.8	3		
	Sea Level Rise	2.1	2.4		
	Sea Surface Temperature	4	3		
	Exposure Score		High		
Overall Vulnerability Rank		Low			

Overall Climate Vulnerability Rank: **Low.** (58% bootstrap results in Moderate, 42% bootstrap results in Low).

Climate Exposure: **High.** Sea surface temperature (4.0), ocean acidification (4.0), and salinity (2.8) contributed to a high score for Atlantic stingray. Hypoxia ranged from low to very high and had a value of 2.6, primary productivity (1.5) was moderate to low, and sea level (2.1) rise was moderate.

Biological Sensitivity: **Low.** The sensitivity attributes contributing to a low biological sensitivity score for Atlantic stingray were early life history survival and settlement requirements (1.0), dispersal of early life stages (1.4), habitat specificity (1.6), and sensitivity to temperature (1.6).

Distributional Vulnerability Rank: **High.** Four attributes contributed to Atlantic stingray's high vulnerability ranking. The species has very highly to highly dispersive early life stages (1.4), is a habitat generalist (1.7), and has highly to very highly mobile adults (1.7) and low to moderate temperature sensitivity (1.6).

Data Quality: 80% of the data quality scores were 2 or greater. (*Identify any interesting data gaps like attributes that have high sensitivity as well as low data quality*)

Climate Effects on Abundance and Distribution: The Atlantic stingray is distributed in nearshore, estuarine, and freshwater habitats (Tagatz 1967, Schmid *et al.* 1988), observed inland up to 200 miles from river's mouths (Bigelow and Schroeder 1953, Piermarini and Evans 1998) and out to marine waters approximately 60m in depth (Jones *et al.* 2020). Due to their wide ranging distribution and utilization of shallow water habitats (McEachran and Fechhelm 1998, Last *et al.* 2016) the probability of exposure to changes in environmental conditions associated with climate change (e.g., sea surface temperature fluctuation, changes in salinity due to increased runoff from more frequent and severe weather activity) for this species is relatively high. However, given that this species has been shown to exhibit tolerance to a wide range of salinities and temperatures (Tagatz 1967, Snelson and Williams 1981, Piermarini and Evans 1998, Fangué and Bennett 2003) and as they have been observed to practice behavioral thermoregulation, both migrating from shallower to deeper waters seasonally (Bigelow and Schroeder 1953, Schwartz and Dahlberg 1978, Snelson and Williams 1981) as well as their ability to exploit warmer temperatures to facilitate certain metabolic processes (Wallman and Bennet 2006), the overall impact of climate change on the Atlantic stingray in the northern Gulf of Mexico region is expected to be low.

Life History Synopsis: The Atlantic stingray is one of the smaller stingrays inhabiting the western North Atlantic, only reaching maximum disc widths (DW) of 330mm for males and 450mm for females (Snelson *et al.* 1988). When they are born, they are between 100-130mm DW (Bigelow and Schroeder 1953, Schwartz and Dahlberg 1978, Snelson and Williams 1981, Snelson *et al.* 1988, Johnson and Snelson 1996). Males reach sexual maturity between 200-210mm DW, while females mature at slightly larger sizes, 220-250mm DW (Schwartz and Dahlberg 1978, Snelson and Williams 1981, Snelson *et al.* 1988, Johnson and Snelson 1996).

The reproductive cycle of the Atlantic stingray is annual, with synchronous ovulation among females generally occurring in the end of March (Trikas *et al.* 2000). Post fertilization, which is usually complete by mid April, gestation persists for approximately four months (Trikas *et al.* 2000). Embryos are initially provided nourishment through the yolk sac, being supplemented during later development by maternal production of nutrient dense uterine histotroph (Musick and Ellis 2005). Parturition usually occurs in July or August (Trikas *et al.* 2000). The mating season is protracted, lasting from October to April of each year (Snelson *et al.* 1988, Maruska *et al.* 1996, Kajiura *et al.* 2000, Trikas *et al.* 2000). It has been hypothesized that early courtship and copulation during the fall and winter, months before female ovulation begins in the spring, could play an important role in female steroid production, oocyte development, and ultimately ovulation (Maruska *et al.* 1996).

Seasonal migration patterns may differ by region. It is apparent that at least some populations are year round residents in estuaries throughout their range. Populations from the Savannah River Estuary, GA south (appear to at least have resident components, and it is possible that individuals that do migrate simply move to deeper waters within the same estuary (Schwartz and Dahlberg 1978, Snelson and Williams 1981, Snelson *et al.* 1988, Ramsden *et al.* 2017). Similarly, individuals found in coastal waters of the northern Gulf of Mexico also appear to move into deeper waters during the winter months (Funicelli 1975, Lewis 1982). A couple of individuals tagged in the Cape Fear River Estuary, NC in the summer were later reported between 80 and 100km south off of Myrtle Beach, SC, indicating that at least a portion of the population may be capable of longer migrations south (Schwartz and Dahlberg 1978).

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Black drum - *Pogonias cromis*

Overall Vulnerability Rank = Low ■

Habitat Sensitivity = Low ■

Climate Exposure = High ■

Data Quality = 85% of scores ≥ 2

<i>Pogonias cromis</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	Low Moderate High Very High
Sensitivity Attributes	Habitat Specificity	1.8	3		
	Prey Specificity	1.6	3		
	Adult Mobility	1.8	2.8		
	Dispersal of Early Life Stages	2.1	2.6		
	Early Life History Survival and Settlement Requirements	1.8	2.5		
	Complexity in Reproductive Strategy	2	2.2		
	Spawning Cycle	1.9	2.6		
	Sensitivity to Temperature	1.6	2.8		
	Sensitivity to Ocean Acidification	2.4	2.6		
	Population Growth Rate	3.2	2.5		
	Stock Size/Status	2.2	1.8		
	Other Stressors	2.3	2.6		
	Sensitivity Score		Low		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	2.4	2.4		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.6	2		
	Salinity	2.9	3		
	Sea Level Rise	2.4	2.8		
	Sea Surface Temperature	4	3		
	Exposure Score		High		
Overall Vulnerability Rank		Low			

Overall Climate Vulnerability Rank: **Low.** (69% bootstrap results in Low, 31% bootstrap results in Moderate).

Climate Exposure: **High.** The exposure factors that contributed to black drum's high climate exposure score for black drum were sea surface temperature (4.0) and ocean acidification (4.0). Salinity was ranked high to moderate (2.9), sea level rise and hypoxia were ranked moderate to high (2.4). Primary productivity (1.6) was ranked moderate to low.

Biological Sensitivity: **Low.** The sensitivity attributes contributing to a low biological sensitivity score for black drum were prey specificity (1.6), sensitivity to temperature (1.6), habitat specificity (1.8), adult mobility (1.8), and early life history survival and settlement requirements (1.8).

Distributional Vulnerability Rank: **High.** The attributes contributing to the high vulnerability ranking included low to moderate sensitivity to temperature (1.6), low habitat specificity (1.8), highly to very highly mobile adults (1.8), and highly dispersive early life stages (2.1).

Data Quality: 85% of the data quality scores were 2 or greater. (*Identify any interesting data gaps like attributes that have high sensitivity as well as low data quality*)

Climate Effects on Abundance and Distribution: A few recent studies have examined the effect of climate factors on the population productivity and distribution of black drum. Monczak *et al.* (2019) found that changes in water temperature directly affect sound production, where positive temperature anomalies increase calling while negative temperature anomalies decrease calling. As such, climate variability could cause the seasonality of courtship sounds to change. This could both alter the length of the reproductive season and cause the reproductive seasons of different species to overlap, which could lead to competition for acoustic space and translate into suboptimal conditions for reproduction, ultimately affecting spawning potential (Monczak *et al.* 2019). Mass mortality is somewhat common when sudden, sustained temperature drops occur (Simmons and Breuer 1962).

Salinity also plays an important role in black drum dynamics. Results from an acoustic tagging study in Texas waters suggest that prolonged periods of hypersalinity act to reduce black drum distribution range and can limit the species' access to prey resources (Ajemian *et al.* 2018). Isotopic analyses similarly indicate that hypersaline conditions limit diet and movement of black drum likely due to increased cost of osmoregulation (Breaux *et al.* 2019). In the Upper Laguna Madre (ULM), a hypersaline estuary that experiences frequent and intense disturbances, black drum reproduce earlier than other populations inhabiting the Gulf of Mexico (Bumgardner *et al.* 1996, Olsen *et al.* 2018). Olsen *et al.* (2014) found that variability in recruitment appears to be at least partially driven by extreme salinity and surface temperature events. Olsen (2019) found recruitment in the ULM to be driven by a complex interaction between suitable habitat and density dependence, and linked higher salinities to higher levels of survival in the post-settle stage (Olsen 2020). The effects of increasing ocean acidification on diet items could have an effect on fitness of black drum in future changing climate scenarios.

Life History Synopsis: Black drum is a coastal and estuarine species widely distributed from Nova Scotia to Argentina (Hoese and Moore 1998). In the Gulf of Mexico, the Upper Laguna Madre supports the highest relative abundance of Black Drum (Olsen 2017).

Adults are usually common over sand or sand/mud bottom types in shallow coastal and estuarine waters, especially in high runoff areas, oyster reefs and shell hash (Pearson 1929, Odell *et al.* 2017).

Adults sometimes move onto near-shelf waters, but are primarily estuarine-dwelling and show little migratory behavior. Simmons and Breuer (1962) reported that tagged black drum in Texas generally moved less than 5 miles from where they were tagged. Beaummarriage (1969) reported similar results in Florida black drum. Stunz *et al.* (2015) found that black drum exhibit relatively high mobility within their embayment but rarely leave the system.

Black drum are euryhaline and commonly found in salinities ranging from 9-26 ppt (McIlwain 1978), but have been documented from waters of 0 - 80 ppt (Gunter 1956, Simmons and Breuer 1962, Leard *et al.* 1993), though adults found at extremely high salinities show signs of stress and physical damage (Murphy and Muller 1995). Peters and McMichael (1990) reported juvenile black drum, while occurring over widely varying temperatures and salinities, most often are collected in low to moderate salinity waters over unvegetated mud bottoms. Larger juveniles occur most often in higher salinity waters.

Timing of spawning is geographically variable (e.g., spawning in Louisiana waters occurs from February through April (Fitzhugh and Beckman 1987) while spawning in Florida occurs November through April with peak spawning in February and March), suggesting reproduction may be temperature dependent. Black drum spawn in bays, estuaries or coastal waters near estuarine mouths.

Larvae are dependent upon tidal currents for transport into estuaries where they utilize seagrass beds as nursery habitat, appearing in February or March. Postlarvae prefer nutrient-rich and somewhat muddy waters of tidal creeks and channels. Juveniles are found more often over muddy bottoms in estuaries.

The species is long lived, attaining a maximum age of 58 years and a maximum size of 1160 mm and weights up to 55 kg. Murphy and Taylor (1989) estimated that in northeastern Florida, males reached maturity at 4-5 years of age when they measured approximately 590 mm, while females reached maturity at 5-6 years of age, at measurements of 650 - 699 mm. They grow fairly rapidly until age 15, then growth slows.

Black drum are highly fecund multiple spawners with continuous oocyte recruitment throughout the spawning season (Fitzhugh *et al.* 1993), and are capable of spawning approximately every 3 days. Fitzhugh *et al.* (1993) estimated fecundity of average sized females weighing 13.4 pounds at 32 million eggs annually. Despite this high fecundity, recruitment is sporadic and it is thought that excessive predation by ctenophores may control and limit year class strength.

Eggs of black drum are pelagic and measure 0.8 - 1 mm. Eggs hatch in less than 24 hours at 20°C (Joseph *et al.* 1964). Larvae measure approximately 1.9 - 2.4 mm TL at hatching (Joseph *et*

al. 1964). The yolk sac is completely absorbed when larvae grow to 2.8 mm (0.11 inches). Upon reaching approximately 15 mm (0.59 inches) TL, the overall adult body shape is recognizable.

Larval black drum diet consists primarily of copepods. Juveniles and adults are opportunistic feeders and consume a large variety of benthic macrofauna, including crustaceans (crabs, shrimp), clams and oysters, polychaetes and some small fishes (Mendenhall 2015, Stunz 2015, Rubio *et al.* 2018).

Black drum prefer waters where temperatures range from 12 - 33°C (McIlwain 1978). Sudden temperature drops during the winter months cause them to migrate to deeper waters.

In USA waters of the Gulf of Mexico, where most of the landings for this species occur, the stock is considered abundant and not overfished by the Gulf States Marine Fisheries Commission (GSMFC) based on data-limited methods, but no formal recent assessments were available (Anon 2016). Genetic studies have found distinct subpopulations (genetic heterogeneity) between the Gulf of Mexico and Atlantic coast (Leidig 2015), with limited dispersal beyond the natal estuary (Leard *et al.* 1993).

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Black grouper - *Mycteroperca bonaci*

Overall Vulnerability Rank = Very High ■

Habitat Sensitivity = High ■

Climate Exposure = Very High ■

Data Quality = 75% of scores ≥ 2

<i>Mycteroperca bonaci</i>		Attribute Mean	Data Quality	Expert Scores Plots (tails by bin)	
Sensitivity Attributes	Habitat Specificity	2.8	3		■ Low ■ Moderate ■ High ■ Very High
	Prey Specificity	1.9	2.6		
	Adult Mobility	2.6	2.6		
	Dispersal of Early Life Stages	2.1	2		
	Early Life History Survival and Settlement Requirements	2.7	1.4		
	Complexity in Reproductive Strategy	3	3		
	Spawning Cycle	3.1	2.8		
	Sensitivity to Temperature	2.2	2.6		
	Sensitivity to Ocean Acidification	2.3	2		
	Population Growth Rate	3.3	3		
	Stock Size/Status	2.2	2		
	Other Stressors	2.4	2.4		
	Sensitivity Score	High			
Exposure Factors	Air Temperature	1	0		
	Hypoxia	1.9	1.8		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.9	2		
	Salinity	3.7	3		
	Sea Level Rise	2	1.8		
	Sea Surface Temperature	4	3		
	Exposure Score	Very High			
Overall Vulnerability Rank		Very High			

Overall Climate Vulnerability Rank: **Very High.** (81% bootstrap results in Very High, 18% bootstrap results in High, 1% bootstrap results in Moderate).

Climate Exposure: **Very High.** Three exposure factors contributed to black grouper's very high climate exposure: sea surface temperature (4.0), ocean acidification (4.0), and salinity (3.7). Sea level rise (2.0) was moderate, and hypoxia (1.9) and primary productivity (1.9) were both moderate to low.

Biological Sensitivity: **High.** The sensitivity attributes contributing to a high biological sensitivity score for black grouper were spawning cycle (3.1), population growth rate (3.3), complexity in reproductive strategy (3.0), habitat specificity (2.8), and early life history survival and settlement requirements (2.7).

Distributional Vulnerability Rank: **Low.** All four attributes contributed to the low vulnerability to distribution shift for black grouper: limited adult mobility (2.6), limited early life stage dispersal (2.1), relatively high habitat specialization (2.8), and relatively narrow temperature requirements (2.2).

Data Quality: 75% of the data quality scores were 2 or greater. (*Identify any interesting data gaps like attributes that have high sensitivity as well as low data quality*)

Climate Effects on Abundance and Distribution: Few studies examined the effect of climate factors on the population productivity of black grouper. Similar to other grouper species, black grouper appear to have a relatively extended larval pelagic stage (up to ~2 months; Keener *et al.* 1988); warming waters may have impacts on larval mortality and/or connectivity. Black grouper are most common in the southernmost extent of the Gulf of Mexico (Southwest Florida) and thus would not seem to be limited in the case of a temperature-driven northward range extension.

Life History Synopsis: Black grouper is a shallow water grouper species that occupies rocky ledges and reef habitats; in the Gulf of Mexico it is found most frequently in Southwest Florida although they have been recorded across the region to Texas (SEDAR 2010). Like other groupers, black groupers are protogynous hermaphrodites and transition from female to male at approximately 16 years of age (SEDAR 2010). Individuals grow rapidly for the first 10 years, after which point growth slows (Crabtree and Bullock 1998); their maximum observed age is 33 years (SEDAR 2010). Mature grouper form transient spawning aggregations which can include hundreds of fish; aggregations tend to form over reef promontories at the shelf edge (Heyman *et al.* 2017), sometimes in locations used by other snapper and grouper species. In the Gulf of Mexico, spawning occurs from December to April with a peak during January to March (Heyman *et al.* 2017).

Black grouper are broadcast spawners with a pelagic egg and larval stage. The pelagic larval duration and recruitment habitat are unknown, but Keener *et al.* (1988) found small numbers of new recruits in tidal inlets in South Carolina, aged between 31 and 57 days old. There is little information on early life stages; in the Southern Gulf of Mexico juveniles are found to live in shallow water rocky reef habitats with high relief, and feed on crustaceans and fish (Brulé *et al.*

2005). Generally, black grouper are thought to move from shallow water to deeper habitats as they age (SEDAR 2010). Based on limited tagging data, black grouper are estimated to have a relatively small home range and move only limited distances (Farmer and Ault 2011).

Black grouper is an important species to both commercial and recreational fisheries in South Florida. The species is often confused with a congener, gag *Mycteroperca microlepis* (O'Hop and Beaver 2009). Black grouper have not undergone a stock assessment recently but are currently thought to not be overfished and not expected to be undergoing overfishing (SEDAR 2010).

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Blacknose shark - *Carcharhinus acronotus*

Overall Vulnerability Rank = Low ■

Habitat Sensitivity = Low ■

Climate Exposure = High ■

Data Quality = 90% of scores ≥ 2

<i>Carcharhinus acronotus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	1.8	2.8		■ Low ■ Moderate ■ High ■ Very High
	Prey Specificity	1.4	2.6		
	Adult Mobility	1.3	3		
	Dispersal of Early Life Stages	1.2	2.6		
	Early Life History Survival and Settlement Requirements	1	2.2		
	Complexity in Reproductive Strategy	2.2	2.6		
	Spawning Cycle	2.4	2.8		
	Sensitivity to Temperature	1.4	2.8		
	Sensitivity to Ocean Acidification	1.4	2.6		
	Population Growth Rate	2.9	2.6		
	Stock Size/Status	2.2	2		
	Other Stressors	2.3	2.2		
Sensitivity Score		Low			
Exposure Factors	Air Temperature	1	0		
	Hypoxia	1.6	2.2		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.8	2		
	Salinity	3.5	3		
	Sea Level Rise	1.4	2.4		
	Sea Surface Temperature	4	3		
Exposure Score		High			
Overall Vulnerability Rank		Low			

Overall Climate Vulnerability Rank: **Low.** (48% bootstrap results in Moderate, 38% bootstrap results in Low, 14% bootstrap results in High).

Climate Exposure: **High.** Sea surface temperature (4.0), ocean acidification (4.0), and salinity (3.5) were the primary exposure factors contributing to blacknose shark's high climate exposure. Primary productivity (1.8), hypoxia (1.6), and sea level rise (1.4) were ranked low to moderate.

Biological Sensitivity: **Low.** The sensitivity attributes that contribute to a low biological sensitivity score for blacknose shark were early life history survival and settlement requirements (1.0), dispersal of early life stages (1.2), adult mobility (1.3), prey specificity (1.4), sensitivity to temperature (1.4), and sensitivity to ocean acidification (1.4).

Distributional Vulnerability Rank: **High.** Three attributes indicated high vulnerability to distribution shift: very highly dispersive early life stages (1.2), very highly mobile adults (1.3), and low to moderate habitat specificity (1.8).

Data Quality: 90% of the data quality scores were 2 or greater. (*Identify any interesting data gaps like attributes that have high sensitivity as well as low data quality*)

Climate Effects on Abundance and Distribution: No studies have examined the impact of climate change on the population productivity of blacknose sharks. Major changes in distribution are unlikely as blacknose sharks are associated with water temperature greater than 17°C (Driggers unpublished data) but could change seasonal trends in centers of distribution (i.e., reduced migrations). As this species is primarily benthic and bottom waters north of Cape Hatteras are characterized by relatively cool waters moving south associated with the Labrador Current, it is unlikely they would expand their distribution north except with the possibility of incursions during warmest months. Increased water temperatures could have significant life history impacts (outlined below) related to faster growth, earlier maturation, and reduced reproductive periodicity in specific regions. As coastal sharks with more "r selected" life history characteristics are typically shorter lived it is also possible that the life span of blacknose sharks could be impacted. In terms of diet, it is not possible to determine the impact of climate change on the diet of blacknose sharks as they are not specialists and consume a wide variety of prey and appear to eat what is most abundant in a given area.

Life History Synopsis: Blacknose sharks are relatively small-bodied and reach a maximum size of less than 1.5 m total length (Castro 2011). In US waters of the western North Atlantic Ocean, the primary range of blacknose sharks is from North Carolina to Texas (Compagno 1982). On a broader scale, the range of the blacknose sharks extends into the Caribbean Sea and western South Atlantic Ocean (Bigelow and Schroeder 1954). Within the western North Atlantic Ocean blacknose sharks have five distinct genetic populations, with three of those existing in US waters (i.e., one off east coast and two within the northern Gulf of Mexico) (Portnoy *et al.* 2014). While the species is occasionally found in estuarine waters during periods of incoming tides, the species is predominately found in high salinity habitats (Ulrich *et al.* 2005). The species occurs at depths ranging from the littoral zone to 100 m (Ulrich *et al.* 2004, NMFS unpublished data). Unlike some other species of coastal sharks, there does not appear to be any depth segregation based on

sex or size (NMFS, unpublished data). However, the locations of nursery and birthing areas remain elusive but based on anecdotal and limited catch data, appear to occur in nearshore waters rather than within estuaries (Driggers, unpublished data). The diet of blacknose sharks consists predominately of small fishes, such as sciaenids, and to a lesser extent of crustaceans and mollusks (Schwartz, 1984, Cortes 1999, Ford, 2012). As crustaceans constitute a portion of the blacknose shark diet, it is possible the diet of the species could be impacted by ocean acidification.

Based on anecdotal, tag-recapture and fisheries-independent data, adult blacknose sharks make predictable seasonally-mediated, north-south migrations off the east coast of the US (Driggers 2001). Briefly, blacknose sharks off the east coast of the US migrate into more northern areas of their range during spring and back into more southern waters off Florida during fall; however, there is evidence that a small portion of blacknose sharks migrate offshore during the fall in the northern extent of their range (Driggers 2001). Migratory patterns in the Gulf of Mexico are not as evident as at least two populations of blacknose sharks occur within the Gulf of Mexico and available data show a mixture of along shore and inshore-offshore seasonal movements (Portnoy *et al.* 2014, Driggers, unpublished data). Anecdotal data indicate during the spring, a portion of each blacknose shark population move into coastal waters of the northern Gulf of Mexico. In the fall, blacknose sharks move into more southern waters for until the following spring. Blacknose sharks are placentally viviparous, have a brood size ranging from 1-5 offspring and give birth in late spring after a gestation period of 10-12 months (Driggers *et al.* 2004a, Sulikowski *et al.* 2007, Driggers *et al.* 2010). Off the east coast, multiple authors have reported that blacknose sharks have a biennial reproductive cycle (e.g., Schwartz 1984, Driggers *et al.* 2004a). However, Sulikowski *et al.* (2007) demonstrated that blacknose sharks in the northern Gulf of Mexico have an annual reproductive cycle. Further, it has been suggested that a portion of females off the east coast can reproduce annually (Ford 2012). Hypotheses attempting to explain the presence varying reproductive periodicities largely focus on energetics related to migrations. Therefore, climate change could reduce the need for seasonally mediated migrations due to a larger amount of preferred thermal habitat during cooler and thus lead to a higher percentage of the east coast population of blacknose sharks reproducing annually.

Like other small-bodied coastal sharks, blacknose sharks grow relatively rapidly early in life with von Bertalanffy growth coefficients of 0.30 for females and 0.36 for males. The maximum observed age for both sexes is 12.5 years and the age at which 50% of the population is mature is approximately 4.5 years for females and males (Driggers 2004b, Driggers *et al.* 2010).

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Blacktip shark - *Carcharhinus limbatus*

Overall Vulnerability Rank = Moderate ■

Habitat Sensitivity = Low ■

Climate Exposure = Very High ■

Data Quality = 90% of scores ≥ 2

<i>Carcharhinus limbatus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	1.6	2.8		Low Moderate High Very High
	Prey Specificity	1.6	2.8		
	Adult Mobility	1.2	3		
	Dispersal of Early Life Stages	1.2	2.8		
	Early Life History Survival and Settlement Requirements	1	2.6		
	Complexity in Reproductive Strategy	2.1	2.8		
	Spawning Cycle	2.4	2.8		
	Sensitivity to Temperature	1.4	2.8		
	Sensitivity to Ocean Acidification	1.4	2.6		
	Population Growth Rate	2.7	2.8		
	Stock Size/Status	1.6	2.4		
	Other Stressors	2.3	2.8		
Sensitivity Score		Low			
Exposure Factors	Air Temperature	1	0		
	Hypoxia	1.6	2.2		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.8	2		
	Salinity	3.5	3		
	Sea Level Rise	1.8	2.6		
	Sea Surface Temperature	4	3		
Exposure Score		Very High			
Overall Vulnerability Rank		Moderate			

Overall Climate Vulnerability Rank: **Moderate.** (53% bootstrap results in Moderate, 26% bootstrap results in Low, and 21% bootstrap results in High).

Climate Exposure: **Very High.** Sea surface temperature (4.0), ocean acidification (4.0), and salinity (3.5) were the primary factors contributing to blacktip shark's high climate exposure ranking. Primary productivity (1.8), sea level rise (1.8), and hypoxia (1.6) were ranked moderate to low.

Biological Sensitivity: **Low.** The sensitivity attributes that contributed to a low biological sensitivity score for blacktip shark were early life history survival and settlement requirements (1.0), adult mobility (1.2), dispersal of early life stages (1.2), sensitivity to temperature (1.4), sensitivity to ocean acidification (1.4), Habitat specificity (1.6), and prey specificity (1.6).

Distributional Vulnerability Rank: **High.** The top three attributes contributing to high vulnerability to distribution shift include: very highly mobile adults (1.2), very highly dispersive early life stages (1.2), and low to moderate sensitivity to temperature (1.4). Blacktip shark also have relatively low habitat specialization (1.6).

Data Quality: 90% of the data quality scores were 2 or greater. (*Identify any interesting data gaps like attributes that have high sensitivity as well as low data quality*)

Climate Effects on Abundance and Distribution: Studies have linked temperature to blacktip movements, reproduction, fishing stress, and potentially post-release mortality. Some adults display annual migratory behavior between Southern Florida and the Florida Keys and the Florida Gulf nursery areas (winter and summer, respectively), sometimes moving between the GOM and US Atlantic Coast region. There are migrations along the US Atlantic coast from north to south with seasonal changes in water temperature and similar migrations in the western GOM. In the central GOM, a segment of the population migrates offshore during winter, but the extent is unknown. As with other elasmobranchs, higher temperatures can accelerate the gestation process. Specific cues have not been reported but are possible given seasonal migrations associated with reproduction (Castro 1996, Hight and Lowe 2007). Whitney *et al.* (2017) found that increasing temperatures were related to longer recovery from fishery capture and higher indicators of stress; this could lead to higher post-release mortality.

Life History Synopsis: The blacktip shark (*Carcharhinus limbatus*) is a medium-sized (up to 255 cm), quick-growing coastal shark species. Males mature at 4 to 5 years, and females at 6 to 7 years of age. Juveniles inhabit shallow nearshore coastal nursery environments, such as mangrove-lined bays and estuaries, away from adult sharks (Castro 1993, Branstetter *et al.* 1990, Heupel and Hueter 2002, Heupel and Simpfendorfer 2005). These nearshore areas may be prone to coastal development. Adult sharks inhabit nearshore beaches, bays, estuaries, coral reefs, and near river mouths (Castro 1996, Bigelow and Schroeder 1948).

Teleost fish (one study found primarily menhaden) are the predominant prey for neonate and juvenile individuals, followed by other items such as crustaceans and invertebrates (Castro 1996, Barry *et al.* 2008). Similarly, for adults, teleost fish are the most common prey. Adults also

consume crustaceans, cephalopods, and smaller elasmobranchs, showing flexibility in their diet (Castro 1996, Hoffmayer and Parsons 2003).

Sharks migrate in large, loosely sex-structured schools when they are not mating. Migrations to and from pupping/nursery areas may be cued by temperature changes (Castro 1996, Heupel 2007, Kajiura *et al.* 2015). They mate between March and June, primarily in May in the GOM region (SEDAR 2012). Females have an 11- to 12-month gestation period, give birth to an average of three pups per litter in the Atlantic and four to five pups per litter in the Gulf of Mexico. There are many genetically differentiated populations (Keeney *et al.* 2003) with distinct migration patterns. Some blacktip sharks occur year-round in the Gulf of Mexico, with others displaying annual migratory behavior between Southern Florida/The Florida Keys and the Florida Gulf nursery areas (winter and summer, respectively), sometimes moving between the GOM and Atlantic Coast region (Kohler *et al.* 1998). Based on GOM studies, their intrinsic rate of population increase is 1.417 (Chen and Yuan 2006), while their Von Bertalanffy K is reported as 0.24 and 0.27 for females and males, respectively (Carlson *et al.* 2006).

Due to their nearshore distribution, blacktip sharks are potentially susceptible to harmful algal blooms and pollutants. A 1999 study found that 47.6% of blacktip sharks sampled off the Florida Atlantic coast had mercury levels above 0.5 ppm. An earlier study reported higher methyl mercury in southern Florida samples versus northern Florida, but direct harm to the sharks was not reported (Hueter *et al.* 1995, Adams and McMichael 1999). A study found that blacktip sharks were exposed to cyanobacteria, evidenced by BMAA in their fin tissue, but direct effects on the sharks are unknown (Mondo *et al.* 2012).

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Blue crab - *Callinectes sapidus*

Overall Vulnerability Rank = Low ■

Habitat Sensitivity = Low ■

Climate Exposure = High ■

Data Quality = 95% of scores ≥ 2

<i>Callinectes sapidus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	1.6	2.6		Low Moderate High Very High
	Prey Specificity	1.2	2.6		
	Adult Mobility	2.2	2.8		
	Dispersal of Early Life Stages	1.6	2.6		
	Early Life History Survival and Settlement Requirements	2.4	2.6		
	Complexity in Reproductive Strategy	2.4	2.6		
	Spawning Cycle	2.1	2.6		
	Sensitivity to Temperature	1.5	2.4		
	Sensitivity to Ocean Acidification	2.2	2.2		
	Population Growth Rate	1.2	2.2		
	Stock Size/Status	1.8	2		
	Other Stressors	2.4	2.4		
	Sensitivity Score		Low		
Exposure Factors	Air Temperature	4	3		
	Hypoxia	2.6	3		
	Ocean Acidification	4	2		
	Precipitation	1	3		
	Primary Productivity	1.4	2		
	Salinity	2.3	3		
	Sea Level Rise	2.9	2.8		
	Sea Surface Temperature	1	0		
	Exposure Score		High		
Overall Vulnerability Rank		Low			

Overall Climate Vulnerability Rank: **Low.** (78% bootstrap results in Low, 22% bootstrap results in Moderate).

Climate Exposure: **High.** Air temperature (4.0, a proxy for estuarine temperature), ocean acidification (4.0) and sea level rise (2.9) were the primary factors contributing to blue crab's high climate exposure ranking. Hypoxia (2.6) and salinity (2.3) were ranked high to moderate, and primary productivity (1.4) was ranked low to moderate.

Biological Sensitivity: **Low.** The sensitivity attributes that contributed to a low biological sensitivity score for blue crab were population growth rate (1.2), prey specificity (1.2), sensitivity to temperature (1.5), habitat specificity (1.6), dispersal of early life stages in parentheses 1.6), and stock size/status (1.8).

Distributional Vulnerability Rank: **High.** Three attributes indicated high vulnerability to distribution shift. Blue crab is a habitat generalist with abundant available habitat (1.6), has highly to very highly dispersive early life stages (1.6), and occurs across a wide range of temperatures and across a wide latitudinal range (1.5). The adults are also highly to moderately mobile (2.2).

Data Quality: 95% of the data quality scores were 2 or greater. (*Identify any interesting data gaps like attributes that have high sensitivity as well as low data quality*)

Climate Effects on Abundance and Distribution: Historically, blue crab have faced significant mortality rates during colder months (Hines *et al.* 2011). Predictably, with increasing seawater temperatures, blue crab will likely see an increase in survival rates during winter and promoted brood production with a more rapid growth (VanderKooy 2013, Hines *et al.* 2011). However, sustained warmer temperatures are predicted to result in increased juvenile mortality and a reduction of size at maturity (Bauer and Miller 2010, Hines *et al.* 2011). Increase in ocean acidification will impose energetic costs on blue crab resulting in less energy stored, as well as, potential changes in shell composition resulting in an increase or decrease in shell strength (Ries *et al.* 2009). Climate change will likely result in fluctuations of freshwater flow impacting blue crab abundance, habitat, refuge and mating grounds, and exposure to deadly parasites (Gandy *et al.* 2011, Lee and Frischer 2004). Increased water temperatures are expected to expand the distribution of blue crabs along the Atlantic coast poleward into the Gulf of Maine (Johnson 2015).

Life History Synopsis: Blue crabs are euryhaline predators of great ecological and economic importance throughout their vast range, which extends from Argentina to the Nova Scotia and into the Gulf of Mexico (Gandy *et al.* 2011, VanderKooy 2013). There is evidence of two management populations in the Gulf: The Eastern stock (coastal Florida to Apalachee) and the Western stock (Texas to Apalachicola Bay) (VanderKooy 2013). Blue crabs are sexually dimorphic, and their lifespan is estimated at 3-6 years (Cooper *et al.* 2013). Their life history has been well studied but is highly variable between Atlantic and Gulf coasts and by latitude within the Gulf of Mexico (Hart *et al.* 2020). Time to sexual maturity varies by location and has been estimated at 12 months in Gulf blue crabs (VanderKooy 2013). Size at maturation also varies

because growth is a function of temperature, salinity, and prey availability (Tagatz 1968, Crowley *et al.* 2014). In Florida's St. Andrews Bay and Suwannee Sound size at maturity has been recorded as 116.5 mm and 121.9 mm carapace width (CW), respectively (Hart *et al.* 2020). Molting rate is strongly affected by temperature as indicated by laboratory studies where molting rate increased between 13°C and 27°C but slowed between 27°C and 34°C (Leffler 1972). Juvenile crabs molt every few days and molt intervals decrease as they increase in size (VanderKooy 2013). After 18-20 post-larval molts female crabs reach a terminal molt coinciding with maturity and, if they ever molt again, will no longer grow (VanderKooy 2013). Females can only mate immediately after their terminal molt, so males may carry a female until she molts to ensure reproductive success (Guillory *et al.* 2001, Gandy *et al.* 2011, Cooper *et al.* 2013). Mating occurs in low salinity waters of upper estuaries between March and November in the northern Gulf (Johnson and Perry 1999). Mature females are catadromous, leaving the low salinity waters where they mated, to spawn in hypersaline waters of the upper estuarine and offshore (Gandy *et al.* 2011). Unlike Atlantic blue crabs, females in the eastern Gulf undergo a mass migration northward from their home estuaries to spawn. It has been suggested that this spawning event transports larvae into the Loop current and subsequently southward thereby providing blue crab recruitment for all of peninsular Florida (Steele *et al.* 1991, VanderKooy 2013, Hart *et al.* 2020). Spawning takes place in the spring, summer, and fall in the northern Gulf and there are reports of yearround spawning in Florida (Johnson and Perry 1999, Gandy *et al.* 2011, VanderKooy 2013). Females can retain sperm from one male and spawn up to eight times in a spawning season (Dickinson *et al.* 2006, VanderKooy 2013). Fecundity is positively correlated with size, in the northern Gulf, females can release up to 3.2 ± 1.5 million eggs (Graham *et al.* 2012, Hart *et al.* 2020). Eggs are released on ebbing tides and are transported offshore where they hatch into planktonic larvae, or zoeae (VanderKooy 2013, Hart *et al.* 2020). Zoeae pass through 7-8 zoeal stages while offshore (Johnson and Perry 1999). After 30-50 days they form legs and abdominal appendages becoming megalopae, at which point they settle into estuaries before metamorphosing into juvenile crabs (Gandy *et al.* 2011, VanderKooy 2013). Early juvenile crabs (5-10 mm CW) will remain in the low to intermediate salinity portions of estuaries until reaching maturity and eventually mating (VanderKooy 2013). Predation of juveniles is much higher in the Gulf compared to the Atlantic despite higher larval ingress and settlement rates, due to a wider variety of predators in the Gulf (Hines *et al.* 2003). Mature blue crabs are preyed upon by a variety of game fish that share the same estuarine habitats, such as the common snook and red drum (Flaherty and Guenther 2011). Mature crabs prey on mollusks, fishes, other crustaceans, and are cannibalistic (Flaherty and Guenther 2011). Juvenile nursery habitats include seagrass and saltmarshes habitats which have lower predation rates than non-vegetated areas, however juveniles have been known to utilize soft mud habitats (VanderKooy 2013). Conversely, mature crabs are found throughout estuaries and habitat partitioning is based on salinity and sex (VanderKooy 2013). A 2013 stock assessment of Gulf blue crabs indicates that neither the Eastern nor Western populations are undergoing overfishing, however the Western stock is "approaching an overfishing limit" (VanderKooy 2013).

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Bonnethead shark - *Sphyrna tiburo*

Overall Vulnerability Rank = Low ■

Habitat Sensitivity = Low ■

Climate Exposure = High ■

Data Quality = 90% of scores ≥ 2

<i>Sphyrna tiburo</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	2.4	2.8		Low Moderate High Very High
	Prey Specificity	2.9	2.6		
	Adult Mobility	1.6	2.6		
	Dispersal of Early Life Stages	1.3	2.8		
	Early Life History Survival and Settlement Requirements	1	2.6		
	Complexity in Reproductive Strategy	1.9	2.6		
	Spawning Cycle	2.2	2.6		
	Sensitivity to Temperature	1.4	2.8		
	Sensitivity to Ocean Acidification	1.9	3		
	Population Growth Rate	2.4	2.8		
	Stock Size/Status	1.9	2.4		
	Other Stressors	2.4	2.4		
Sensitivity Score		Low			
Exposure Factors	Air Temperature	1	0		
	Hypoxia	2	2.4		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.8	2		
	Salinity	3.3	3		
	Sea Level Rise	2.2	2.6		
	Sea Surface Temperature	4	3		
Exposure Score		High			
Overall Vulnerability Rank		Low			

Overall Climate Vulnerability Rank: **Low.** (56% bootstrap results in Moderate, 32% bootstrap results in Low, and 13% bootstrap results in High).

Climate Exposure: **High.** Sea surface temperature (4.0), ocean acidification (4.0), and salinity (3.3) contributed to a high climate exposure ranking for bonnethead shark. Sea level rise (2.2), hypoxia (2.0), and primary productivity (1.8) were moderate to high, moderate, and moderate to low, respectively.

Biological Sensitivity: **Low.** The sensitivity attributes that contributed to a low biological sensitivity score for bonnethead shark were early life history survival and settlement requirements (1.0), dispersal of early life stages (1.3), sensitivity to temperature (1.4), and adult mobility (1.6).

Distributional Vulnerability Rank: **High.** Three attributes indicated a high vulnerability to distribution shift: very highly dispersive early life stages (1.3), low sensitivity to temperature and broad latitudinal distribution (1.4), and very highly to highly mobile adults (1.6).

Data Quality: 90% of the data quality scores were 2 or greater. (*Identify any interesting data gaps like attributes that have high sensitivity as well as low data quality*)

Climate Effects on Abundance and Distribution: Increasing ocean acidification would most likely have the greatest effect on the abundance of bonnethead sharks due to the large portion of their diet being composed of crustaceans (primarily callinectid crabs and penaeid shrimp) (Bethea *et al.* 2007). Bonnethead sharks also rely heavily on seagrass beds during their life cycle. Short and Neckles (1999) noted that seagrasses could be negatively impacted by climate change and sea level rise through changes in growth rates due to increased eutrophication, increased water depths, and salt water intrusion. These changes in the seagrass habitat potentially could negatively affect the abundance and distribution of bonnethead sharks. However, it should be noted that Plumlee *et al.* (2018) showed increased in bonnethead abundance in northwest Gulf of Mexico between 1985 and 2014.

Life History Synopsis: The bonnethead shark is a small coastal shark species that is found in shallow estuaries and bays and coastal and nearshore habitats, typically from 10 to 80 m ranging from North Carolina to Brazil, including the Gulf of Mexico and the Caribbean Sea (Compagno 1984, Ebert *et al.* 2013). Adults are mobile, moving offshore during the winter to deeper beach habitats (versus shallow coastal estuaries). Telemetry and tag-recapture studies suggest high site fidelity, with the majority of tagged sharks being recaptured within the same estuary, and groups of bonnetheads maintaining group cohesion (Heupel *et al.* 2006, Driggers *et al.* 2014).

Bonnetheads are viviparous, reproducing annually, with mating occurring in November and sperm being stored until ovulation/fertilization the following March or April (Parsons 1993, Manire *et al.* 1995). Gestation lasts ~4.5-5 months with litter size averaging 9.7 pups in the Gulf of Mexico (SEDAR 2013). Lombardi-Carlson *et al.* (2003) found pupping varies latitudinally in the Gulf of Mexico, occurring in mid-to-late August in Florida Bay (southernmost location), early September in Tampa Bay (middle location) and mid-to-late September off north-west Florida (northernmost location). Seagrass beds/estuarine areas serve as nursery grounds by young of the year bonnetheads, although there does not appear to be specific nursery areas (Heupel *et al.*

2006). In the Gulf of Mexico, the maximum observed aged was 7.5 years, and an age of 50% maturity of 2.9 years (SEDAR 2013).

Crustaceans composed much of the diet of bonnetheads, including penaeid shrimp, portunid crabs, xanthid crabs, stomatopods, cephalopods, and small amounts of algae (Cortes *et al.* 1996, Bethea *et al.* 2007, Harrington *et al.* 2016). Blue crab, *Callinectes sapidus* was found to be a major diet component both in juveniles and adults. The seagrass present in stomachs suggest specialization/preference for feeding in seagrass areas, although Bethea *et al.* (2007) suggested that more research is needed to “fully evaluate the role plant material plays in the overall nutrition of bonnethead.”

Based on tag-recapture data, there appears to be little to no movement of bonnetheads from US Atlantic waters into the Gulf of Mexico, or vice versa (Bethea and Grace 2013, Tyminski *et al.* 2013, Driggers *et al.* 2014), including movements to the southwestern Gulf of Mexico, although the full extent is unknown due to the under-reporting of recaptured sharks from Mexican waters (Kohler *et al.* 2013). Genetic variation has been found between separate populations in the Gulf of Mexico (SEDAR 2013) as well as between the Atlantic and Gulf of Mexico (Escatel-Luna *et al.* 2015, Portnoy *et al.* 2015). The most recent stock assessment found that bonnethead shark was not overfished and overfishing was not occurring. (SEDAR 2013). However, it should be noted that the life history data supported splitting the population into separate Atlantic and Gulf of Mexico stocks, but since it was conducted as a standard assessment, the major assumptions could not be changed in the model.

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Brown shrimp - *Farfantepenaeus aztecus*

Overall Vulnerability Rank = Low ■

Habitat Sensitivity = Low ■

Climate Exposure = High ■

Data Quality = 90% of scores ≥ 2

<i>Farfantepenaeus aztecus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	2.1	2.4		Low Moderate High Very High
	Prey Specificity	1.3	2.4		
	Adult Mobility	1.9	2.6		
	Dispersal of Early Life Stages	1.7	2.6		
	Early Life History Survival and Settlement Requirements	2.5	2.4		
	Complexity in Reproductive Strategy	2.2	2.2		
	Spawning Cycle	1.5	2.6		
	Sensitivity to Temperature	2	2.2		
	Sensitivity to Ocean Acidification	1.9	1.6		
	Population Growth Rate	1	2.2		
	Stock Size/Status	1.1	2.4		
	Other Stressors	2.4	2.4		
	Sensitivity Score		Low		
Exposure Factors	Air Temperature	4	3		
	Hypoxia	3	2.8		
	Ocean Acidification	4	2		
	Precipitation	1	3		
	Primary Productivity	1.3	2		
	Salinity	2.2	3		
	Sea Level Rise	3	2.8		
	Sea Surface Temperature	1	0		
	Exposure Score		High		
Overall Vulnerability Rank		Low			

Overall Climate Vulnerability Rank: **Low.** (88% bootstrap results in Low, 12% bootstrap results in Moderate).

Climate Exposure: **High.** Air temperature (4.0, a proxy for estuarine temperatures), ocean acidification (4.0), and hypoxia (3.0) were the top three exposure factors contributing to brown shrimp's high climate exposure. Sea level rise (3.0) was also high, and primary productivity (1.3) and precipitation (1) were low.

Biological Sensitivity: **Low.** The sensitivity attributes that contributed to a low biological sensitivity score for Brown shrimp were population growth rate (1.0) stock size/status (1.1), prey specificity (1.3), and spawning cycle (1.5).

Distributional Vulnerability Rank: **High.** The top three attributes contributing to the high ranking for vulnerability to distribution shift are highly to very highly dispersive early life stages (1.7), highly mobile adults (1.9), and moderate habitat specificity (2.1).

Data Quality: 90% of the data quality scores were 2 or greater. (*Identify any interesting data gaps like attributes that have high sensitivity as well as low data quality*)

Climate Effects on Abundance and Distribution: Brown shrimp growth rates are especially sensitive to temperatures and could be impacted during their juvenile life stage in the form of slower growth at higher temperatures. Heat stress could lead to increased mortality because preferred habitat is relatively shallow. However, shrimp are mobile and could seek deeper water. Mortality rates are size dependent, so slower growth would indirectly result in increased mortality due to longer durations spent in small size classes. Habitat loss due to sea-level rise and marsh fragmentation would affect production of sub-adults from nurseries (Roth *et al.* 2008) Ocean Acidification effects are considered generally negative and include dissolution of calcified elements and reduced calcification rates (Taylor *et al.* 2015) causing indirect (diet items; molluscs and crustaceans) and direct (changes in shell transparency and exoskeleton function due to decreased pH).

Life History Synopsis: Brown shrimp are a commercially important penaeid shrimp found on the US Atlantic coast as far north as Massachusetts, throughout the Gulf and along the Atlantic coast of Mexico from Tamaulipas to Campeche. They are found at depths of 4-160 m, with highest densities at 27-54 m, on muddy, peat, sandy or clay bottoms. The time from spawning until harvest for this species is usually less than 1 year (Cook and Lindner 1970). Adult brown shrimp spawn offshore with peak activity at depths of 27 to 46 m from October to December and March to May (Christmas and Etzold 1977; Renfro and Brusher 1982). Fertilization is external via broadcast of semi-buoyant eggs. Eggs hatch within 14-18 hours (Cook and Lindner 1970), and after passing through several larval stages (Lassuy 1983), postlarvae move into estuaries settling as juveniles in inshore bays (Dall *et al.* 1990, Fry 2008). Young shrimp are found in highest densities associated with emergent marsh vegetation such as saltmarsh cordgrass and mangrove propagules, as well as submerged aquatic vegetation such as seagrass (Baxter and Renfro 1964, Cook and Lindner 1970). Juveniles grow rapidly to sub-adult size then migrate offshore to complete their growth and spawn (Temple and Fischer 1967). Brown Shrimp are omnivorous,

consuming diatoms, copepods, amphipods, tanaids, other shrimps, polychaetes, nematodes, chironomid larvae, and mysids (Perez-Farfante *et al.* 1969, McTigue and Zimmerman 1991, 1998). Brown Shrimp exhibit relatively high mobility, and adults are able to migrate to offshore grounds in relatively deep water. Brown Shrimp have been shown to exhibit avoidance of hypoxic areas in the Gulf of Mexico (Craig and Crowder 2005). Brown Shrimp become reproductively active after reaching a size of 140 mm (Renfro 1964).

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Butterfish - *Peprilus triacanthus*

Overall Vulnerability Rank = Low ■

Habitat Sensitivity = Low ■

Climate Exposure = High ■

Data Quality = 65% of scores ≥ 2

<i>Peprilus triacanthus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	1.4	2.6		Low Moderate High Very High
	Prey Specificity	1.4	2.8		
	Adult Mobility	1.5	2.4		
	Dispersal of Early Life Stages	1.7	1.9		
	Early Life History Survival and Settlement Requirements	2.1	1.2		
	Complexity in Reproductive Strategy	1.6	1.2		
	Spawning Cycle	1.6	2.2		
	Sensitivity to Temperature	1.8	2.2		
	Sensitivity to Ocean Acidification	2	2		
	Population Growth Rate	1.4	2.2		
	Stock Size/Status	2.3	1		
	Other Stressors	1.4	1.6		
	Sensitivity Score		Low		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	1.7	2		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.4	2		
	Salinity	2.3	3		
	Sea Level Rise	1.6	2.2		
	Sea Surface Temperature	4	3		
	Exposure Score		High		
Overall Vulnerability Rank		Low			

Overall Climate Vulnerability Rank: **Low.** (100% bootstrap results in Low).

Climate Exposure: **High.** Sea surface temperature (4.0), ocean acidification (4.0) were the main factors contributing to butterfish's high climate exposure. Salinity (2.3) was moderate to high. Hypoxia (1.7), sea level rise (1.6), and primary productivity (1.4) were all low to moderate.

Biological Sensitivity: **Low.** The sensitivity attributes that contributed to a low biological sensitivity score for butterfish were habitat specificity (1.4), prey specificity (1.4), population growth rate (1.4), other stressors (1.4), adult mobility (1.5) and complexity in reproductive strategy (1.6).

Distributional Vulnerability Rank: **High.** The top three attributes contributing to butterfish's high vulnerability to distribution shift ranking were low to moderate habitat specificity (1.4), very highly to highly mobile adults (1.5), and high to very highly dispersive early life stages (2.1). The species also has moderate to low sensitivity to temperature (1.8).

Data Quality: 65% of the data quality scores were 2 or greater. (*Identify any interesting data gaps like attributes that have high sensitivity as well as low data quality*)

Climate Effects on Abundance and Distribution: The majority of the research that has been performed on *P. triacanthus* has been brief, and no studies have directly examined climate change. Temperature appears to greatly impact the time and duration of *P. triacanthus* and *P. burti* spawning events, such that separate spawning events currently observed in the winter and fall may combine into low-level continuous spawning events (Murphy and Chittenden 1991). This change in spawning time and duration could impact recruitment to nearshore habitat and eventual adult populations. Much remains unknown about *P. triacanthus* and *P. burti* populations and how climate could impact the abundance and distribution of these species.

Life History Synopsis: Butterfish, *Peprilus triacanthus*, are small, short-lived, and rapid-growing pelagic fishes that range from the North Atlantic to the Gulf coast of Florida. However, the primary range of *P. triacanthus* extends from the Gulf of Maine to Cape Hatteras (Bigelow and Schroeder 1953, Haedrick 1967, Powell *et al.* 1972, Brodziak 1995). A similarly related species, *P. burti* (Gulf butterfish), is found throughout the entire Gulf of Mexico from the west coast of Florida to Yucatan, Mexico and up the northeastern seaboard where it likely mingles with *P. triacanthus* (Murphy and Chittenden 1991, Carpenter and DeAngelis 2002). Both species follow similar trends in biology, habitat preferences, and life history. Regardless of location, *Peprilus spp.* is easily identified by its oval shape and strongly compressed body form. The caudal fin is deeply forked and pectoral fins are long and pointed.

Loose schools of *P. triacanthus* migrate seasonally, moving inshore in the spring. During the summer *P. triacanthus* inhabit shallow bays and estuaries, moving south and offshore in response to cooler water temperatures in the fall (Fritz 1965, Schrieber 1973, Waring 1975). Generally, *P. triacanthus* can be found at depths up 155-225m during the day and move into the water column to feed at night (Carpenter and DeAngelis 2002). Adult *P. triacanthus* range between 150-230mm SL on average, with females being slightly larger than males (Klein-

MacPhee 2003). Butterfish achieve sexual maturity quickly, generally by the second summer (DuPaul and McEachran 1973), and individuals rarely live past the third summer (Carpenter and DeAngelis 2002).

Once sexually mature, *P. triacanthus* reproduce via broadcast spawning in the evening or night, but few direct observations currently exist (Ferraro 1980). It appears that water temperature is the major regulatory factor that controls the timing of mass-spawning events, with more northerly populations spawning later in the year (Able and Fahay 1998). Released eggs are buoyant and incubate for roughly 48 hours (Elliot and Jimenez 1981), with 50% of eggs hatching within 72 hours (Martin and Drewry 1978). Larval *P. triacanthus* range from 2.6 to 16mm SL and may perform diel vertical migrations (Kendall and Naplin 1981). Juveniles range between 16mm-120mm SL and grow to about half their adult size within the first year. Juvenile *P. triacanthus* are often found in association with large jellyfish that provide protection from predators and act as a reliable food source (Mansueti 1963). Once larger than 120mm, *P. triacanthus* are considered to be adults. The primary diet of adult *P. triacanthus* consists of planktonic prey including mollusks, crustaceans, polychaetes, small fish, and ctenophores (Fritz 1965, Schreiber 1973). Due to their relatively small size, *P. triacanthus* are preyed upon by several species including haddock, hake, weakfish, swordfish, and longish inshore squid (Bigelow and Schroeder 1953, Brodziak 1995). *Peprilus spp.* are highly esteemed in otter trawl markets, but often viewed as by-catch in shrimp fisheries in the northern Gulf.

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Cobia - *Rachycentron canadum*

Overall Vulnerability Rank = Low ■

Habitat Sensitivity = Low ■

Climate Exposure = High ■

Data Quality = 80% of scores ≥ 2

<i>Rachycentron canadum</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	1.6	2.6		Low Moderate High Very High
	Prey Specificity	1.9	2.4		
	Adult Mobility	1.6	2.6		
	Dispersal of Early Life Stages	2.1	2		
	Early Life History Survival and Settlement Requirements	2	1.8		
	Complexity in Reproductive Strategy	2	2.2		
	Spawning Cycle	1.7	2.6		
	Sensitivity to Temperature	1.8	2.4		
	Sensitivity to Ocean Acidification	1.8	2.2		
	Population Growth Rate	1.9	2.2		
	Stock Size/Status	1.8	2.4		
	Other Stressors	1.8	1.8		
	Sensitivity Score		Low		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	1.7	2.4		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.8	2		
	Salinity	3.5	3		
	Sea Level Rise	1.8	2.6		
	Sea Surface Temperature	4	3		
	Exposure Score		High		
Overall Vulnerability Rank		Low			

Overall Climate Vulnerability Rank: **Low.** (53% bootstrap results in Low, 47% bootstrap results in Moderate).

Climate Exposure: **High.** Sea surface temperature (4.0), ocean acidification (4.0), and salinity (3.5) contributed to the high climate exposure score for cobia. Hypoxia (1.7), primary productivity (1.8), and sea level rise (1.8) were all ranked low to moderate.

Cobia is a large migratory, coastal-pelagic species that uses coastal, nearshore as well pelagic habitats along the continental shelf during all life stages. It makes seasonal North - South coastal migrations, i.e., to overwinter in South Florida between about late October - March and returns back to the Northeast Gulf by the Spring (Franks *et al.* 1999). Some fish appear to be overwintering in the Northeastern Gulf at 100-125m water depths (Howse *et al.* 1992).

Although most eggs and larvae of cobia have been found offshore (Shaffer and Nokamura 1989 and references therein), there is recent evidence that cobia aggregations also occur inshore. Based on collected cobia eggs and larvae, spawning appears to be taking place in sounds and estuarine areas of South Carolina (Darden *et al.* 2014, Perkinson and Denson 2012) suggesting that similar aggregations and nearshore spawning may also exist for the Gulf of Mexico Stock.

Biological Sensitivity: **Low.** The sensitivity attributes that contributed to a low biological sensitivity score for cobia were habitat specificity (1.6), adult mobility (1.6), spawning cycle (1.7), and other stressors (1.8). Eleven out of twelve (91.6%) sensitivity attributes scored 2.0 or below. The only score above two was for dispersal of early life stages (2.1). Cobia are a very fast growing large fish with relatively low population growth rates (Franks *et al.* 1999). Adults do move onshore and offshore seasonally particularly in the northeastern part of the Gulf of Mexico during the spring and summer months.

Distributional Vulnerability Rank: **High.** The top three attributes contributing to cobia's high vulnerability to distribution shift include low to moderate sensitivity to temperature (1.8), high to very high adult mobility (1.6), and low to moderate habitat specialization (1.6). Cobia also have very highly dispersive early life history stages (2.1). Cobia can be considered habitat generalists that can be highly mobile (cobia from an aquaculture facility in Ecuador and were spotted three months later in Panama, 600 miles north of the origin of escape.).

Data Quality: 80% of the data quality scores were 2 or greater. Data quality scores were 2.0, 2.6, and 2.6 for dispersion of early life history stages, to habit specificity and adult mobility, respectively.

Climate Effects on Abundance and Distribution: No studies so far appear to have examined the effect of climate factors on the population productivity cobia. Due to cobia's predictable, seasonal migratory and distribution patterns following seasonal temperature changes, it is highly likely that warmer water temperature may lead to changes in its migrations such as changes in the timing, as well as the spatial extent of their seasonal, coastal migration patterns.

Life History Synopsis: Cobia, *Rachycentron canadum* is a monotypic species in the Family

Rachycentridae. It is a large migratory coastal pelagic species with a circum-tropical distribution, except for the Eastern Pacific (Shaffer and Nakamura 1989). Females are considerably larger than male and more abundant with a sex ratio of 1: 2.5-2.7 males to females (Franks *et al.* 1999).

In Gulf of Mexico, it is most common in the northern parts (Shaffer and Nakamura 1989) and ranges from South Florida all along the entire Gulf of Mexico coast to Campeche, Mexico (Dawson 1971). Franks *et al.* (1999) reported from tagging studies that the range of the Gulf of Mexico stock in the winter months is to up to Cape Canaveral on the Florida East coast. This finding has also been corroborated by genetic studies (Darden *et al.* 2014) and has led to a new stock management boundary for cobia between the Gulf of Mexico and South Atlantic Fisheries Management Councils now placed at the FL- GA state line.

Cobia utilize nearshore ocean waters and coastal estuaries and large sounds from about April to July, by August they tend to move farther offshore. Cobia exhibit a curious hovering behavior around fixed or moving objects such as large sharks, rays, sea turtles, buoys, flotsam, rafts of *Sargassum* and oil rigs (in the Gulf of Mexico). Cobia has also the habit or ability to just sit on its belly and/or pelvic fins on the bottom of tanks in captivity, especially after being fed (Benetti *et al.* 2007). This behavior has been confirmed by divers (Orhun pers. communication).

Diet and prey found in stomach contents of juvenile cobia in the Gulf of Mexico appear to be dominated by fish (60%) and then crustaceans followed by cephalopods (Franks *et al.* 1996). Adults consume a wide variety of teleost fishes, portunid crabs, shrimps, cephalopods, and even juvenile elasmobranchs although the study was from North Carolina (Meyer and Franks). Adult cobia are highly migratory; they tend to migrate south to Florida or the Florida Keys in winter while some may overwinter on the outer portions of the continental shelf (Shaffer and Nakamura 1989, Howse 1992, Herndon *et al.* 2008). In spring they tend to redistribute in inshore and estuarine waters. Migrations and spawning cues may be temperature related. Cobia spawn in coastal waters near inlets; cobia form aggregations and spawn during daylight usually from June through August. Eggs and larvae which are pelagic have been collected in estuaries suggesting that cobia use these areas as nurseries (Lefebvre and Denson 2012). It is reasonable to assume that early life history stages of cobia are vulnerable to estuarine disruption and degradation.

The distribution of cobia is greatly affected by temperature. Generally, cobia occur in the cooler portion of their range only during the warm months of the year. Cobia either migrate to warmer waters, or move offshore to deeper waters during the colder months (see 3.51). They have been collected from waters of 16.8-32.0°C (Table 1). Hassler and Rainville (1975) reported 37.7 °C to be lethal to juveniles. The juveniles tolerated temperatures down to 17.7°C, although they ceased feeding entirely at 18.3°C.

Cobia are fast growers and females, up to 70%, reach sexual maturity at age 2; maximum age is about age 15 (SEDAR 2013). A recent assessment of the stock indicated that the stock is not overfished ($SSB_{2017}/MSST = 1.88$), and that overfishing is not occurring ($F_{2015-2017}/F_{40\%} = 0.29$) (SEDAR 58 2020).

On a side note, in 2015, it was reported that probably thousands of cobia from a net-pen aquaculture farm in Ecuador had escaped (Cohen 2016, Castellanos-Galindo *et al.* 2016). They reported also that the fish were moving at a rate of 200 miles per month and were sighted in Panama already 600 miles from the site of escape. In 2017, two years after the initial escape, it was reported that two mature fish 9-11kg cobia in weight had caught and had mature ovaries (Castellanos-Galindo *et al.* 2018). From this finding it was concluded that cobia were able to integrate themselves into the food web of the tropical eastern Pacific and were now capable to reproduce where they prior it had no distribution. This also demonstrates the resilience of cobia to adapt to new environments that are within its temperature range.

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Dolphin - *Coryphaena hippurus*

Overall Vulnerability Rank = Moderate ■

Habitat Sensitivity = Low ■

Climate Exposure = Very High ■

Data Quality = 75% of scores ≥ 2

<i>Coryphaena hippurus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	1.3	3		Low Moderate High Very High
	Prey Specificity	1.3	2.8		
	Adult Mobility	1.2	3		
	Dispersal of Early Life Stages	1.7	2.6		
	Early Life History Survival and Settlement Requirements	1.6	2.8		
	Complexity in Reproductive Strategy	1.5	2.8		
	Spawning Cycle	1.5	3		
	Sensitivity to Temperature	1.6	2.6		
	Sensitivity to Ocean Acidification	1.4	2		
	Population Growth Rate	1.5	2.4		
	Stock Size/Status	1.4	1.6		
	Other Stressors	1.5	1.8		
	Sensitivity Score		Low		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	1.3	2		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.6	2		
	Salinity	3.7	3		
	Sea Level Rise	1	0		
	Sea Surface Temperature	4	3		
	Exposure Score		Very High		
Overall Vulnerability Rank		Moderate			

Overall Climate Vulnerability Rank: **Moderate.** (92% bootstrap results in Moderate, 8% bootstrap results in Low).

Climate Exposure: **Very High.** Sea surface temperature (4.0), ocean acidification (4.0), and salinity (3.7) were the main exposure factors contributing to a very high climate exposure score for dolphin. Hypoxia (1.3) and primary productivity (1.6) were low to moderate. Dolphin are an open ocean species that occurs up to depths of 85m (Collette 2011). They are thought to reproduce year round in temperatures greater than 21°C, spawning when temperatures rise (Collette *et al.* 2011, Gibbs and Collette 1959, Beardsley 1967). Since dolphin prefer warmer temperatures, an expansion of range can be expected with warming ocean temperatures (Salvadeo *et al.* 2020). Similarly, dolphin prefer salinity around 35 psu (Salvadeo *et al.* 2020) so shifts in mean salinity can also drive an alteration in species range. Ocean acidification may negatively affect larval metabolism and swimming behavior which can slow growth and lead to greater rates of mortality in the population (Pimentel *et al.* 2014).

Biological Sensitivity: **Low.** All sensitivity attributes contributed to a low biological sensitivity score for dolphin. The highest attribute mean was for dispersal of early life stages (1.7). Dolphin utilize a wide range of habitat and prey species, often in association with floating Sargassum mats (Matooch 1984). This species is highly mobile with pelagic eggs and larvae (Oxenford 1999), and coupled with a high growth rate and year-round spawning (Collette *et al.* 2011), the dolphin population is not biologically sensitive.

Distributional Vulnerability Rank: **High.** The top three attributes contributing to dolphin's high vulnerability to distribution shifts include: very highly to highly mobile adults (1.2), low to moderate habitat specificity (1.3), and low to moderate sensitivity to temperatures (1.6). Dolphin are highly mobile, opportunistic predators that prefer warmer waters and utilize the open ocean for all life stages (Manooch 1984).

Data Quality: 75% of the data quality scores were 2 or greater. There are data gaps in the effects of air temperature, precipitation, and sea level rise as exposure factors, but these factors are not expected to be impactful to dolphin in open ocean environments.

Climate Effects on Abundance and Distribution: Some studies have looked closely at the effects of climate change on dolphin populations. The species is highly adaptable with many versatile prey species and high mobility, but ocean acidification may pose a threat to an otherwise stable population status. In a laboratory setting, Pimentel *et al.* (2014) found that early larval stages were very sensitive to ocean acidification and even short term exposure to more acidic conditions affected oxygen consumption rates and decreased metabolism in individuals. Conversely, Bignami *et al.* (2014) did not find adverse effects due to more acidic conditions so the sensitivity of the species to ocean acidification needs further study. A poleward shift in distribution is expected as temperatures rise and a preferred temperature range of 24-28°C shifts or expands into northern latitudes (Salvadeo *et al.* 2020).

Life History Synopsis: Dolphinfinch are widespread, pelagic, fast-growing, short-lived, and opportunistic predators that prefer warmer temperatures (Manooch 1984, Oxenford 1999). They are found in schools in open and near coastal waters of the Atlantic, Gulf of Mexico, Caribbean, Indian, and Pacific Oceans. Dolphinfinch are highly associated with Sargassum mats (Manooch 1984, Collette *et al.* 2011). They prefer temperature ranges from 21-30°C and depths up to 85m. Prey species range from fishes, zooplankton, crustaceans, and squid but dolphinfinch will focus on mobile prey such as flying fish and mackerels when necessary (Massuti *et al.* 1963, Manooch 1984, Manooch *et al.* 1984, Oxenford 1999, Oxenford and Hunte 1999, Collette *et al.* 2011). Age of sexual maturity ranges from 3-4 months in the Gulf of Mexico, 6-7 months in the N.E. Atlantic, and 4 month in the Caribbean with an overall average growth rate of 2-3mm per day (Gibbs and Collette 1959, Perez and Sadovy 1991, Oxenford 1999, Ditty 2005, Lessa *et al.* 2008, Schwenke and Buckel 2008). Dolphinfinch batch spawn two to three times per spawning period (Gibbs and Collette 1959) which occurs year-round in open ocean at water temperatures greater than 21°C (Collette *et al.* 2011). Eggs are pelagic and larvae remain pelagic for over 8 weeks, feeding on copepods, invertebrate eggs and fish (Kloebe *et al.* 2017). Maximum age is estimated at 4 years but lifespan usually lasts less than 2 years for dolphinfinch (Oxenford and Hunte 1983, Oxenford 1999, Lessa *et al.* 2008, Collette *et al.* 2011). Stock assessments have shown evidence of multiple populations but genetic connectivity between the Atlantic, Gulf of Mexico, and Caribbean migratory groups leads to uncertainty in the actual stock structure (Wingrove 2000, Diaz-James *et al.* 2019). Additionally, stock assessments indicate the population is not overfished but limited and outdated data leaves this designation highly uncertain (Prager 2000). No literature has shown any dependence on nearshore habitats for recruitment or food sources, so the species remains largely unaffected by land based human activities.

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Dusky shark - *Carcharhinus obscurus*

Overall Vulnerability Rank = High ■

Habitat Sensitivity = High ■

Climate Exposure = High ■

Data Quality = 75% of scores ≥ 2

<i>Carcharhinus obscurus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	1.9	2.4		Low Moderate High Very High
	Prey Specificity	1.3	2.6		
	Adult Mobility	1.1	2.8		
	Dispersal of Early Life Stages	1.2	2.8		
	Early Life History Survival and Settlement Requirements	1	2.4		
	Complexity in Reproductive Strategy	1.7	1.8		
	Spawning Cycle	2.2	2.6		
	Sensitivity to Temperature	1.2	2.6		
	Sensitivity to Ocean Acidification	1.4	2.4		
	Population Growth Rate	3.7	2.2		
	Stock Size/Status	3.4	2.4		
	Other Stressors	1.8	1.6		
	Sensitivity Score	High			
Exposure Factors	Air Temperature	1	0		
	Hypoxia	1.4	2.2		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.6	2		
	Salinity	3.3	3		
	Sea Level Rise	1	0		
	Sea Surface Temperature	4	3		
	Exposure Score	High			
Overall Vulnerability Rank		High			

Overall Climate Vulnerability Rank: **High.** (84% bootstrap results in High, 16% bootstrap results in Very High).

Climate Exposure: **High.** Sea surface temperature (4.0), ocean acidification (4.0), and salinity (3.3) contributed to dusky shark's high climate exposure ranking. Primary productivity (1.6) and hypoxia (1.4) were ranked low to moderate.

Biological Sensitivity: **High.** Two sensitivity attributes primarily contributed to a high biological sensitivity score for dusky shark. These were population growth rate (3.7) and stock size/status (3.4). Spawning cycle (2.2), sensitivity to ocean acidification (1.4), and other stressors (1.8) all had scores ranging from low to very high.

Distributional Vulnerability Rank: **High.** Very highly mobile adults (1.1), very highly dispersive early life stages (1.2), and low sensitivity to temperature or a distribution across a wide latitudinal range (1.2) contribute to dusky shark's high vulnerability to distribution shift..

Data Quality: 75% of the data quality scores were 2 or greater. (*Identify any interesting data gaps like attributes that have high sensitivity as well as low data quality*)

Climate Effects on Abundance and Distribution: The effect of climate change on dusky shark is sparsely studied. Dusky shark featured in two climate vulnerability analyses: one for the Australian Great Barrier

Reef (Chin *et al.* 2010) and one for the North East United States Continental Shelf (Hare *et al.* 2016). In Chin *et al.* (2010), overall vulnerability to climate change and sensitivity to all examined climate exposure factors were scored as low. Climate exposure, biological sensitivity, and overall climate vulnerability were all scored as high for dusky shark in the Hare *et al.* (2016) work, owing to high sensitivities in population status, population growth rate, sea surface temperature, and ocean acidification. The difference between the two studies may partially arise from the depleted population status of northwestern Atlantic dusky shark.

Telemetry along the east coast of the United States found that juvenile dusky shark were associated with 16°C to 26°C waters and Chl-*a* distributions between approximately 2 and 7 mg/m³. These preferences were reflected in the seasonal migration patterns of dusky shark along the east coast of the United States (Bangley *et al.* 2020). Telemetry from adults tagged in the northern Gulf of Mexico indicated that they spent 83% of their time in 23 to 30 °C waters and 87% of their time between 20 and 125 m water depth (Hoffmayer *et al.* 2014). These individuals also undertook large-scale movements, on the order of 200 km, and tended to occupy shelf edge habitat. Given these observations, changes in temperature and Chl-*a* distributions could potentially disrupt habitat occupancy and/or movement patterns, but the species is highly migratory with a broad diet and these attributes could offset any issues associated with changes in temperature or primary productivity.

Life History Synopsis: Dusky shark (*Caracharinus obscurus*) is a large, highly migratory, coastal-pelagic shark with a worldwide tropical to warm temperate distribution (Castro 1993, McCandless *et al.* 2014). In the northwestern Atlantic, a single, heavily overfished stock occurs

across from New England to the Caribbean and Gulf of Mexico (Compagno 1984, Musick and Colvocoresses 1986, Heist and Gold 1999, Cortés *et al.* 2006, Benavides *et al.* 2011).

Dusky shark generally does not use low salinity waters, however, juveniles use estuarine areas as nursery habitat along the United States east coast from New Jersey to South Carolina (Castro 1993, McCandless *et al.* 2007, McCandless *et al.* 2014). Dusky shark occur from the surf zone to about 400 m depth (Compagno 1984, McCandless *et al.* 2014).

Although diets have not been fully described, dusky shark appears to prey on a diverse group of species and their diets and foraging areas shift ontogenetically. Generally, dusky shark consumes teleost fishes, cephalopods, other elasmobranchs, decapod crustaceans, mollusks, and marine mammals (Cortés 1999). However, juveniles tend to consume more teleosts and adults consume more elasmobranchs (Gelsleichter *et al.* 1999, Simpfendorfer *et al.* 2001). Foraging areas also seem to shift from inshore to shelf break regions as they grow (Beerkircher *et al.* 2002, Hussey *et al.* 2011, Hoffmayer *et al.* 2014).

Dusky sharks have slow population growth rates, this and fishing contributes to their depleted population status. They possess late age at maturity (17.6 years for females), long life spans (maximum age is 42 years), low fecundity (3-14 offspring per litter and a three year reproductive cycle), and a generation time of 29.6 years (Natanson *et al.* 1995, Cortez *et al.* 2006, Castro 2009, Romine *et al.* 2009, ICCAT 2012, Natanson *et al.* 2013).

Landings of dusky shark have been prohibited in United States waters since 2000 (Romine *et al.* 2009, SEDAR 2011) owing to its depleted status. A 2014 status review under the Endangered Species Act assessed whether dusky shark in the northwestern Atlantic warranted listing the stock as threatened or endangered (McCandless *et al.* 2014). That review found that, while dusky shark in the northwestern Atlantic were vulnerable due to low productivity, the population was not declining and, as such, faced a relatively low risk of extinction in the near future (McCandless *et al.* 2014).

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Eastern oyster - *Crassostrea virginica*

Overall Vulnerability Rank = High 

Habitat Sensitivity = High 

Climate Exposure = High 

Data Quality = 85% of scores ≥ 2

<i>Crassostrea virginica</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)		
Sensitivity Attributes	Habitat Specificity	3	2.6		Low Moderate High Very High	
	Prey Specificity	1.1	2.6			
	Adult Mobility	4	3			
	Dispersal of Early Life Stages	2.1	2.6			
	Early Life History Survival and Settlement Requirements	2.9	2.6			
	Complexity in Reproductive Strategy	2.2	2.6			
	Spawning Cycle	1.9	2.6			
	Sensitivity to Temperature	1.7	2.4			
	Sensitivity to Ocean Acidification	3.7	2.6			
	Population Growth Rate	1.6	1.8			
	Stock Size/Status	1.9	1.4			
	Other Stressors	3.3	2.4			
	Sensitivity Score		High			
	Exposure Factors	Air Temperature	4	3		
Hypoxia		3.2	2.8			
Ocean Acidification		4	2			
Precipitation		1	3			
Primary Productivity		1.4	2			
Salinity		2.3	3			
Sea Level Rise		3.1	3			
Sea Surface Temperature		1	0			
Exposure Score		High				
Overall Vulnerability Rank		High				

Overall Climate Vulnerability Rank: **High.** (92% bootstrap results in High, 8% bootstrap results in Very High).

Climate Exposure: **High.** Air temperature (4.0), ocean acidification (4.0), hypoxia (3.2), and sea level rise (3.1) contributed to eastern oyster's high climate exposure. Salinity (2.3), primary productivity (1.4), and precipitation (1.0) ranged from low to moderate. The intertidal zone is a common place that eastern oysters settle where they can be exposed to changing air temperatures. They also occupy lagoons and estuaries, which are prone to point and non-point inputs from human activities that can lead to eutrophication and hypoxic conditions (Burrell 1997, MacKenzie 1997a, EOBRT 2007). Hypoxic periods, even short ones, can be stressful or lethal, especially for spat or seed (Berrigan 1988, Dugas *et al.* 1997, Perret *et al.* 1999, EOBRT 2007). Eastern oysters shell is made up of calcium carbonate which may be affected by ocean acidification. Sea level rise may affect adult eastern oysters since they are sessile.

Biological Sensitivity: **High.** The sensitivity attribute contributed to a high biological sensitivity score for Eastern oyster where adult mobility (4.0), sensitivity to ocean acidification (3.7), other stressors (3.3), habitat specificity (3.0), and early life history survival and settlement requirements (2.9). Eastern oysters are sessile as adults, occupying lagoons and estuaries from 0.6-5m depth. They attach to various substrates, including mud, in intertidal areas where salinity is normally between 5-40ppt and water temperatures are between 20-30°C (Burrell 1997, MacKenzie 1997a, EOBRT 2007). Outside of these ranges, growth and feeding rate slows (Barnes 2007). Ocean acidification may lead to slower and weaker shell development in eastern oysters. Other biological stressors include eutrophication and increased potential for red/brown tides that may affect oyster survival at all life stages. Pollution also critically affects larvae and later life stage health (Loosanoff 1964, Galtsoff 1964).

Distributional Vulnerability Rank: **Low.** Sessile adults (4.0) and high habitat specificity (3.0) make eastern oyster less vulnerable to distributional shifts. Free-swimming larvae have the potential to move to better locations before settling and becoming sessile (EOBRT, 2007) and contribute to a highly dispersive early life stage ranking (2.1). The species is insensitive to moderately sensitive to temperature and occurs across a wide latitudinal range (1.7).

Data Quality: 85% of the data quality scores were 2 or greater. Effects of increased sea surface temperature as an exposure factor is the only major data gap for this species.

Climate Effects on Abundance and Distribution: Eastern oysters are being affected by climate induced ocean acidification that is exacerbated further by eutrophication in coastal habitats and estuaries that they inhabit (Ekstrom *et al.* 2015). Due to their broad geographic range, studies have shown that Eastern oysters possess the physiological plasticity to tolerate a wide range of temperature and salinity, meaning populations in historically northern ranges have the ability to withstand climate change induced shifts (Casas *et al.* 2018).

Life History Synopsis: The eastern oyster is a sessile, long-lived, fast maturing species that occupies coastal estuaries and lagoons from the mid-Atlantic states to the Gulf of Mexico (Burrell 1997, MacKenzie 1997a, EOBRT 2007). Eastern oysters are broadcast spawning reproducers who have the ability to change sex on an annual basis depending on the sex of

surrounding oysters or because of environmental, nutritional or physiological stressors (Menzel 1951, Davis and Hillman 1971, Ford *et al.* 1990). Oysters can reach sexual maturity 4-12 weeks after settlement and each female can produce between 75-100 million eggs (EORBT, 2007) when water temperature, salinity, and other physiochemical interactions cue spawning (Loosanoff 1953, Galtsoff 1964, Hayes and Menzel 1981, Hofstetter 1977, 1983). Spawning typically occurs in summer months in the northern Atlantic and during all but the colder months in the Gulf of Mexico, or whenever water temperatures reach greater than 20°C and salinity exceeds 10 ppt (Breuer 1962, Berrigan *et al.* 1991, EOBRT 2007). Larvae remain in a planktonic stage for two to three weeks after hatching, moving by both passive and active transport (Hopkins 1931, Kennedy 1996, EOBRT 2007). Larvae rely on a balance of hydrographic conditions that allow them to remain near existing reefs but with enough exchange to maintain a good food supply. They also need relatively calm water in order to accomplish settlement onto a suitable substrate (Kennedy 1996, EOBRT 2007). Eastern oyster larvae are predated upon by planktivores prior to settlement (Galtsoff 1964). Eastern oysters are filter feeders, relying on food laden water to move past them in order to extract plankton and suspended detritus (Langdon and Newell 1996). Their proximity to the coast makes them vulnerable to point and nonpoint source runoff and eutrophication from human activities (Berrigan 1988). Hypoxia/anoxia, red and brown tides, coastal development, and parasites can kill or severely inhibit survival of eastern oysters (Galtsoff 1964, Berrigan 1988). Climate change is also expected to increase competition for resources from competing species such as the hooked mussel and increase exposure to predators like the veined rapa whelk (MacKenzie 1981, White and Wilson 1996, Mann and Hardy 2003).

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Gag grouper - *Mycteroperca microlepis*

Overall Vulnerability Rank = High ■

Habitat Sensitivity = High ■

Climate Exposure = High ■

Data Quality = 85% of scores ≥ 2

<i>Mycteroperca microlepis</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	2.8	3		Low Moderate High Very High
	Prey Specificity	1.8	2.6		
	Adult Mobility	2.6	3		
	Dispersal of Early Life Stages	2.1	2.2		
	Early Life History Survival and Settlement Requirements	2.6	2		
	Complexity in Reproductive Strategy	3	3		
	Spawning Cycle	2.9	3		
	Sensitivity to Temperature	2	2.8		
	Sensitivity to Ocean Acidification	2	2		
	Population Growth Rate	3.2	3		
	Stock Size/Status	2.8	2.6		
	Other Stressors	2.3	2		
	Sensitivity Score		High		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	2.2	1.6		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.6	2		
	Salinity	2.9	3		
	Sea Level Rise	2.4	2.4		
	Sea Surface Temperature	4	3		
	Exposure Score		High		
Overall Vulnerability Rank		High			

Overall Climate Vulnerability Rank: **High.** (81% bootstrap results in High, 19% bootstrap results in Moderate).

Climate Exposure: **High.** Sea surface temperature (4.0), ocean acidification (4.0), salinity (2.9), sea level rise (2.4), and hypoxia (2.2) contributed to gag grouper's high climate exposure. Primary productivity (1.6) was ranked moderate to low.

Biological Sensitivity: **High.** The sensitivity attributes that contributed to a high biological sensitivity score for gag grouper were spawning cycle (2.9), stock size/status in parentheses 2.8), population growth rate (3.2), habitat specificity (2.8), and early life history survival and settlement requirements (2.6).

Distributional Vulnerability Rank: **Low.** Three attributes indicated low vulnerability to distribution shift for gag grouper: high habitat specificity (2.8), limited adult mobility (2.6), and moderate early life stage dispersal (2.1).

Data Quality: 85% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution: Few studies examined the effect of climate factors on the population productivity and distribution of gag grouper. Rising water temperatures are likely to alter the patterns of circulation that gag rely on for larval dispersal (Weisberg *et al.* 2014, Jue 2015) and spawning (Todd 2013), but it is unclear how those changes will impact abundance and distribution of gag grouper in the Gulf of Mexico. Gag may also experience effects of increased ocean acidification due to their diets of crustaceans, both as juveniles and, to a lesser extent, adults (Ross and Moser 1995).

Life History Synopsis: Gag have a disjunct distribution in the western Atlantic from North Carolina south along the U.S., rarely in Bermuda, throughout the Gulf of Mexico except Cuba, and in southern Brazil from the State of Rio de Janeiro to Santa Catarina (Robertson and Van Tassell 2015). It is not found in the Bahamas or most of the Caribbean.

Juveniles occur in estuaries and seagrass beds (Ross and Moser 1995, Koenig and Coleman 1996). In areas where seagrass is absent (e.g., South Carolina) high-salinity oyster reefs and other shallow estuarine structures provide juvenile habitat (Mullaney and Gale 1996). As they mature, gag undergo multiple ontogenetic habitat shifts (McGovern *et al.* 1998). Gag are a reef-associated species usually found offshore on rocky bottom (rarely to 152 m), and occasionally inshore on rocky or grassy bottom. Adult gag prefer habitats characterized by maximum structural complexity, such as living *Oculina* coral reefs, at depths between 70 and 100 m (McGovern *et al.* 1998). *Mycteroperca microlepis* is the most common grouper on rocky ledges.

Juveniles (less than 20 cm) feed mainly on crustaceans that live in shallow grass beds. The principal prey items of estuarine gag included calanoid copepods, mysids, gammaridean amphipods, grass shrimp, penaeid shrimp, and fishes (Mullaney 1993). Adult gag feed on fishes, crabs, shrimps, and cephalopods.

According to tagging studies, this species is capable of conducting movements of hundreds of kilometres (e.g., from South Carolina to the northeast Gulf of Mexico; Van Sant *et al.* 1990, Collins *et al.* 1996, Heinisch and Fable 1999, McGovern *et al.* 2005, Lindberg *et al.* 2006).

Gag spawn exclusively on shelf-edge reefs, preferably on rocky ridges next to drop-offs (Koenig *et al.* 1996, Koenig and Coleman 2011). Previously unexploited spawning aggregations of *Mycteroperca microlepis* and *M. phenax* comprised of hundreds of individuals were observed in 1980 by Gilmore and Jones (1992) during manned submersible dives in the Oculina Banks off Ft. Pierce, Florida. Males remain near spawning sites in deep water year-round (Collins *et al.* 1987, McGovern *et al.* 1998, Koenig and Coleman 2011). In December and January, females form pre-spawning aggregations in shallower areas prior to migrating to deeper water (Koenig and Coleman 2011), where they form multiple small spawning aggregations (20-50 individuals) in February through mid-April on the shelf edge (50-120 m) in the southeastern U.S. (McGovern *et al.* 1998, Koenig and Coleman 2011).

This species is a protogynous hermaphrodite and a multiple (batch) spawner with indeterminate fecundity (McErlean and Smith 1964, Collins *et al.* 1997, Trejo-Martínez *et al.* 2006). Females reach maturity between 3-6 years of age around fork lengths of 70.5-72.1 cm (Hood and Schlieder 1992, Heemstra and Randall 1993, Brulé *et al.* 2003). Sex transition occurs between 75-111 cm total length at 5-9 years of age (Collins *et al.* 1997, Brulé *et al.* 2003). Though the exact mechanism for sex change remains unclear, Lowerre-Barbieri *et al.* (2020) documented transitional males in both spawning grounds and pre-spawning female-only aggregation, indicating that male social cues are not required for sex change. The dramatic decline in the proportion of males in spawning aggregations is of concern regarding sperm limitation, disruption of sex change processes and inbreeding (Coleman *et al.* 1996, Chapman *et al.* 1999, Koenig *et al.* 2000, Koenig and Coleman 2011). A recent 3-year study by Lowerre-Barbieri *et al.* (2020) found the sex ratio in a Gulf of Mexico Marine Protected Area (MPA) to be just 5%, instead of the expected 15%. It was 0% outside of the MPA.

After a planktonic larval duration of between 40-60 days during which fish are transported from offshore spawning areas (typically 35 to 100 miles offshore) to estuaries, larval gag settle as juveniles in seagrass habitat or other suitable shallow water habitat (Coleman and Koenig Lab).

Gag exhibit a preferred temperature range of 18-27 degrees C, mean 23 degrees C (fishbase.org). The species utilizes various depths within the water column, from shallow estuarine areas as juveniles to mid-to-deep reefs (to 167 m) as adults.

The most recent assessment (Anon 2016) indicates the stock is not overfished and not experiencing overfishing in the Gulf of Mexico. Chapman *et al.* (1999) commented the size-limited population of *M. microlepis* suffered from restricted gene flow among genetically differentiated population, reflecting the offsprings would be more likely to be genetically related due to inbreeding. In contrast, a recent study found support for the fact that gag populations throughout the Gulf of Mexico are connected via present day larval dispersal, with genetic movement from Campeche Bank to the West Florida Shelf (Jue 2015).

Other potential stressors for gag include possible anthropogenic degradation of inshore estuarine habitat, temperate reef degradation (e.g., destruction of *Oculina* reefs by fishing gear), potential lionfish predation and red tide events.

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Golden tilefish - *Lopholatilus chamaeleonticeps*

Overall Vulnerability Rank = Moderate ■

Habitat Sensitivity = Moderate ■

Climate Exposure = High ■

Data Quality = 80% of scores ≥ 2

<i>Lopholatilus chamaeleonticeps</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	1.9	2.8		Low Moderate High Very High
	Prey Specificity	1.8	2.8		
	Adult Mobility	2.7	2.2		
	Dispersal of Early Life Stages	2	2.2		
	Early Life History Survival and Settlement Requirements	2.2	1.4		
	Complexity in Reproductive Strategy	2.6	2.4		
	Spawning Cycle	2.2	2.4		
	Sensitivity to Temperature	2.6	2.8		
	Sensitivity to Ocean Acidification	2	2		
	Population Growth Rate	3	3		
	Stock Size/Status	2.5	2.6		
	Other Stressors	2	2.4		
	Sensitivity Score		Moderate		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	1.8	2.2		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.5	2		
	Salinity	2.9	3		
	Sea Level Rise	1	0		
	Sea Surface Temperature	4	3		
	Exposure Score		High		
Overall Vulnerability Rank		Moderate			

Overall Climate Vulnerability Rank: **Moderate.** (69% bootstrap results in Moderate, 4% bootstrap results in High).

Climate Exposure: **High.** Sea surface temperature (4.0), ocean acidification (4.0), and salinity (2.9) contributed to a high climate exposure for golden tilefish.

Biological Sensitivity: **Moderate.** The sensitivity attributes that contributed to a moderate biological sensitivity score for Golden tilefish were dispersal of early life stages (2.0), spawning cycle (2.2), prey specificity (1.8), and sensitivity to ocean acidification (2.0).

Distributional Vulnerability Rank: **High.** The top three attributes contributing to the high vulnerability to distribution shift ranking included: high habitat specificity (3.0), high to moderate adult mobility (2.6), and highly dispersive early life stages (2.1). The species is also moderately sensitive to temperature (2.0).

Data Quality: 80% of the data quality scores were 2 or greater. (*Identify any interesting data gaps like attributes that have high sensitivity as well as low data quality*)

Climate Effects on Abundance and Distribution: The impacts on climatic change can be detrimental to tilefish populations (Fisher *et al.* 2014). Tilefish reside in a very specific habitat preferring a soft, but malleable sediment along the continental shelf in water depths 80-400 m, inhabit burrows, and live within a specific thermal cline (9-18°C) (Nelson and Carpenter 1968, Freeman and Turner 1977, Able *et al.* 1982, Grimes *et al.* 1986, Walter *et al.* 2011, Murawski *et al.* 2018). In 1882, a mass mortality event of tilefish occurred along the Mid-Atlantic Bight and southern New England region and was most likely caused by cold water upwelling into the tilefish habitat (Collins 1884, Marsh *et al.* 1999). Trends in water temperature and circulation patterns can be directly correlated to tilefish commercial landings, during more favorable conditions tilefish showed increase in recruitment and survival (Fisher *et al.* 2014).

Life History Synopsis: Tilefish (*Lopholatilus chamaeleonticeps* Goode and Bean) is a commercially important demersal fish found along the deep continental margin of the northwestern Atlantic and Gulf of Mexico (Dooley 1978). The golden tilefish has a unique burrowing behavior and habitat preference. Burrowing construction has been observed through the use of submersibles in the Hudson submarine canyon, southern New England waters (Able *et al.* 1982), east coast of the United States (Grimes *et al.* 1986) and waters off of Texas (Jones *et al.* 1989). Tilefish occupy burrows along a narrow fringe of the continental shelf break in the Gulf of Mexico occurring at depths of 150-400 m and within a specific thermal cline (9-18°C; Nelson and Carpenter 1968, Walter *et al.* 2011, Murawski *et al.* 2018). Based on bottom longline surveys, tilefish were found mainly along the De Soto Canyon and western Gulf of Mexico (Nelson and Carpenter 1968, Ingram and Pollack 2011) and throughout the Campeche Bank (Hulmueller 2019). Golden tilefish prefer malleable but stable sediments to form burrows, a mixture of clay and silt (Able *et al.* 1982). Statistical analysis resulted in strong effects of depth, percentage clay, organic carbon and critical shear stress for habitat preference (Walter *et al.* 2011). There is still little known regarding the early life history stages (egg, larval, juvenile) of tilefish; however, recent stable isotope research using levels of carbon and nitrogen in the

laminar structure of the fish eye lenses, concluded that tilefish exhibited little lifetime movement (Vecchio *et al.* 2021). Golden tilefish are a long-lived fish reaching maximum ages of up to 40 years (Turner *et al.* 1983, Harris and Grossman 1985, Palmer *et al.* 2004, Lombardi *et al.* 2010). Longevity was confirmed to 26 years through the use of the radioactive disequilibrium of lead-210 and radium-226 in otoliths as an independent estimate of age (Lombardi-Carlson and Andrews 2015). Female tilefish from the Gulf of Mexico exhibited a spawning season extending from January to June with peak development in April, with females reaching maturity at 344 mm TL in length and age 2 (Lombardi *et al.* 2010). In addition to their unique habitat choice, golden tilefish display unique reproductive strategy in the Gulf of Mexico with the possibility of hermaphroditism or intersexual tendencies with 67% of functional males having multiple stages of oocytes, and 26% of functional females containing male tubules, research is continuing (Lombardi-Carlson 2012). Given the golden tilefish's specific habitat preferences, complex life history and sessile behavior, these characteristics make this species highly susceptible to capture and to overfishing (Grimes *et al.* 1988, Harris and Grossman 1985, Matlock *et al.* 1991). Although the stock status of golden tilefish in the Gulf of Mexico was determined to be in good standing, it is considered a data poor species with issues in age composition and recruitment and abundance trends and landings data (SEDAR 2011).

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Goliath grouper - *Epinephelus itajara*

Overall Vulnerability Rank = High ■

Habitat Sensitivity = High ■

Climate Exposure = High ■

Data Quality = 90% of scores ≥ 2

<i>Epinephelus itajara</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	2.8	3		Low Moderate High Very High
	Prey Specificity	2.1	2.6		
	Adult Mobility	2.5	2.6		
	Dispersal of Early Life Stages	2.2	2.8		
	Early Life History Survival and Settlement Requirements	2.6	2		
	Complexity in Reproductive Strategy	2.9	2.8		
	Spawning Cycle	3	2.6		
	Sensitivity to Temperature	1.9	2.6		
	Sensitivity to Ocean Acidification	2	2		
	Population Growth Rate	3.7	3		
	Stock Size/Status	3.3	2.3		
	Other Stressors	2.3	2		
	Sensitivity Score		High		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	2	2.4		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.8	2		
	Salinity	3.5	3		
	Sea Level Rise	2.6	2.6		
	Sea Surface Temperature	4	3		
	Exposure Score		High		
Overall Vulnerability Rank		High			

Overall Climate Vulnerability Rank: **High.** (52% bootstrap results in High, 47% bootstrap results in Very High, 1% bootstrap results in Moderate).

Climate Exposure: **High.** Sea surface temperature (4.0), ocean acidification (4.0), and salinity (2.9) contributed to a high climate exposure ranking for goliath grouper. Sea level rise (2.6) was moderate to high and hypoxia (2.0) was moderate. This species often resides in nearshore waters. Eggs and larvae are pelagic (Richards 2005) traveling 100+ kilometers before settling approximately 40-60 days after spawning (Lara *et al.* 2009). During these initial life stages, goliath grouper are susceptible to varying sea surface temperatures and salinities. Juvenile goliath grouper are primarily observed in inshore mangrove and seagrass habitats (Bullock *et al.* 1992, Sadovy and Eklund 1999, Koeing *et al.* 2007) that are sensitive to temperatures and sea level rise. Adults can reside on coral reefs and regularly consume prey species (e.g., crabs and lobsters) that are highly vulnerable to ocean acidification (Sadovy and Eklund 1999, Koenig and Coleman 2009, Koenig and Coleman 2016).

Biological Sensitivity: **High.** The sensitivity attributes that contribute to a high biological sensitivity score for goliath grouper were population growth rate (3.7), stock size/status in parentheses 3.3), complexity in reproductive strategy (2.9), and habitat specificity (2.8). Goliath grouper have a slow growth rate ($k=0.126$, Bullock *et al.* 1992), are long-lived (>37 years, Bullock *et al.* 1992), have a late age at maturity (6 or 7 years, Sadovy and Eklund 1999, Bullock *et al.* 1992), very large maximum body size (maximum weight is 680 pounds or 308.44 kilograms; maximum length is 98.43 inches or 250 centimeters), and a moderately low natural mortality rate ($M=0.18$, SEDAR 2016). These characteristics indicate goliath grouper will likely be slow to recover from a population disturbance. In addition, goliath grouper populations have historically been overfished which led to moratorium on landings beginning in 1990 that is still ongoing today. While stocks are presently not overfished and overfishing is not occurring, they have very limited pressure (e.g., accidental bycatch, misidentification, poaching, and catch-and-release mortality; Porch *et al.* 2006, SEDAR 2016). Goliath grouper aggregate to spawn and due to low numbers many historical aggregations ceased to aggregate by 1999 (Sadovy and Eklund 1999). This fish species needs to maintain enough reproductive adults at any given aggregation site to increase their chances of reproductive success and to maintain genetic diversity to better allow goliath grouper to overcome any climate changes.

Distributional Vulnerability Rank: **Low.** The attributes contributing to goliath grouper's low vulnerability to distribution shift ranking were high habitat specificity (2.8), moderately dispersive early life stages (2.2), moderate to temperature and limited latitudinal range (1.9), and moderately to highly mobile adults (2.5).

Data Quality: 90% of the data quality scores were 2 or greater. The majority of the exposure and sensitivity scores closely matched data quality. However, ocean acidification was scored as a very high exposure and the data quality was listed as moderate.

Climate Effects on Abundance and Distribution: Few studies have examined the effect of climate factors on the population productivity of goliath grouper. Similarly, changes in distribution have

not been investigated due to low population sizes however, in recent years the population appears to be rebounding. Notably, this species prefers warmer waters (22-28°C) and juvenile stages are vulnerable to cold snaps (Hallac *et al.* 2010).

Life History Synopsis: Goliath grouper is a large reef-associated grouper species found in nearshore (up to 328 feet or 100 meters) and estuarine waters of the tropical western Atlantic Ocean from northeastern Florida, south along the U.S., throughout the Gulf of Mexico and Caribbean Sea, and along South America to Santa Catarina, Brazil (Lieske and Myers 1994, Hostim-Silva *et al.* 2005)

Juvenile goliath grouper (< 6 years) are found primarily in inshore mangrove habitat (Koeing *et al.* 2007, Coleman and Koenig 2010), but also inhabit seagrass beds, tidepools, shallow rocky areas, brackish backwater habitats, and artificial reef habitats including jetties and docks (Bullock *et al.* 1992, Sadovy and Eklund 1999). These inshore areas could be subject to anthropocentric disturbances such as pollution and habitat alteration/degradation. While adults can be found in inshore areas as well, as they get older they generally move offshore to high-relief habitats such as natural coral reefs and rocky ledges, and artificial habitats such as oil and gas platforms and wrecks (Brusher and Schull 2009, Koenig *et al.* 2007, Koenig and Coleman 2009, Collins and Barbieri 2010, Collins 2014).

Juvenile goliath grouper are known to feed primarily on Callinectid crabs (Frietas *et al.* 2015), while adults feed primarily on decapod crustaceans (especially spiny lobster, but also other crabs) and fishes (Sadovy and Eklund 1999, Koenig and Coleman 2016).

Adults are capable of mobility but tagging studies show high site fidelity, with most tagged individuals moving less than 1 km from their tagging site, but some individuals have been found to travel >300km from residence reefs to spawning sites (Collins and Barbieri 2010, Ellis *et al.* 2014).

Goliath grouper spawning aggregations range from few to 150 individuals. Many historical aggregations had ceased to aggregate by 1999 (Sadovy and Eklund 1999), likely due to severe overfishing. Spawning occurs offshore from July to October (Koenig and Coleman 2009). In the Gulf of Mexico, peak spawning occurs at night during new moons from July through September (Kobara *et al.* 2017). Eggs and larvae are pelagic (Richards 2005) drifting with currents to suitable mangrove/inshore habitat. Settlement generally occurs at 40-60 days after spawning (range 30-80 days; Lara *et al.* 2009, Coleman and Koenig 2010). The distance traveled by larvae could be 100+ kilometers (Lara *et al.* 2009).

While goliath grouper were not initially thought to be protogynous (Bullock *et al.* 1992), later work by Koeing and Coleman (2016) has shown that the species may exhibit diandric protogyny, in which some males are born male and other females transition to male based on some behavioral or socially mediated cue. However, functional hermaphroditism has not been confirmed.

Goliath grouper enjoy a subtropical-tropical temperature range, found in waters from 22-28°C (mean 26°C (Fishbase). Cold temperature events in southwest Florida nursery areas have been linked to mortality events in juveniles (Hallac *et al.* 2010).

Goliath grouper are likely to be affected by ocean acidification, as a large part of juvenile diet is comprised of *Callinectes* sp. crabs, while adults feed primarily on another crustacean, spiny lobster. In addition, adults through some areas of their range reside on coral reefs. Goliath grouper have a slow population growth rate, as evidenced by their maximum age (>37 years, Bullock *et al.* 1992), low growth coefficient ($k=0.126$, Bullock *et al.* 1992), late age at maturity (6 or 7 years, Sadovy and Eklund 1999, Bullock *et al.* 1992), very large maximum body size (maximum weight is 680 pounds or 308.44 kilograms; maximum length is 98.43 inches or 250 centimeters), moderately low natural mortality rate ($M=0.18$, SEDAR 2016). These characteristics indicate goliath grouper could be slow to recover from a population disturbance.

Goliath grouper populations were severely overfished historically (1950s-1980s) and no-landing regulations were imposed in 1990. The species appears to have recovered since then throughout the Gulf (Coleman and Koenig 2010) and in particular, from State of Florida reports, in Ten Thousand Islands. A recent stock assessment (SEDAR 2016) found that goliath grouper were not overfished ($B_{cur}/B_{MSST} = 1.48$) and that overfishing was not occurring in most recent years ($F_{cur}/F_{MFMT} = 0.22$). Little genetic differentiation was found between goliath grouper from the eastern Gulf of Mexico, Florida Keys and southeast Florida, although evidence from an analysis of kinship study shows specimens from southeast Florida and the Florida Keys are more closely related to each other than to specimens from the Gulf of Mexico (M.Tringali, S. Seyoum, and A. B. Collins, FWC, St. Petersburg, FL, personal communication).

Other potential stressors for goliath grouper likely include possible water temperature decreases or increases, red tide events, coral bleaching, temperate reef degradation, and lionfish predation. Another important stressor on goliath grouper populations if fishing regulations are relaxed would be excessive or highly targeted fishing pressure due to high enthusiasm to catch such a large fish and because this species often resides at known locations, making few movements.

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Gray snapper - *Lutjanus griseus*

Overall Vulnerability Rank = Low ■

Habitat Sensitivity = Low ■

Climate Exposure = High ■

Data Quality = 80% of scores ≥ 2

<i>Lutjanus griseus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	1.9	3		Low Moderate High Very High
	Prey Specificity	1.4	2.8		
	Adult Mobility	2.2	2.2		
	Dispersal of Early Life Stages	1.9	2.8		
	Early Life History Survival and Settlement Requirements	1.9	2.2		
	Complexity in Reproductive Strategy	2	2.6		
	Spawning Cycle	2.1	3		
	Sensitivity to Temperature	1.6	2.8		
	Sensitivity to Ocean Acidification	2	1.6		
	Population Growth Rate	2.3	3		
	Stock Size/Status	2.1	3		
	Other Stressors	2.7	2.6		
	Sensitivity Score		Low		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	1.6	1.6		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.8	2		
	Salinity	3.5	3		
	Sea Level Rise	2.4	2.4		
	Sea Surface Temperature	4	3		
Exposure Score		High			
Overall Vulnerability Rank		Low			

Overall Climate Vulnerability Rank: **Low.** (47% bootstrap results in Low, 47% bootstrap results in Moderate, 6% bootstrap results in High).

Climate Exposure: **High.** The exposure factors contributing to this a high climate exposure for gray snapper were sea surface temperature (4.0), ocean acidification (4.0), and salinity (3.5). Sea level rise and primary productivity were scored as moderate (2.4 and 1.8 respectively),

Biological Sensitivity: **Low.** The sensitivity attributes contributing to a low biological sensitivity score for gray snapper were prey specificity (1.4), and sensitivity to temperature (1.6). A number of sensitivity attributes had moderate modes in expert scores.

Distributional Vulnerability Rank: **High.** The attributes contributing to a high vulnerability to distribution shift for gray snapper were high adult mobility (2.2), high early life stage dispersal (1.9), and moderate habitat specificity (1.9) and moderate to low sensitivity to temperature (1.6).

Data Quality: 80% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution: Potential effects of a changing climate on gray snapper include changes to oceanic circulation affecting larval transport to estuarine nursery areas, increasing ocean acidification affecting some invertebrates that are preferred diet items and thus affecting fitness/survival, degradation of coral reef habitat preferred by adults due to ocean acidification, and effects of sea level rise on preferred nursery areas (mangroves/seagrass beds).

Life History Synopsis: Gray snapper is an estuarine and marine species found in the western Atlantic Ocean from North Carolina to Brazil, including the Caribbean, Gulf of Mexico, and Bermuda (Starck and Schroeder 1971, Rutherford *et al.* 1989, Andrade and Santos 2019). Juvenile gray snapper inhabit complex habitats in coastal and estuarine areas such as seagrass beds, mangroves, oyster reefs, and backreef areas (Flaherty *et al.* 2014), while adults are generally found around nearshore or offshore artificial reefs or natural hardbottom or coral reef habitats (Luo *et al.* 2009, Bacheler *et al.* 2016). Juvenile and adult gray snapper are mainly nocturnal predators and have a large breadth of diet, eating a variety of invertebrate and vertebrate prey items including shrimp, crabs, gastropods, cephalopods, and fish (Yeager *et al.* 2014). Adults are highly mobile and typically school with conspecifics. In some parts of their range, gray snapper appear to aggregate to spawn at night during summer months on a full moon (Claro and Lindeman 2003), but in most areas of the southeast United States, large spawning aggregations of gray snapper have not been observed, suggesting some plasticity in reproductive strategy. Gray snapper are gonochoristic and spawning season occurs from June through August in Florida, with individuals likely spawning repeatedly during the season (Starck and Schroeder 1971, Erdman 1976). Gray snapper eggs are pelagic and hatch after approximately 20 hours at 27° C (Allen 1985). Gray snapper eggs and larvae are transported by water currents to complex habitats in estuarine nursery areas (Flaherty *et al.* 2014). Gray snapper occur over a large area of the western Atlantic Ocean in water temperatures ranging from 18 to 27° C, and may be moderately or highly sensitive to increased ocean acidification because they prey upon some invertebrate species (i.e., crabs, shrimp) that may themselves be sensitive to ocean acidification

(Yeager *et al.* 2014). The overall population growth rate of gray snapper was judged to be slow to moderate, with several biological traits suggesting slow population growth rates (e.g., maximum age = 28; growth rate [k] = 0.15; age at maturity ranging from 50% mature at age-2.3 to 90% mature at age 5.3: SEDAR 2018). Gray Snapper are not currently overfished but the species has experienced overfishing since 1976 in the Gulf of Mexico and is currently undergoing overfishing ($F_{curr}/F_{SPR30} = 1.20$: SEDAR 2018), similar to the Florida Keys (Ault *et al.* 2005). Expert scorers determined that gray snapper may be highly sensitivity to other potential stressors including habitat degradation in estuaries that may influence estuarine-dependent juveniles, incidences of harmful algal blooms, myxozoan parasites (Holzer *et al.* 2013), coral bleaching that may influence reef-dependent adults, and possible lionfish predation.

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Gray triggerfish - *Balistes capriscus*

Overall Vulnerability Rank = Low ■

Habitat Sensitivity = Low ■

Climate Exposure = High ■

Data Quality = 90% of scores ≥ 2

<i>Balistes capriscus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	1.9	3		Low Moderate High Very High
	Prey Specificity	1.5	3		
	Adult Mobility	2	3		
	Dispersal of Early Life Stages	1.6	3		
	Early Life History Survival and Settlement Requirements	2.1	2.4		
	Complexity in Reproductive Strategy	2.3	3		
	Spawning Cycle	2.2	3		
	Sensitivity to Temperature	1.7	2.6		
	Sensitivity to Ocean Acidification	2.1	2.4		
	Population Growth Rate	2	2.6		
	Stock Size/Status	3.1	3		
	Other Stressors	1.8	2.4		
	Sensitivity Score		Low		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	2.2	2		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.8	2		
	Salinity	3.5	3		
	Sea Level Rise	1.8	2.4		
	Sea Surface Temperature	4	3		
	Exposure Score		High		
Overall Vulnerability Rank		Low			

Overall Climate Vulnerability Rank: **Low.** (48% bootstrap results in Low, 4*% bootstrap results in Moderate, 4% bootstrap results in High).

Climate Exposure: **High.** The exposure factors contributing to a high climate exposure ranking for gray triggerfish were sea surface temperature (4.0), ocean acidification (4.0 and salinity (3.5). Hypoxia was moderate (2.2), and sea level rise (1.8) and primary productivity were moderate to low.

Biological Sensitivity: **Low.** The sensitivity attributes contributing to a low biological sensitivity ranking for Gray triggerfish were prey specificity (1.5), dispersal of early life stages (1.6), and sensitivity to temperature (1.7).

Distributional Vulnerability Rank: **High.** The top three attributes contributing to gray triggerfish's high vulnerability to distribution shift were very highly to highly dispersive early life stages (1.6), moderate to low sensitivity to temperature or occurs across a wide latitudinal range (1.7), and moderate to low habitat specificity (1.9). Adults were also ranked as highly mobile (2.0).

Data Quality: All data quality scores were 2 or greater. There are some gaps in information about early life history survival and settlement requirements (2.4) and effects of ocean acidification (2.4).

Climate Effects on Abundance and Distribution: Overall climate effects on gray triggerfish appear to be minimal. The species may be moderately affected by increasing ocean acidification because of their dietary preferences for a variety of invertebrates, as well as their preference for structurally complex reef habitats, which could be affected by increasing acidification. The species has a wide thermal tolerance and likely won't be highly affected by increasing ocean temperatures.

Life History Synopsis: Gray triggerfish is a marine fish species that is found throughout the tropical and temperate Atlantic Ocean (Liu *et al.* 2019). Juvenile gray triggerfish drift long distances at the surface amongst *Sargassum* sp. for up to 7 months (Bortone *et al.* 1977, Wells and Rooker 2004), and eventually settle into benthic reef habitats in water between 5 and 110 m deep (Kurz 1995, Simmons and Szedlmayer 2011). During their benthic stage as late juveniles and adults, gray triggerfish prefer to inhabit specific areas with complex structure such hard bottom reefs, ledges, and artificial reef structures (Bacheler *et al.* 2016). Adults can be highly mobile, but often display relatively high site fidelity to particular reef habitats (Herbig and Szedlmayer 2016, McKinzie 2018, Bacheler *et al.* 2019). Juvenile and adult gray triggerfish typically prey on a wide variety of invertebrates such as barnacles, bivalves, polychaetes, crustaceans, echinoderms, and isopods (Vose and Nelson 1994). Gray triggerfish are gonochoristic, but exhibit substantial reproductive complexity by forming reproductive harems, building demersal nests, and providing parental care of eggs (Simmons and Szedlmayer 2012). They are also batch spawners, with individuals spawning multiple times within a spawning

season that can last from May to September (Moore 2001). Their large geographic distribution highlights their insensitivity to water temperature, with a broad preferred range of 9 to 26° C. Gray triggerfish may be moderately to highly affected by ocean acidification given their reliance upon invertebrate prey with calcium carbonate shells (Goldman *et al.* 2016). Most life history traits of gray triggerfish suggest high population growth rate potential (e.g., $r_{\max}$, K , age-at-maturity), but maximum age and natural mortality rates indicate a somewhat lower population growth rate potential (i.e., higher sensitivity to climate change; Burton *et al.* 2015, Liu *et al.* 2015). A recent population model in the region indicated that stock status of gray triggerfish was overfished (SEDAR 2015). There does not appear to be any genetic heterogeneity within the region or among regions (Sallient and Antoni 2014). Other potential stressors for gray triggerfish appear minimal but may include coral or temperate reef degradation and lionfish predation.

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Great hammerhead shark - *Sphyrna mokarran*

Overall Vulnerability Rank = Very High ■

Habitat Sensitivity = High ■

Climate Exposure = Very High ■

Data Quality = 80% of scores ≥ 2

<i>Sphyrna mokarran</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	1.6	2.6		Low Moderate High Very High
	Prey Specificity	1.5	2.8		
	Adult Mobility	1.1	2.8		
	Dispersal of Early Life Stages	1.2	3		
	Early Life History Survival and Settlement Requirements	1	2.4		
	Complexity in Reproductive Strategy	1.6	2.2		
	Spawning Cycle	1.8	2.6		
	Sensitivity to Temperature	1.6	2.6		
	Sensitivity to Ocean Acidification	1.5	2.4		
	Population Growth Rate	3.5	2.2		
	Stock Size/Status	3.3	1.4		
	Other Stressors	2.5	2		
	Sensitivity Score		High		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	1.6	2.2		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.8	2		
	Salinity	3.5	3		
	Sea Level Rise	1	0		
	Sea Surface Temperature	4	3		
Exposure Score		Very High			
Overall Vulnerability Rank		Very High			

Overall Climate Vulnerability Rank: **Very High.** (56% bootstrap results in Very High, 43% bootstrap results in High, and 1% bootstrap results in Moderate).

Climate Exposure: **Very High.** Sea surface temperature (4.0), ocean acidification (4.0), and salinity (3.5) were the top three exposure factors contributing to great hammerhead shark's very high climate exposure score. Primary productivity (1.8) was moderate, and hypoxia (1.6) was moderate to low.

Biological Sensitivity: **High.** The sensitivity attributes that contributed to a high biological for great hammerhead shark were population growth rate (3.5), stock size/status (3.3), and other stressors (2.5). Eight sensitivity attributes had dominant modes in the low category.

Distributional Vulnerability Rank: **High.** The top two attributes contributing to a high vulnerability for distribution shift for great hammerhead shark were very highly mobile adults (1.1), very highly dispersive early life stages (1.2). Both low habitat specificity (1.6) and low sensitivity to temperature or broad latitudinal distribution (1.6) had the same ranking.

Data Quality: All but one of the data quality scores were 2 or greater. The stock size/status of great hammerhead shark had a data quality score of 1.4 indicating that additional information is needed in this area.

Climate Effects on Abundance and Distribution: No studies have directly investigated the impact of climate on great hammerhead sharks. However, the species' sensitivity to other stressors suggests a potential for climate change effects. Fishing interactions throughout their habitat are of concern due to high at-vessel or post-release mortality. This species has a pronounced physiological stress response to capture, making it less likely to survive despite release. Outside of US areas, pelagic habitats may be subjected to targeted and incidental fishing pressure, posing a risk to highly mobile individuals spending a portion of their time in the US GOM areas. (Miller *et al.* 2014, Morgan and Burgess 2007, Morgan *et al.* 2010, Gallagher *et al.* 2014, Jerome *et al.* 2018).

Life History Synopsis: The great hammerhead shark (*Sphyrna mokarran*) is a large-bodied (up to 4 to 6m), highly migratory, coastal-pelagic shark species (Compagno 1984). Animals mature between 5 and 6 years in the Atlantic (Piercy *et al.* 2010). Females may migrate to coastal areas to give birth during the spring-summer parturition season. The species is generally nomadic, less associated with sexual segregation or schooling than other hammerhead species. Pups are born late spring to summer after an 11 to 12-month gestation, with females reproducing every two years. The Von Bertalanffy K is 0.11 for females and 0.16 for males (Piercy *et al.* 2010), and the intrinsic rate of population increase is unknown.

Research on habitat preferences of all life stages in the GOM is lacking; however, as the species is highly migratory and ubiquitous, there may not be distinct specializations. No great hammerhead pups have been observed off the US east coast from NC through FL, but are reported in the GOM. Juveniles are seen with adults throughout their range in shallow, <60m, coastal areas, encompassing continental shelf areas and adjacent reefs (Stevens and Lyle 1989,

Cliff 1995, Heithaus *et al.* 2007, Vaudo and Heithaus 2009). The location of nurseries is currently unknown, although gravid females have been observed in coastal waters. Adults are known to move over broad expanses and are observed in association with seagrass beds, reefs, open ocean, and coastal waters (Stevens and Lyle 1989, Cliff 1995, Vaudo and Heithaus 2009). The species occurs in water temperatures from 17-31°C, with a preferred range from 26-30°C. (Compagno 1984, Heithaus *et al.* 2007).

Great hammerheads consume mostly teleosts and other elasmobranchs, followed by crustaceans and cephalopods (Stevens and Lyle 1989, Cliff 1995, Cortes 1999). Juveniles likely consume similar prey of a smaller size. There appear to be several movement patterns: (1) residential individuals who undergo seasonal migrations to overwinter in warmer areas, either onshore/offshore or from the northern GOM or US east coast; and (2) highly mobile individuals (Stevens and Lyle 1989, Heithaus *et al.* 2007). One study used satellite tracking to show an individual traveled 1200 km from the Florida northeast coast into international waters over 62 days (Hammerschlag *et al.* 2011).

Coastal parturition areas may be exposed to shore-associated human impacts. There is potential for accumulation of metals and polychlorinated biphenyls and brevetoxins from harmful algae blooms in gill/liver tissues; however, lethal or detrimental levels are unknown (Lyle 1984, Storelli *et al.* 2003, Flewelling *et al.* 2010)

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Greater amberjack - *Seriola dumerili*

Overall Vulnerability Rank = Low ■

Habitat Sensitivity = Low ■

Climate Exposure = High ■

Data Quality = 75% of scores ≥ 2

<i>Seriola dumerili</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	1.7	2.6		Low Moderate High Very High
	Prey Specificity	1.6	2.4		
	Adult Mobility	1.6	2.8		
	Dispersal of Early Life Stages	2.1	2.2		
	Early Life History Survival and Settlement Requirements	1.9	1.6		
	Complexity in Reproductive Strategy	2	2		
	Spawning Cycle	1.7	2.6		
	Sensitivity to Temperature	1.6	2.2		
	Sensitivity to Ocean Acidification	1.6	2		
	Population Growth Rate	1.8	2.2		
	Stock Size/Status	2.1	2.4		
	Other Stressors	1.9	1.8		
	Sensitivity Score		Low		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	1.6	2.2		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.8	2		
	Salinity	3.5	3		
	Sea Level Rise	1	0		
	Sea Surface Temperature	4	3		
	Exposure Score		High		
Overall Vulnerability Rank		Low			

Overall Climate Vulnerability Rank: **Low.** (51% bootstrap results in Low, 49% bootstrap results in Moderate).

Climate Exposure: **High.** Three exposure factors contributed to the high climate exposure score for greater amberjack: sea surface temperature (4.0), ocean acidification (4.0), and salinity (3.5). Hypoxia (1.6) and primary productivity (1.8) were in the low to moderate categories. Exposure to the primary factors is most likely for young-of-the-year, which rely heavily on pelagic *Sargassum* mats during their first year of life (Bortone *et al.* 1977, Wells and Rooker 2004b).

Biological Sensitivity: **Low.** The sensitivity attributes contributed to a low biological sensitivity score for greater amberjack were prey specificity (1.6), adult mobility (1.6), sensitivity to temperature (1.6), sensitivity to ocean acidification (1.6), habitat specificity (1.7), and spawning cycle (1.7). No sensitivity scores were identified as being high or very high for greater amberjack.

Distributional Vulnerability Rank: **High.** The top three attributes contributing to greater amberjack's high vulnerability to distribution shift included very highly to highly mobile adults (1.6), low to moderate sensitivity to temperature with a broad latitudinal distribution (1.6), and low to moderate habitat specificity (1.7).

Data Quality: All data quality scores were 2 or greater except early life history survival and settlement requirements (1.6) and other stressors (1.8). Early life history information is limited, due largely to difficulties in identifying larvae to species from long-term ichthyoplankton monitoring programs.

Climate Effects on Abundance and Distribution: Little is known regarding potential impacts of climate factors on the abundance, distribution, and population productivity of greater amberjack. Given their broad geographic distribution, it is unlikely that warming temperatures will have any significant impacts on the overall distribution and range of adult greater amberjack, although potential climatic effects on critical nursery habitat (*Sargassum* mats) are likely.

Life History Synopsis: Greater amberjack in the western Atlantic are broadly distributed, ranging from Nova Scotia to Brazil, including the Gulf of Mexico and Caribbean. Greater amberjack grow rapidly during their first year of life, reaching a maximum size of 210 mm SL by the end of their first year (Wells and Rooker 2004a). They reach a maximum age of approximately 15 years (Manooch and Potts 1997b, Thompson *et al.* 1999, Murie and Parkyn 2008), although fish as old as 17 years have been recorded (Manooch and Potts 1997a). Sex-specific differences in growth and maximum age are evident, with females generally being larger than males (Burch 1979, Thompson *et al.* 1999, Murie and Parkyn 2008, Harris *et al.* 2017) and comprising a disproportionate number of fish $\geq 1,000$ mm FL. Greater amberjack are gonochoristic with 50% of females reaching reproductive maturity at 3 - 4 years of age and approximately 800 - 900 mm FL (Thompson *et al.* 1991, Harris *et al.* 2007, Murie and Parkyn 2008). They spawn in coastal or offshore waters with peak spawning from March - May (Thompson *et al.* 1991, Beasley 1993, Wells and Rooker 2004 a,b). Greater amberjack are highly fecund, releasing 18 - 59 million eggs per female in a single spawning season, with batch fecundity increasing with size (Harris *et al.*

2007). Young-of-the-year are often found in association with pelagic *Sargassum* mats prior to settling at approximately 200 mm SL (Bortone *et al.* 1977, Wells and Rooker 2004b). They become structure oriented at approximately age-2, congregating around submerged oil rigs, reefs, rocky outcrops, and wrecks (Manooch and Potts 1997, Pollack and Ingram 2013). There is little movement of greater amberjack between the Gulf and Atlantic (McClellan and Cummings 1997, Murie *et al.* 2011), with most individuals being captured within 100 km of their original tagging location. Little is known regarding their tolerance of specific environmental conditions. Greater amberjack are primarily piscivorous (Foss 2016), although little is known regarding their potential predators. The most recent stock assessment for greater amberjack indicate that Gulf of Mexico stocks are overfished and experiencing overfishing (SEDAR 70 2020).

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Gulf menhaden - *Brevoortia patronus*

Overall Vulnerability Rank = Low ■

Habitat Sensitivity = Low ■

Climate Exposure = High ■

Data Quality = 90% of scores ≥ 2

<i>Brevoortia patronus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	1.9	2.6		Low Moderate High Very High
	Prey Specificity	2	2.4		
	Adult Mobility	1.9	2.4		
	Dispersal of Early Life Stages	1.8	2.4		
	Early Life History Survival and Settlement Requirements	2.3	2.2		
	Complexity in Reproductive Strategy	2.2	2		
	Spawning Cycle	2.1	2.4		
	Sensitivity to Temperature	2	2		
	Sensitivity to Ocean Acidification	1.8	2		
	Population Growth Rate	1.4	2.6		
	Stock Size/Status	1.4	2.6		
	Other Stressors	2	2		
	Sensitivity Score		Low		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	1.9	2.8		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.4	2		
	Salinity	2.3	3		
	Sea Level Rise	2.1	2.2		
	Sea Surface Temperature	4	3		
	Exposure Score		High		
Overall Vulnerability Rank		Low			

Overall Climate Vulnerability Rank: **Low.** (99% bootstrap results in Low, 1% bootstrap results in Moderate).

Climate Exposure: **High.** Two main exposure factors contributed to a high climate exposure score for Gulf menhaden: sea surface temperature (4.0) and ocean acidification (4.0). Salinity was moderate to high (2.3), and hypoxia (1.9) and sea level rise (2.1) were moderate.

Biological Sensitivity: **Low.** The sensitivity attributes that contributed to a low biological sense for Gulf menhaden were population growth rate (1.4), stock size/status (1.4), and sensitivity to ocean acidification (1.8). All of the sensitivity attribute means were near moderate to low. Gulf menhaden are a short-lived, highly fecund species, which leads to a lower level of biological sensitivity and therefore a higher level of biological resiliency.

Distributional Vulnerability Rank: **High.** The top three attributes contributing to gulf menhaden's high vulnerability to distribution shift were highly to very highly dispersive early life stages (1.8), highly mobile adults (1.9), and moderate habitat specificity (1.9). Gulf menhaden also had moderate sensitivity to temperature (2.0).

Data Quality: All data quality scores were 2 or greater indicating that some data was available for all areas. The lowest attribute data quality scores (2.0) were in complexity in reproductive strategy and sensitivity to temperature, and other stressors.

Climate Effects on Abundance and Distribution: Few studies have examined the effect of climate factors on the population productivity of Gulf menhaden. Recruitment has been linked with river discharge (Govoni 1997, Vaughan *et al.* 2007), but later studies found contrary results (Sanchez-Rubio and Perry 2015). Thus, the impact of climate on Gulf menhaden abundance and distribution is uncertain.

Life History Synopsis: Gulf menhaden is a fast-growing, short-lived, forage fish species that is dependent upon both coastal and estuarine habitats. Gulf menhaden are found in the northern Gulf of Mexico from the Yucatan peninsula to Florida (SEDAR 2018). The center of their distribution appears to be off the coast of Louisiana. Gulf menhaden are indeterminate, batch spawners, which actively spawn from October to mid-March (Brown-Peterson *et al.* 2017), and reach maturity at 1 year of age (Lewis and Rothmayr 1981). Gulf menhaden are highly fecund and have increased numbers of batches of eggs with size (Brown-Peterson *et al.* 2017). Spawning is thought to occur in offshore waters with eggs and larvae advecting into estuarine environments (SEDAR 2018). Eggs and larvae have been collected in waters with salinities ranging from 6 to 36 ppt (Fore 1970, Christmas and Waller 1975). Larvae transform into juveniles, and juveniles are in the estuaries until about 100 mm FL (Lassuy 1983) before migrating out to join the adult population. Recruitment of Gulf menhaden has been shown to be inversely related to river flow from the Mississippi and Atchafalaya Rivers (Govoni 1997, Vaughan *et al.* 2007); however, additional work on the topic has indicated that recruitment is better under cold, wet conditions (Sanchez-Rubio and Perry 2015). Adult menhaden form dense, near surface schools that are harvested by a large, commercial purse seine fishery (SEDAR

2018). Adult Gulf menhaden do not exhibit extensive east to west movements in the Gulf of Mexico, but older fish are more likely to be found near the Mississippi River delta, which is the center of the species range (Ahrenholz 1981). As of 2017, the Gulf menhaden stock is not overfished and overfishing is not occurring (SEDAR 2018).

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Gulf sturgeon - *Acipenser oxyrinchus*

Overall Vulnerability Rank = Very High ■

Habitat Sensitivity = Very High ■

Climate Exposure = High ■

Data Quality = 95% of scores ≥ 2

<i>Acipenser oxyrinchus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	3.4	3		Low Moderate High Very High
	Prey Specificity	2.1	3		
	Adult Mobility	2.6	3		
	Dispersal of Early Life Stages	3.6	2.4		
	Early Life History Survival and Settlement Requirements	3.3	2		
	Complexity in Reproductive Strategy	3.3	3		
	Spawning Cycle	3.7	2.8		
	Sensitivity to Temperature	3.2	2.4		
	Sensitivity to Ocean Acidification	2.4	2.4		
	Population Growth Rate	3.7	2.4		
	Stock Size/Status	3.7	2.4		
	Other Stressors	3.6	2.4		
	Sensitivity Score		Very High		
Exposure Factors	Air Temperature	4	3		
	Hypoxia	2.4	2.4		
	Ocean Acidification	4	2		
	Precipitation	1	3		
	Primary Productivity	1	2		
	Salinity	1.6	3		
	Sea Level Rise	2.8	2.4		
	Sea Surface Temperature	1	0		
	Exposure Score		High		
Overall Vulnerability Rank		Very High			

Overall Climate Vulnerability Rank: **Very High.** (100% bootstrap results in High).

Climate Exposure: **High.** The two main exposure factors contributing to Gulf sturgeon's high climate exposure ranking were air temperature (4.0, a proxy for estuarine and freshwater temperatures) and ocean acidification (4.0). Sea level rise (2.8) and hypoxia (2.4 - but with a range from low to very high) were high to moderate, and salinity was moderate to low (1.6). Gulf Sturgeon are an anadromous fish that over-summers and spawns in freshwater, develops in freshwater and estuarine habitats, and feeds as adults in estuarine and marine habitats (Sulak *et al.* 2016). Gulf Sturgeon are particularly vulnerable to changes in freshwater habitats (e.g., temperature, DO) because all life stages occupy these areas.

Biological Sensitivity: **Very High.** The sensitivity attributes which contribute to a very high biological sensitivity score for Gulf sturgeon were spawning cycle (3.7), population growth rate (3.7), stock size/status (seven) dispersal of early life stages (3.6), other stressors (3.6), habitat specificity (3.4), early life history survival and settlement requirements (3.3), complexity in reproductive strategy (3.3), and sensitivity to temperature (3.2). Gulf Sturgeon were listed as Endangered under the Endangered Species Act in 1991 and are long-lived, slow growing, and reach maturity at a relatively advanced age (USFWS *et al.* 1995). Spawning occurs in rivers flowing into the Gulf of Mexico typically in spring, and eggs and free embryos (yolksac larva) develop near spawning habitats (Sulak *et al.* 2016).

Distributional Vulnerability Rank: **Low.** The attributes contributing to Gulf sturgeon's low vulnerability to distributional shift were very low dispersal of early life stages (3.6), very high to high habitat specificity (3.4), high to very high sensitivity to temperature (3.2), and moderate to high adult mobility (2.6). Spawning occurs in tributaries of the Gulf of Mexico along a relatively narrow range of latitudes and elevations such that changes in climate (i.e., increased temperature) may uniformly influence spawning habitat. Gulf Sturgeon are anadromous and straying between spawning rivers occurs although the frequency of spawning in non-natal rivers is uncertain (Sulak *et al.* 2016).

Data Quality: Although all of the data quality scores were 2 or greater, several had data quality scores in the 2 to 2.4 range. Early life history survival and settlement requirements was 2.0, dispersal of early life stages, sensitivity to temperature, sensitivity to ocean acidification, population growth rate, stock size/status, and other stressors were all 2.4. Gulf Sturgeon are the most southern distributed acipenserid and summer surface water temperatures in the Gulf of Mexico routinely exceed their physiological tolerance.

Climate Effects on Abundance and Distribution: USFWS and NMFS (2009) provides some discussion of the potential effects of climate on abundance and distribution of Gulf Sturgeon. USFWS and NMFS (2021) describe specific mechanisms of potential effects including:

- increased frequency of hurricanes and associated fish kills caused by low dissolved oxygen in storm water runoff;
- increased frequency and scope of red tides and associated fish kills; and

- increased water temperature and decreased flows in freshwater spawning habitat and associated decreased spawning success and recruitment.

Directional Effect in the Northeast U.S. Shelf: The effect of climate change on a con-specific Atlantic sturgeon is estimated to be negative, but this estimate has a high degree of uncertainty (<66% certainty in expert scores). Most climate factors have the potential to decrease productivity (sea level rise; reduced dissolved oxygen, increased temperatures). However, understanding the magnitude and interaction of different effects is difficult. The effect of ocean acidification over the next 30 years is likely to be minimal.

Life History Synopsis: Gulf sturgeon are a long-lived, anadromous species found in most large river estuarine systems and surrounding coastal waters from Louisiana to Southwest Florida (USFWS *et al.* 1995). Gulf sturgeon mature at ages ranging from 7 to 12 years (USFWS *et al.* 1995) with females likely spawning at approximately 3 to 4 year intervals (Sulak *et al.* 2016). Spawning occurs over coarse substrates in riverine habitats typically during the spring (USFWS *et al.* 1995). Free embryos remain in benthic substrates until they develop into exogenous feeding larva and disperse from spawning areas (Sulak *et al.* 2016). Juveniles migrate into the estuary the winter following hatching at approximately 9 months of age (Sulak *et al.* 2016). The juvenile Gulf sturgeon annual migration typically does not extend beyond their natal estuary for several years (Sulak *et al.* 2016). Adult and subadult Gulf sturgeon are found in coastal and estuarine waters during late fall and winter and migrate back to freshwater in spring (Sulak *et al.* 2016). The majority of spawning occurs in spring, with fall spawning documented in some rivers (Randall and Sulak 2012). Adult and subadult Gulf sturgeon migrate from riverine habitats to the estuaries and nearshore areas in late fall. In marine and estuarine environments Gulf sturgeon forage over soft bottoms on benthic invertebrates including brachiopods amphipods, ghost shrimp, and lancelets (Sulak *et al.* 2016). Gulf sturgeon were listed as threatened under the Endangered Species Act in 1991 and direct take of the species is prohibited in all four states within the current range of the species (USFWS *et al.* 1995).

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United States Fish and Wildlife Service and National Marine Fisheries Service (USFWS; NMFS) (2022) Gulf sturgeon (*Acipenser oxyrinchus desotoi*) 5-year review: summary and evaluation. United States Fish and Wildlife Service, Southeast Region, Panama City and National Marine Fisheries Service, Southeast Region, Office of Protected Resources, St. Petersburg, FL.

Hogfish - *Lachnolaimus maximus*

Overall Vulnerability Rank = Moderate ■

Habitat Sensitivity = Moderate ■

Climate Exposure = High ■

Data Quality = 85% of scores ≥ 2

<i>Lachnolaimus maximus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	2.6	2.8		Low Moderate High Very High
	Prey Specificity	2.2	2.8		
	Adult Mobility	2.2	2.2		
	Dispersal of Early Life Stages	2.1	2.4		
	Early Life History Survival and Settlement Requirements	2.3	2.4		
	Complexity in Reproductive Strategy	3	3		
	Spawning Cycle	2.3	3		
	Sensitivity to Temperature	1.8	2.8		
	Sensitivity to Ocean Acidification	2.3	2		
	Population Growth Rate	2.8	3		
	Stock Size/Status	1.7	3		
	Other Stressors	2.5	2.4		
	Sensitivity Score		Moderate		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	1.6	1.4		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.8	2		
	Salinity	3.5	3		
	Sea Level Rise	2	2		
	Sea Surface Temperature	4	3		
	Exposure Score		High		
Overall Vulnerability Rank		Moderate			

Overall Climate Vulnerability Rank: **Moderate.** (47% bootstrap results in Moderate, 47% bootstrap results in High, 6% bootstrap results in High).

Climate Exposure: **High.** The top three exposure factors contributing to a high climate exposure score for hogfish were sea surface temperature (4.0), ocean acidification (4.0), and salinity (3.5). Primary productivity (1.8) and sea level rise (2.0) were both in the moderate category. Hypoxia (1.6) was in the moderate to low category.

Biological Sensitivity: **Moderate.** The sensitivity attributes that contribute to a moderate biological sensitivity score for hogfish were complexity in reproductive strategy (3.0), habitat specificity (2.6), population growth rate (2.8), and other stressors (2.5).

Distributional Vulnerability Rank: **Moderate.** The top three attributes contributing to hogfish's moderate vulnerability to distribution shift ranking were high to moderate habitat specificity (2.6), moderate to low sensitivity to temperature (1.8), highly dispersive early life stages (2.1).

Data Quality: All of the data quality scores were 2 or greater. Sensitivity to ocean acidification (2.0) had the lowest data quality score, followed by adult mobility (2.2), early life stage dispersal (2.4), early life history survival and settlement requirements (2.4), and other stressors (2.4).

Climate Effects on Abundance and Distribution: Few studies examined the effect of climate factors on the population productivity of hogfish. However, the extended planktonic larval phase suggests that current changes would have substantial impact on recruitment. Changes in ocean currents, degradation of coral reef habitat due to ocean acidification, and increased episodic events are potential concerns affecting habitat essential to hogfish.

Life History Synopsis: Hogfish is a large reef-associated species of wrasse (family Labridae) found in inshore waters from North Carolina through the Caribbean, including Bermuda, to northern Brazil and throughout the Gulf of Mexico.

Juvenile hogfish are most commonly found in shallow seagrass beds or inshore reef habitat (Richards 2005). Adults are found on coral or temperate rocky reefs at depths of 3-40 m, especially the sandy outer reef slopes, preferring reef edges and hard sand and rock bottoms near patch reefs (Richards 2005).

Juvenile hogfish feed primarily on molluscs, crustaceans and echinoderms. Adults feed on sand-dwelling mollusks (pelecypods, gastropods, scaphopods; Randall and Warmke 1967) as well as crustaceans (hermit crabs and amphipods), and echinoderms (sea urchins), and small fishes. Labridae are generally omnivorous and planktivorous.

While adults are highly mobile, male hogfish exhibit site fidelity to fairly restricted home ranges during spawning season (Colin 1982, Munoz et al 2010) and possibly outside of spawning season as well (Lindholm *et al.* 2006).

Hogfish are monandric protogynous hermaphrodites (McBride and Johnson 2007), with a very slow rate of sex change (several months) which occurs after one or more spawning seasons as a female. Spawning season in the southeastern U. S. is from December to May, and spawning

occurs when a male approaches a female from his harem and initiates a spawning rush, involving an upward swim and release of gametes into the water column. While harem mating systems are common, both pair and group spawning occurs throughout the year, usually in late afternoon (Thresher 1984, Warner and Robertson 1978). Males patrol their territories and chase away intruder males (Burton, personal observation).

Pelagic eggs hatch approximately 24 hours after fertilization (Colin 1982, Farm 1993, Jones 1993, Holt and Riley 2001). The pelagic larval stage lasts several weeks (mean PLD in the Atlantic ranges from 21 — 104 days (Victor 1986, Schultz and Cowen 1994, Jones 1993, Sponaugle and Cowen 1997), until they grow into juveniles and settle out of the water column, usually in inshore seagrass beds. Larvae are likely transported by currents to suitable inshore nursery areas (e.g., Florida Bay).

Hogfish enjoy a subtropical-tropical distribution, preferring temperatures from 23-28 ° C (Fishbase) although their presence on offshore rocky ledge reefs off North Carolina indicate they can survive in temperate waters as well.

Hogfish are likely to be affected by increased ocean acidification as their diet is composed primarily of crustaceans and mollusks.

Hogfish have a moderately slow population growth rate, as evidenced by a low von Bertalanffy growth coefficient, relatively delayed ages at maturity and transition, a large maximum body size, a maximum age of 25 years, and a moderate value for natural mortality rate.

A study of hogfish populations in Florida Keys protected areas versus unprotected areas found virtually no reproduction in the fished areas compared to populations in the marine protected areas (Munoz *et al.* 2010). A microsatellite study of hogfish found that there was distinct genetic structure in populations from west Florida, Florida Keys-east Florida, and Georgia-North Carolina populations (Seyoum *et al.* 2014).

The most recent hogfish population assessment divided the hogfish population into three populations based upon genetic analysis. The West Florida population, which includes most of the Gulf of Mexico except for the Florida Keys, is not overfished or undergoing overfishing. The Florida Keys/East Florida population, which includes the Florida Keys and the east coast of Florida, is overfished and experiencing overfishing. The Georgia-North Carolina population's overfishing and overfished status is unknown. The bulk of fishing pressure in all regions comes from the recreational sector.

Other potential stressors for hogfish include possible anthropogenic pollution and alteration of seagrass bed nursery habitat, coral bleaching, temperate reef degradation, and lionfish predation.

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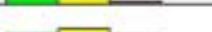
King mackerel - *Scomberomorus cavalla*

Overall Vulnerability Rank = Moderate 

Habitat Sensitivity = Low 

Climate Exposure = Very High 

Data Quality = 70% of scores ≥ 2

<i>Scomberomorus cavalla</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	1.8	2.6		Low Moderate High Very High
	Prey Specificity	1.5	2.4		
	Adult Mobility	1.5	2.8		
	Dispersal of Early Life Stages	2.2	2		
	Early Life History Survival and Settlement Requirements	1.8	1.4		
	Complexity in Reproductive Strategy	1.6	2.2		
	Spawning Cycle	1.8	2.4		
	Sensitivity to Temperature	1.5	2.6		
	Sensitivity to Ocean Acidification	1.5	1.6		
	Population Growth Rate	2	2.2		
	Stock Size/Status	1.6	2.6		
	Other Stressors	1.6	1.6		
	Sensitivity Score		Low		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	1.7	2.4		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.7	2		
	Salinity	3.7	3		
	Sea Level Rise	1	0		
	Sea Surface Temperature	4	3		
	Exposure Score		Very High		
Overall Vulnerability Rank		Moderate			

Overall Climate Vulnerability Rank: **Moderate.** (96% bootstrap results in Moderate, 4% bootstrap results in Low).

Climate Exposure: **Very High.** The three exposure factors contributing to a very high climate exposure score for king mackerel were sea surface temperature (4.0), ocean acidification (4.0), and salinity (3.7). Primary productivity (1.7) and hypoxia (1.7) were in the moderate to low categories.

Biological Sensitivity: **Low.** The main sensitivity attributes contributing to a low biological sensitivity score for king mackerel were prey specificity (1.5), adult mobility (1.5), sensitivity to temperature (1.5), sensitivity to ocean acidification (1.5), stock size/status (1.6), and other stressors (1.6).

Distributional Vulnerability Rank: **High.** The top three attributes contributing to king mackerel's high vulnerability to distribution shift ranking were very highly to highly mobile adults (1.5), low sensitivity to temperature (1.5), and moderate to low habitat specificity (1.8). Early life stages experience high dispersal (2.2).

Data Quality: All but two of the data quality scores were 2 or greater. Information is needed in the areas of early life stage survival and settlement requirements (1.4) and sensitivity to ocean acidification (1.6) as well as in other stressors (1.6). Ocean acidification has a high exposure score (4.0) and a sensitivity to ocean acidification has a relatively low data quality score (1.6).

Climate Effects on Abundance and Distribution: King mackerel growth was found to have a negative relationship with a low-frequency climate signal, the Atlantic Multidecadal Oscillation (Dzaugis *et al.* 2017). Most elements of the king mackerel life history -- including adult migrations, spawning, larval growth and distribution, and juvenile distributions -- appear to be closely related to specific temperature and salinity ranges. Because both temperature and salinity is expected to change, king mackerel dynamics may be impacted at multiple life stages.

Life History Synopsis: King mackerel are a fast-growing coastal pelagic species that are found throughout the Gulf of Mexico, Atlantic and Caribbean regions, and are managed jointly by the Gulf of Mexico and South Atlantic Fishery Management Councils as a single stock with separate migratory groups. Tagging data, genetic studies, and comparisons of otolith shape support the idea that there is a single stock with separate populations that form distinct migratory groups, including an eastern and western population in the Gulf of Mexico (SEDAR 2014, and refs within). Eastern and western populations of king mackerel in the Gulf of Mexico migrate respectively to Mexican waters and South Florida, where they overwinter and mix with Mexican and Atlantic populations. As temperatures warm in the spring, they then migrate back to the central Gulf, tending to follow a specific temperature range (Beaumariage 1973). Spawning occurs on the continental shelf between Texas and northwest Florida, from May to October, in areas of low turbidity, with salinities around 30 ppt and temperatures of approximately 27°C. Eggs are spawned and fertilized in pelagic environment and hatch after 24 hours (Finucane *et al.* 1986, Grimes *et al.* 1990). Highest abundances of small juveniles are found in the middle shelf (65 to 135m) whereas larger juveniles appear to occur in shallower depths (Grimes *et al.* 1990).

Larvae are commonly found in temperatures between 26 - 31°C and in Mississippi River discharge frontal zones with salinities of 26-31 ppt (Williams 1991). Larval growth is approximately 0.89 mm per day, although faster growth rates have been observed in the Mississippi River plume area (McEachran 1980, Grimes *et al.* 1990, Williams 1991). Individuals reach a maximum age of 24 years and can mature as quickly as two years. (Palmer *et al.* 2013). Growth is dimorphic, with females growing faster than males, and also varies by region (SEDAR 2014). Juveniles and adults are piscivorous; a study of juvenile stomachs from Texas waters showed that diet consisted almost entirely of fish, primarily engraulids and clupeids. (Naughton and Saloman, 1981). Adults are opportunistic feeders and prey on a variety of fishes.

King mackerel are targeted by recreational and commercial fisheries, with a small gillnet fishery operating in some areas. The most recent stock assessment estimated that the Gulf of Mexico stock of King Mackerel was not overfished and not undergoing overfishing (SEDAR 2020).

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Lane snapper - *Lutjanus synagris*

Overall Vulnerability Rank = Low ■

Habitat Sensitivity = Low ■

Climate Exposure = High ■

Data Quality = 65% of scores ≥ 2

<i>Lutjanus synagris</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	1.8	3		Low Moderate High Very High
	Prey Specificity	1.6	3		
	Adult Mobility	1.8	2		
	Dispersal of Early Life Stages	1.8	2.4		
	Early Life History Survival and Settlement Requirements	1.9	1.8		
	Complexity in Reproductive Strategy	2.1	2.2		
	Spawning Cycle	2.1	2.2		
	Sensitivity to Temperature	1.6	2.4		
	Sensitivity to Ocean Acidification	1.8	1.8		
	Population Growth Rate	1.7	2.6		
	Stock Size/Status	1.9	2		
	Other Stressors	2.2	1.8		
Sensitivity Score		Low			
Exposure Factors	Air Temperature	1	0		
	Hypoxia	1.7	1.2		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.8	2		
	Salinity	3.5	3		
	Sea Level Rise	2.2	1.8		
	Sea Surface Temperature	4	3		
Exposure Score		High			
Overall Vulnerability Rank		Low			

Overall Climate Vulnerability Rank: **Low.** (52% bootstrap results in Low, 48% bootstrap results in Moderate).

Climate Exposure: **High.** The top three attributes contributing to a high climate exposure ranking for lane snapper were sea surface temperature (4.0), ocean acidification (4.0), and salinity (3.5). Sea level rise (2.2), primary productivity (1.8), and hypoxia (1.7) were all approximately in the moderate category.

Biological Sensitivity: **Low.** The sensitivity attributes contributing to a low biological sensitivity score for lane snapper were prey specificity (1.6), sensitivity to temperature (1.6), and population growth rate (1.7).

Distributional Vulnerability Rank: **High.** The top three attributes contributing to lane snapper's high vulnerability to distribution shift ranking include moderate to low sensitivity to temperature (1.6), highly to very highly dispersive early life stages (1.8), moderate to low habitat specificity (1.8). The adults are also highly to very highly mobile (1.8).

Data Quality: All of the data quality scores except five were 2 or greater. Early life history survival and settlement requirements, sensitivity to ocean acidification, other stressors (1.8), and sea level rise all had 1.8 data quality scores. Hypoxia had a data quality score of 1.2.

Climate Effects on Abundance and Distribution: Few studies that have examined the effect of climate on the abundance and distribution of lane snapper. Fodrie *et al.* (2010) noted that when comparing catches in seagrass beds in the northern Gulf of Mexico between the 1970s and 2006/2007, lane snapper went from not being present to the eighth most abundance species in the collections. In additions, Fodrie *et al.* (2010) documented an increase in the air and sea surface temperatures during the same period. Gericke *et al.* (2014) also showed increases in the abundance of lane snapper in the seagrass nurseries. Ocean acidification may have an indirect effect on lane snapper, as amphipods and decapod crustaceans (mainly shrimp and crabs) were the primary diet items found in stomachs in the Gulf of Mexico (Franks and VanderKooy 2000).

Life History Synopsis: Lane snapper are an estuarine dependent species that is widely distributed along the coast from North Carolina to Brazil, including Bermuda and the Bahamas, throughout the Gulf of Mexico and Caribbean (Lindeman *et al.* 2016). Adults are typically found offshore around natural and artificial reefs along with other hard bottom areas, usually between 30-120 m (Rivas 1970, Thompson and Munro 1974, Bortone and Williams 1986), but have been found out to 400 m (Anderson 2002). Bortone and Williams (1986) observed that once lane snapper reached maturity, they tended to remain in a certain area.

Lane snapper have a protracted spawning season from March through September with seasonal peaks in activity from June to August (Manooch and Mason 1984). They are known to form large spawning aggregations offshore (Wicklund 1969, Thompson and Munro 1974). Their eggs are pelagic and are transported into estuaries, which are used as nursery habitat (Lindeman and Snyder 1999). Juveniles are regularly found in seagrass beds and other nearshore hardbottom habitats (Manooch and Mason 1984, Fodrie *et al.* 2020) and have shown expansion throughout

parts of the northern Gulf of Mexico since the 1970s (Fodrie *et al.* 2010). Nurseries may supply individuals to a wide-ranging area, with Fodrie *et al.* (2020) finding lane snapper from Florida, Mississippi and Alabama seagrass beds on offshore Alabama artificial reefs.

Franks and Vanderkooy (2000) found the most abundant diet items for juvenile lane snapper were amphipods, decapod crustaceans, and fishes. Based on the percent Index of Relative Importance, shrimp remains were the most important prey item (Franks and Vanderkooy 2000). In Colombia, Duarte and Garcia (1999) found lane snapper to be a generalist, opportunistic carnivore, primarily feeding on brachyuran crustaceans, especially portunid crabs, shrimps (suborders Penaeidea and Caridea), bony fishes, and stomatopods.

In the Gulf of Mexico, lane snapper reached maturity at 2 years old and reached a maximum age of 17 years (Johnson *et al.* 1995). Brennan (2004) indicated moderately fast growth, with a von Bertalanffy growth coefficient of 0.33 for north Florida fish and 0.63 for fish from south Florida/Florida Keys (Brennan 2004). Johnson *et al.* (1995) estimated natural mortality (Z) ranging from 0.3750 to 0.5767 and natural mortality (M) from 0.1125 to 0.2388 in the northern Gulf of Mexico.

In the Gulf of Mexico, a data-limited stock assessment was attempted for lane snapper, but was unsuccessful (SEDAR 49 2016). Although it is currently managed as a single stock, Karlsson *et al.* (2009) has shown there is a significant amount of genetic variation between lane snapper found in the eastern and western Gulf of Mexico, with the break in populations occurring at 88° longitude.

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Lemon shark - *Negaprion brevirostris*

Overall Vulnerability Rank = Moderate ■

Habitat Sensitivity = Moderate ■

Climate Exposure = High ■

Data Quality = 75% of scores ≥ 2

<i>Negaprion brevirostris</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	1.8	2.8		Low Moderate High Very High
	Prey Specificity	1.4	2.8		
	Adult Mobility	1.3	2.8		
	Dispersal of Early Life Stages	1.4	2.8		
	Early Life History Survival and Settlement Requirements	1.1	2.2		
	Complexity in Reproductive Strategy	2.1	2.8		
	Spawning Cycle	2.2	2.6		
	Sensitivity to Temperature	1.4	2.8		
	Sensitivity to Ocean Acidification	1.2	2.4		
	Population Growth Rate	3.5	1.8		
	Stock Size/Status	2.3	1		
	Other Stressors	2.8	2.2		
Sensitivity Score		Moderate			
Exposure Factors	Air Temperature	1	0		
	Hypoxia	1.5	2.2		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.8	2		
	Salinity	3.5	3		
	Sea Level Rise	1	0		
	Sea Surface Temperature	4	3		
Exposure Score		High			
Overall Vulnerability Rank		Moderate			

Overall Climate Vulnerability Rank: **Moderate.** (49% bootstrap results in Moderate, 47% bootstrap results in High, and 1% bootstrap results in Low).

Climate Exposure: **High.** Sea surface temperature (4.0), ocean acidification (4.0), and salinity (3.5) were the primary factors contributing to lemon shark's high climate vulnerability ranking. Primary productivity (1.8) was ranked as moderate to low, and hypoxia (1.5) was ranked as low to moderate.

Biological Sensitivity: **Moderate.** The sensitivity attributes contributing to a moderate biological sensitivity score for lemon shark were stock size/status (2.3), complexity in reproductive strategy (2.1), and spawning cycle (2.2). Population growth rate (3.5) was scored as high to very high, while early life history survival and settlement requirements (1.1) was scored as low.

Distributional Vulnerability Rank: **High.** All four attributes contributed to lemon shark's high vulnerability to distribution shift ranking: very high to high adult mobility (1.3), low to moderate sensitivity to temperature (1.4), very highly to highly dispersive early life stages (1.4), and low to moderate habitat specificity (1.8).

Data Quality: All data quality scores except one were 2 or greater. Stock size/status had a data quality score of 1.0 indicating that more information is needed in this area.

Climate Effects on Abundance and Distribution: Climate stressors have been related to lemon shark movements and post-release survival. On the Florida east coast, water temperatures aligned with seasonal migration patterns to and from mating and pupping grounds (Kessel *et al.* 2014). In the Bahamas, juvenile lemon sharks were more likely to suffer post-release mortality at high water temperatures (>31°C) (Danylchuk *et al.* 2014).

Life History Synopsis: The lemon shark (*Negaprion brevirostris*) is a moderately-large shark (maximum length 250 to 300 cm), late-maturing coastal shark species. Males mature at 11.6 years, and females at 12.7 years of age (Brown and Gruber 1988). Their Von Bertalanffy K is estimated as 0.057 (Brown and Gruber 1988), and the intrinsic rate of population increase as 0.034 (Smith *et al.* 1998). Juveniles' diet consists mostly of teleost fish, followed by small crustaceans, molluscs, and octopods (Schmidt 1986, Cortes and Gruber 1990, Weatherbee *et al.* 1990). Adults consume predominantly teleosts, as well as other cartilaginous fish (Springer 1950, Cortés and Gruber 1990).

Adults undergo seasonal migrations along the US eastern seaboard (such as South Florida to the Carolinas), and females return to nursery areas for giving birth. Recurrent aggregations of adults have been reported near the coast of Jupiter, Florida (Kessel *et al.* 2014). Although females show site fidelity for pupping, there is some level of habitat generalism. Adults inhabit shallow areas including coral reefs, mangrove ecosystems, sand- and mud-bottom areas, saline creeks, enclosed bays/sounds, and river mouths (Yeiser *et al.* 2008, Knip *et al.* 2010, DiBattista *et al.* 2011, Kessel *et al.* 2014).

Juveniles use shallow coastal areas, lagoons, and mangrove ecosystems (Morrissey and Gruber 1993a, 1993b, Heupel *et al.* 2007, DiBattista *et al.* 2011). Juveniles/neonates show high site fidelity to these nursery areas (Chapman *et al.* 2009), suggesting vulnerability to habitat modification or water quality declines given proximity to human activity. Large juveniles continue to use these habitat types, with some migrations away from sheltered areas.

Juveniles and neonate habitats are vulnerable to habitat destruction (shoreline development), water quality declines, and human activity in general (Morrissey and Gruber 1993, Feldheim *et al.* 2001, Heupel *et al.* 2007, Jennings *et al.* 2008, Knip *et al.* 2010). Fatalities were recorded after a harmful algal bloom (HAB) in nearshore Florida waters (Nam *et al.* 2011). Mercury was also found after the HAB event, but detrimental levels for the species are unknown.

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Lesser amberjack - *Seriola fasciata*

Overall Vulnerability Rank = Low ■

Habitat Sensitivity = Low ■

Climate Exposure = High ■

Data Quality = 40% of scores ≥ 2

<i>Seriola fasciata</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	1.6	2.6		Low Moderate High Very High
	Prey Specificity	1.6	2.2		
	Adult Mobility	1.5	2.6		
	Dispersal of Early Life Stages	2.2	1.8		
	Early Life History Survival and Settlement Requirements	1.8	1		
	Complexity in Reproductive Strategy	1.9	1.6		
	Spawning Cycle	2	1.6		
	Sensitivity to Temperature	1.7	2.4		
	Sensitivity to Ocean Acidification	1.6	1.8		
	Population Growth Rate	1.9	1.2		
	Stock Size/Status	1.9	1		
	Other Stressors	1.7	1.4		
	Sensitivity Score		Low		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	1.6	1.8		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.5	2		
	Salinity	2.7	3		
	Sea Level Rise	1	0		
	Sea Surface Temperature	4	3		
	Exposure Score		High		
Overall Vulnerability Rank		Low			

Overall Climate Vulnerability Rank: **Low.** (100% bootstrap results in Low).

Climate Exposure: **High.** The top three exposure factors contributing to a high climate exposure score for lesser amberjack were sea surface temperature (4.0), ocean acidification (4.0), and salinity (2.7). Hypoxia (1.6) was low to moderate, and primary productivity (1.5) was moderate to low.

Biological Sensitivity: **Low.** The sensitivity attributes contributing to a low biological sensitivity score for lesser amberjack were adult mobility (1.5), habitat specificity (1.6), prey specificity (1.6), and sensitivity to ocean acidification (1.6). The highest mean sensitivity attribute score was for dispersal of early life stages (2.2).

Distributional Vulnerability Rank: **High.** The top three attributes contributing to lesser amberjack's high vulnerability to distribution shift were highly mobile adults (1.5), low to moderate habitat specificity (1.6), and low to moderate sensitivity to temperature (1.7). Early life stage dispersal (2.2) was estimated to be high to moderate.

Data Quality: A number of data quality scores were less than 2.0 including early life history survival and settlement requirements (1.0), stock size/status (1.0), population growth rate (1.2), other stressors (1.4) spawning cycle (1.6) complexity in reproductive strategy (1.6), sensitivity to ocean acidification (1.8) dispersal of early life stages (1.8), and hypoxia (1.8). This indicates a considerable need for information on lesser amberjack life history and environmental responses.

Climate Effects on Abundance and Distribution: No studies were found regarding the effects of climate on Lesser amberjack abundance and distribution occurring in the Gulf of Mexico. However, working in the South Atlantic, Bacheler *et al.* (2022) suggest that amberjacks may shift distributions poleward in response to increasing temperatures. Such distribution shifts are also discussed for Tasmania (Stuart-Smith *et al.* 2018) and the Mediterranean (Andaloro *et al.* 2005, Deidum *et al.* 2011) where it became a commercially harvested species a decade after the first recorded occurrence identification in 1989 (Sonin *et al.* 2009). Because of the potential for distribution shifts, Bacheler *et al.* (2022) recommend continued monitoring in order to better characterize climate-related distribution shifts as such shifts can influence stock assessments.

Life History Synopsis: Lesser amberjack is listed as a data-poor species in the Gulf of Mexico and much of the information that would support a stock assessment must come from congeners, meta-analyses, or via the dynamics of an indicator species in an assemblage that includes lesser amberjack (Shertzer and Williams 2008, Adams *et al.* 2016).

Lesser amberjack occurs along the eastern seaboard of the Americas from Massachusetts to Brazil (Smith-Vaniz *et al.* 1990). They also occur along the eastern Atlantic from Spain to Ghana and recently made incursions into the Mediterranean as far as the Levant (Smith-Vaniz *et al.* 1990, Sonin *et al.* 2009). Adults are found in near-bottom waters ranging from 55 to 130 m. Large juveniles can be pelagic or benthic and occur on the continental shelf (Smith-Vaniz *et al.* 1990). Smaller juveniles are epipelagic (Smith-Vaniz *et al.* 1990). Lesser amberjack generally prey upon smaller fishes and cephalopods (Smith-Vaniz *et al.* 1990). Stomach content analysis

suggests that larger individuals collected in the northwestern Atlantic may specialize to some degree on northern shortfin squid (Galbraith *et al.* 2002).

Lesser amberjack in the northern Gulf experienced statistically significant declines that may have been due to invasive lionfish predation and/or the 2010 Deepwater Horizon oil spill (Dahl *et al.* 2016).

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Mutton snapper - *Lutjanus analis*

Overall Vulnerability Rank = Moderate ■

Habitat Sensitivity = Low ■

Climate Exposure = Very High ■

Data Quality = 65% of scores ≥ 2

<i>Lutjanus analis</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	2	2.8		Low Moderate High Very High
	Prey Specificity	1.6	2.4		
	Adult Mobility	1.9	2.2		
	Dispersal of Early Life Stages	1.8	2.4		
	Early Life History Survival and Settlement Requirements	2.4	1.6		
	Complexity in Reproductive Strategy	2.4	2.8		
	Spawning Cycle	2.5	2.6		
	Sensitivity to Temperature	2.4	2		
	Sensitivity to Ocean Acidification	2.1	1.6		
	Population Growth Rate	2.5	2.4		
	Stock Size/Status	2.4	1.8		
	Other Stressors	2.3	1.6		
Sensitivity Score		Low			
Exposure Factors	Air Temperature	1	0		
	Hypoxia	1.6	1.4		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.9	2		
	Salinity	3.8	3		
	Sea Level Rise	2.1	2.2		
	Sea Surface Temperature	4	3		
Exposure Score		Very High			
Overall Vulnerability Rank		Moderate			

Overall Climate Vulnerability Rank: **Moderate.** (63% bootstrap results in High, 37% bootstrap results in Moderate).

Climate Exposure: **Very High.** Sea surface temperature (4.0), ocean acidification (4.0), and salinity (3.8) contributed to a very high climate exposure score for mutton snapper. Sea level rise (2.1), and primary productivity were ranked as moderate, while hypoxia (1.6) was ranked as low to moderate.

Biological Sensitivity: **Low.** The sensitivity attributes contributing to a low biological sensitivity score for mutton snapper were prey specificity (1.6), dispersal of early life stages (1.8), and adult mobility (1.9).

Distributional Vulnerability Rank: **High.** The attributes contributing to mutton snapper's high vulnerability to distribution shift ranking were highly dispersive early life stages (1.8), highly to very highly mobile adults (1.9), and moderate habitat specificity (2.0).

Data Quality: All data quality scores were 2 or greater except early life history survival and settlement requirements (1.6), sensitivity to ocean acidification (1.6), stock size/status (1.8), other stressors (1.6), and hypoxia (1.4) indicating that there are a number of areas requiring additional research for mutton snapper.

Climate Effects on Abundance and Distribution: Little information is available regarding the effects of climate change on the distribution and abundance of mutton snapper. Warming temperatures may allow the species to expand poleward.

Life History Synopsis: Mutton snapper is a tropical/subtropical coastal reef species widely distributed from North Carolina to Florida, including Bermuda and the Bahamas, through the Gulf of Mexico from the Florida Keys north to Tampa, off the Mississippi Delta region, and from south Texas south along Mexico to Cuba, throughout the Caribbean Sea, and along South America to Santa Catarina, Brazil (Cervigón 1993). The latitudinal distribution is 43 degrees N - 28 degrees S. Mutton snapper are thought to be a single genetic stock along the US eastern seaboard, the Gulf of Mexico and south to Brazil (Shulzitski *et al.* 2005). Within the Gulf of Mexico, they are typically most abundant off the southwest coast of Florida.

Preferred temperatures range from 19-28 degrees C, with a mean of 24.8 degrees C. Mutton snapper are found in depths of 1-95 m. Mutton snapper are most commonly found in salinities ranging from 20-35 ppt, values indicative of habitats ranging from seagrass beds and mangrove creeks to offshore reefs.

This species inhabits reef, mangrove creeks, seagrass beds, and rubble bottoms, occurring over continental as well as insular shelf areas in clear waters (Cervigón *et al.* 1992). Early life stages can be found among a variety of structural habitat types including settlement stages in seagrasses. Large adults are usually found among rocks and coral while juveniles occur over sandy, vegetated (usually *Thalassia*) habitats (Starck 1971, Cervigón 1993). The juvenile usage of several backreef habitats in comparison to congeners is reviewed in Nagelkerken (2009).

Juvenile stages feed on mainly crustaceans, whereas those 6 cm or larger consume post-larval and juvenile fish (Sierra and Popova 1997). Adult mutton snapper are carnivorous trophic generalists and use a great variety of prey, feeding during the day as well as at night. The main prey are bony fishes, crustaceans, molluscs and echinoderms (Allen 1985).

Mutton snapper are not limited in their mobility. They exhibit solitary behavior normally, but will come together in large spawning aggregations. Acoustic tracking of one individual near no-take marine reserves in the Dry Tortugas, Florida, estimated a home range of about 7.5 km² (Farmer and Ault 2011). While this suggests that subpopulations separated by 100 km or less may be able to respond independently to disturbances, there may be limited exchange between the subpopulation in the Gulf of Mexico and the wider Caribbean Sea. Feeley *et al.* (2018) found that individual mutton snapper in the Dry Tortugas migrated as many as five times during the year up to 35 km to spawning grounds at Riley's Hump.

Mutton snapper spawning aggregations are documented from Belize (Heyman and Kjerfve 2008) with a sharp reduction in landings and fishing effort in the late 1980s (Grandados-Dieseldorff *et al.* 2013). In Cuba, spawning aggregations occur on several shelf regions between May and August in depths of 20-40 m (Claro and Lindeman 2003). A well-known spawning aggregation site at Riley's Hump occurs during summer months (June-August) on lunar cycles. Aggregations occurred at the La Parguera, Puerto Rico, shelf edge during at night following the full moon of April and May of 2003 at an average depth of 20-40 m over rocky coralline bottoms and sandy bottoms with abundant gorgonians (Esteves 2005).

Mutton snapper in the Florida Keys/Dry Tortugas spawn April - August, peaking in May -July (Feeley *et al.* 2018). Individuals have been observed in spawning condition in the US Caribbean from February through July (Erdman 1976), and have been reported in spawning condition by anglers from April through September in east central Florida (Tishler-Meadows 2012).

Fertile eggs are pelagic, floating to the surface and hatching in approximately 24 hours. Hatch size is 2.22.5 mm and settlement occurs at 27-37 days (mode 31 days) after hatching at 15-18 mm. Pelagic eggs and larvae rely on tidal currents for transport into suitable estuaries where they utilize shallow water high salinity seagrass beds as nursery habitat. Juveniles and subadults are found in seagrass beds as well as mangrove habitats and nearshore hardbottom.

The species appears to have a low population growth rate, with an east coast Florida study finding a maximum age of 29 years (Burton 2002), while a study from the Gulf of Mexico that had deep-water commercially caught fish found a maximum age of 40 years (Faunce *et al.* 2007). Maturity is not achieved until age 5 or 6. Natural mortality was estimated at $M = 0.29$, and the von Bertalanffy growth coefficient was 0.16.

The most recent stock assessment (SEDAR, 2015) indicated that Gulf of Mexico mutton snapper (including the Keys/Tortugas) are not experiencing overfishing (rate of removal is not too high), and are not overfished (stock abundance is too low; $SSB_{2013}/SSB_{MSY} = 1.13$), but the adult population is smaller than previously estimated. Therefore, a reduction in mutton snapper harvest limits was necessary to ensure that overfishing does not occur

(<https://www.fisheries.noaa.gov/bulletin/final-rulemodify-gulf-mexico-mutton-snapper-and-gag-management-measures>).

In addition to fishing, other stressors that could impact mutton snapper include environmental alterations of their nursery habitat due to development, lionfish predation on juveniles and subadults on nearshore reefs, disruption of favorable tidal transport currents and possibly increasing temperatures.

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Nassau grouper - *Epinephelus striatus*

Overall Vulnerability Rank = Very High ■

Habitat Sensitivity = High ■

Climate Exposure = Very High ■

Data Quality = 80% of scores ≥ 2

<i>Epinephelus striatus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	2.9	3		Low Moderate High Very High
	Prey Specificity	1.8	2.6		
	Adult Mobility	2.5	2.8		
	Dispersal of Early Life Stages	2.1	2.6		
	Early Life History Survival and Settlement Requirements	2.5	2		
	Complexity in Reproductive Strategy	3	3		
	Spawning Cycle	3.6	3		
	Sensitivity to Temperature	2.4	3		
	Sensitivity to Ocean Acidification	2.4	2		
	Population Growth Rate	3.4	2.8		
	Stock Size/Status	3.4	2.1		
	Other Stressors	2.1	2		
	Sensitivity Score		High		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	1	0		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	2	2		
	Salinity	3.8	3		
	Sea Level Rise	1	0		
	Sea Surface Temperature	4	3		
	Exposure Score		Very High		
Overall Vulnerability Rank		Very High			

Overall Climate Vulnerability Rank: **Very High** (100% bootstrap results in Very High

Climate Exposure: **Very High.** The top three exposure factors contributing to a very high climate exposure for Nassau grouper were sea surface temperature (4.0), ocean acidification (4.0), and salinity (3.8). Primary productivity (2.0) was ranked moderate.

Biological Sensitivity: **High.** The sensitivity attributes contributing to a high biological sensitivity score for Nassau grouper were complexity in reproductive strategy (3.0), habitat specificity (2.9), early life history survival and settlement requirements (2.5), population growth rate (3.4), and stock size/status (3.4).

Distributional Vulnerability Rank: **Moderate.** The top three attributes contributing to Nassau grouper's moderate vulnerability to distribution shift ranking were high habitat specificity (2.9), highly to moderately mobile adults (2.5), and moderate to high sensitivity to temperature (2.4).

Data Quality: All data quality scores were 2 or greater. Early life history survival and requirements (2.0), sensitivity to ocean acidification (2.0), other stressors (2.0), and stock size/status (2.1) had the lowest data quality scores.

Climate Effects on Abundance and Distribution: Sea temperature plays an important role in providing an environmental cue for Nassau grouper to begin their migration to spawning aggregation sites. Studies have shown that spawning has occurred with sea temperatures ranging from 23.1-27.9°C, however a narrower temperature window of 24-27°C was found to be the most reproductively viable (Tucker 1994, Watanabe *et al.* 1995a, Tucker *et al.* 1996). If sea surface temperature rises in the future, it could cause lower yield spawning events or require the species to shift its geographical range (Science and Conservation of Fish Aggregations 2019).

Nassau grouper habitat degradation is also a potential impact of climate change. Rising sea surface temperature can jeopardize temperature sensitive corals, causing them to bleach, a potentially lifethreatening response (Hoegh-Guldberg 1999). Once the corals have died in response in this stressor, the three-dimensional calcium carbonate structure left behind becomes more susceptible to erosion and macro-algae recolonization (Marshall and Baird 2000, McClanahan *et al.* 2002). Ocean acidification is predicted to adversely affect reef building coral density by reducing the corals skeletal growth rate (Munday *et al.* 2008). Both sea surface temperature and ocean acidification could result in less available desirable habitat for the Nassau grouper.

Life History Synopsis: Nassau grouper is a slow-growing and long-lived serranid that is found in the tropical western Atlantic, as well as throughout the Caribbean and Gulf of Mexico. The population within the Gulf of Mexico is believed to be severely limited, with few reported sightings (Carter *et al.* 1994). In the Atlantic waters of the southeastern U.S. the range of Nassau grouper is limited to south Florida and the Florida Keys. This species was at one time the most important reef fishery species in the Caribbean; however, fishing on spawning aggregations and habitat loss have resulted in dramatic population declines throughout its range (Carter *et al.* 1994, Canty *et al.* 2019). Nassau grouper is listed as “critically endangered” by the International Union for Conservation of Nature and “threatened” under the US Endangered Species Act (Waterhouse *et al.* 2020). The commercial and

recreational fishery for Nassau grouper in the U.S. Atlantic federal waters has been closed since 1992. Harvest of the species is also prohibited in U.S. federal waters of the Gulf of Mexico.

Nassau grouper are believed to be protogynous hermaphrodites, developing first as females and transitioning to males (Carter *et al.* 1994). The change from female to male occurs around 300-800 mm (Jory and Iversen 1989). They form large spawning aggregations (up to 100,000 individuals) during the winter months (Jory and Iversen 1989). Spawning cues include lunar and diurnal cycles, water temperatures, and local current conditions (Chérubin *et al.* 2020). Spawning occurs on the outer reef slope or shelf break, and it is currently not known how these fish are able to locate their aggregation sites year after year (Chérubin *et al.* 2020). These large and seasonally predictable spawning aggregations make Nassau grouper particularly vulnerable to overfishing. There have been about 60-80 recorded spawning aggregations, consequently due to exploitation, many of those sites no longer exist (Science and Conservation of Fish Aggregations 2019). Fish spend a week or more at spawning sites, spawning over the course of a few nights on successive full moons from December to February. Nassau grouper spawn only a few days a month during three months of the year, and not all females participate in all spawning events (Heyman *et al.* 2019). In the Gulf of Mexico, spawning is believed to occur from December to February based upon data from observed spawning information from the Florida Keys and Cuba although spawning has not been observed within the Gulf of Mexico (Biggs *et al.* 2018).

The fertilized eggs hatch after ~24 h and remain pelagic for 35 to 45 days. Juveniles settle into algal mats and seagrass beds and are thought to recruit to juvenile habitats *en masse* following aggregation events (Shenker *et al.* 1993). Nassau grouper take 5-7 years to reach reproductive maturity and may live 29 or more years (Waterhouse *et al.* 2020). Nassau grouper are considered mature at 5 years and 40 cm (total length) and have an estimated natural mortality of 0.18 (Biggs *et al.* 2018).

Adult Nassau grouper habitat includes tropical and subtropical coral and rocky reefs, favoring higher relief structures (Carter *et al.* 1994, Stevens *et al.* 2019). Tagging studies have shown that adult Nassau grouper have a “strong home reef specificity” (Beaumariage and Bullock 1976), although they have been found to travel farther distances when residing in habitats with lower relief structures (Jory and Iversen 1989). In contrast to their small home range, adults will make long migrations to participate in spawning aggregations (Starr *et al.* 2007).

Nassau grouper are considered to be top trophic level predators on coral reefs. While the prey they consume varies by geographic location, gut content analysis studies show their predominant prey to be smaller sized fish (Carter *et al.* 1996). Crustaceans including crabs, lobster, shrimp, and cephalopods are also considered to be a significant portion of their diet (Carter *et al.* 1994). Shelled mollusks are infrequently consumed.

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Nurse shark - *Ginglymostoma cirratum*

Overall Vulnerability Rank = Low ■

Habitat Sensitivity = Low ■

Climate Exposure = High ■

Data Quality = 80% of scores ≥ 2

<i>Ginglymostoma cirratum</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	1.8	2.8		Low Moderate High Very High
	Prey Specificity	1.6	2.6		
	Adult Mobility	1.7	2.8		
	Dispersal of Early Life Stages	1.3	2.8		
	Early Life History Survival and Settlement Requirements	1	2.2		
	Complexity in Reproductive Strategy	1.8	2.2		
	Spawning Cycle	2	2.4		
	Sensitivity to Temperature	1.3	2.8		
	Sensitivity to Ocean Acidification	1.8	2.4		
	Population Growth Rate	3.4	1.6		
	Stock Size/Status	1.7	1		
	Other Stressors	2	2		
	Sensitivity Score		Low		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	1.8	2.2		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.8	2		
	Salinity	3.4	3		
	Sea Level Rise	2.2	2.6		
	Sea Surface Temperature	4	3		
	Exposure Score		High		
Overall Vulnerability Rank		Low			

Overall Climate Vulnerability Rank: **Low.** (71% bootstrap results in Low, 29% bootstrap results in Moderate).

Climate Exposure: **High.** The top three exposure factors that contributed to nurse shark's high climate exposure were sea surface temperature (4.0), ocean acidification (4.0) and salinity (3.4).

Biological Sensitivity: **Low.** The sensitivity attributes contributing to a low biological sensitivity score for nurse shark were early life history survival and settlement requirements (1.0), dispersal of early life stages (1.3), sensitivity to temperature (1.3), and prey specificity (1.6).

Distributional Vulnerability Rank: **High.** The top three attributes contributing to nurse shark's high vulnerability to distribution shift ranking were low to moderate sensitivity to temperature (1.3), very highly dispersive early life stages (1.3), and highly mobile adults (1.7). Nurse sharks are also habitat generalists (1.8).

Data Quality: All data quality scores were 2 or greater except stock size/status (1.0) and population growth rate (1.6).

Climate Effects on Abundance and Distribution: No studies have directly examined the impact of climate change on the population productivity of nurse sharks. The primary distribution of nurse shark could move north if portions of the range warm above the preferred water temperature of the species. However, it is unlikely the distribution would move north of approximately Cape Hatteras as this species is primarily benthic and bottom waters north of Cape Hatteras are characterized by relatively cool waters moving south associated with the Labrador Current. Increased water temperatures could have significant life history impacts related to faster growth, earlier maturation, and reduced reproductive periodicity in specific regions, however, in most cases, baseline data are lacking that will facilitate comparison. It is not possible to determine the impact of climate change on the diet of nurse sharks as they are not specialists and consume a wide variety of prey.

Life History Synopsis: Nurse sharks are large-bodied and reach a maximum size of approximately 3 m total length (Castro 2011). In US waters of the western North Atlantic Ocean, the primary range of nurse sharks is from North Carolina to Texas (Castro 2011). In the western Atlantic Ocean, on a broader scale, the range of the nurse shark extends into the Caribbean Sea and western South Atlantic Ocean (Bigelow and Schroeder 1954). The species occurs in shallow, nearshore marine waters out to a depth of approximately 60 m (Ulrich *et al.* 2005, Hannan *et al.* 2012). Unlike some other species of coastal sharks, there does not appear to be any depth segregation based on sex or size for older juveniles and adults and nurse sharks are often found in aggregations thought to be related to substrate and prey availability (NMFS, unpublished data, Castro 2011, Hannan *et al.* 2012). Young of the year and young juveniles are typically found in the shallower depth range of the species (Castro 2000).

While the extent of mating and nursery areas in US waters is not fully understood, shallow waters associated with the Florida Keys and the Dry Tortugas are known to be utilized by nurse sharks for these purposes. Tag recapture data indicate that nurse shark do not make large scale movements comparable to other coastal sharks (Pratt *et al.* 2018, Kohler and Turner 2019),

therefore, it is likely that mating and nursery areas exist in other locales (e.g., DeAngelis *et al.* 2008).

Nurse sharks are placentally viviparous, have a biennial reproductive cycle, a brood size ranging from 21-50 offspring and give birth during early winter after a gestation period of 5-6 months (Castro 2000).

Age and growth estimates nurse sharks are essentially non-existent; however, based on length data obtained during a tag-recapture, Carrier and Luer (1990) determined that juvenile nurse sharks captured in the Florida Keys grew an average of 13.1cm/year. Male nurse sharks mature at approximately 215 cm total length whereas females mature at a slightly larger size ranging from 223-231 cm TL (Castro 2000).

The diet of nurse sharks consists of a wide variety of invertebrates, including, cephalopods, crabs, and shrimp, and to a larger extent, small fishes, such as those within the family Haemulidae (Bigelow and Schroeder 1948, Castro 2000).

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Pinfish - *Lagodon rhomboides*

Overall Vulnerability Rank = Low ■

Habitat Sensitivity = Low ■

Climate Exposure = High ■

Data Quality = 85% of scores ≥ 2

<i>Lagodon rhomboides</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	Low Moderate High Very High
Sensitivity Attributes	Habitat Specificity	1.9	2.8	</	

Overall Climate Vulnerability Rank: **Low.** (97% bootstrap results in Low, 3% bootstrap results in Moderate).

Climate Exposure: **High.** The top exposure factors contributing to pinfish's high climate exposure were sea surface temperature (4.0), ocean acidification (4.0), and salinity (3.1). Sea level rise (2.3) and hypoxia (2.2) were scored as moderate to high. Primary productivity was scored as moderate to low (1.7). Juvenile and small adult pinfish are found primarily in shallow inshore areas around seagrass beds, marsh, rip-rap, etc. while larger adults can be found offshore (Binion-Rock *et al.* 2019; Faletti *et al.* 2019). Like many other shallow habitats, these factors are expected to impact all of species occupying these niches.

Biological Sensitivity: **Low.** The sensitivity attributes that contributed to a low biological sensitivity score for pinfish were sensitivity to temperature (1.5), population growth rate (1.6), and complexity in reproductive strategy (1.7). All sensitivity attribute means except other stressors (1.3) were two or less. Pinfish are cosmopolitan in nature, highly mobile, omnivorous, and reproduce at an early age, and are routinely found in habitats that undergo large annual temperature fluctuations. As such, they are not overly sensitive to any particular attribute.

Distributional Vulnerability Rank: **High.** The top three attributes contributing to pinfish's high vulnerability to distribution shift were moderate sensitivity to temperature (2.0), highly to very highly dispersive early life stages (1.8), and moderate to low habitat specificity (1.9). Pinfish also had highly mobile adults (1.9). Pinfish is a species found inshore and offshore, is highly fecund, and cosmopolitan in nature. They spawn offshore in the fall and eggs and larvae disperse to the estuaries. Pinfish are expected to move to accommodate new niches opened up by climate effects. Where bounded northsouth, they are expected to be able to cope with ambient conditions or move into deeper waters or into fresher waters before moving offshore to spawn.

Data Quality: All data quality scores except stock size/status (1.4) were 2 or greater. Although little is known about the population structure of pinfish, enough is known about their life history to have confidence in the quality of the information.

Climate Effects on Abundance and Distribution: Impacts from Climate Effects are expected due to habitat loss resulting from the loss of seagrasses; however, in locations without seagrasses, submerged aquatic vegetation and structured habitats support pinfish populations. As such, impacts on abundance may be minimal if alternative habitats are available. Because they are already found along the Atlantic coast and throughout the Gulf of Mexico, distribution shifts are likely to be inshore due to saltwater intrusion into traditionally freshwater habitats.

Life History Synopsis: Pinfish is a widespread-subtropical and estuarine dependent species that occurs throughout the southeast U.S. and Gulf of Mexico. They can also be found at lower densities in the MidAtlantic region. Pinfish have been recognized as an important forage fish, particularly due to the high abundance of juveniles in many estuarine systems (Binion-Rock *et al.* 2019, Camp *et al.* 2019, Faletti *et al.* 2019). While pinfish are often included in community level studies and are a model species for estuarine habitat use, older life stages are not well

described. Little is known about the sub-annual movement patterns of pinfish or if any stock structure exists; however, they exhibit movement patterns similar to many other estuarine fishes that spawn offshore, settle inshore, grow in estuaries, then migrate back offshore to complete the cycle (Caldwell 1957). The oldest individuals identified have been age-7, based on a study off the west Florida coast where the largest pinfish were between 200 and 250 mm standard length (Nelson 2002).

Limited information is available on the reproductive ecology of pinfish. Cody and Bortone (1991) concluded that most individuals above 100 mm were mature in Gulf of Mexico collections, which corresponds to age-1 fish (Nelson 2002). Based on examination of gonads from adult fish in the Gulf of Mexico, the spawning season ranges from late fall through the winter (Cody and Bortone 1991, Nelson 2002). Pinfish are known to spawn on the continental shelf, which is supported by larval collections on the west Florida continental shelf during winter, mostly in water < 50 m depth (Houde *et al.* 1979). Studies from an aquaculture setting suggest that, like other sparid species, pinfish are highly fecund batch spawners and pelagic eggs and larvae develop quickly (Broach *et al.* 2017). Pinfish have also been known to aggregate in the Fall into Fish Spawning Aggregations (Gibson 2014)

Larval pinfish are tidally transported through inlets during the winter and early spring. For example, near Beaufort Inlet, NC pinfish were the second most abundant species in larval collections from incoming surface waters over an 18 year period (Taylor *et al.* 2009). Juvenile pinfish utilize a variety of estuarine habitats. In NC, pinfish are the dominant species in seagrass habitats (Baillie *et al.* 2015), and they have been shown to be highly associated with submerged aquatic vegetation in other systems (Faletti *et al.* 2019). However, their habitat requirements are fairly adaptable and they are also known to use oyster reefs, salt marshes, and tidal creeks (Lehnert and Allen 2002, Baillie *et al.* 2015, Kimball *et al.* 2020). Further, pinfish appear to be more adaptable than other species in using human-modified structures such as bulkheads and aquaculture gear (Gittman *et al.* 2016, Powers *et al.* 2007). Larger pinfish are generally found in deeper waters on the continental shelf at depths shallower than 30m (Nelson 2002, Whitfield *et al.* 2014). Adult pinfish can be found year-round on the continental shelf, both over soft substrates and structured bottom (Whitfield *et al.* 2014, Ocean Adapt).

Juvenile pinfish are omnivorous and feed on both seagrass and algae, as well as a diversity of invertebrates including polychaetes, amphipods, copepods, and bryozoans (Barbosa and Taylor 2020). Based on a study in Pamlico Sound, NC larger pinfish (> 100 mm) are also benthic omnivores, feeding on mollusks, polychaetes and other invertebrates, as well as seagrass (Binion-Rock *et al.* 2019). Pinfish diet on the continental shelf remains unknown.

The population status of pinfish is unknown. Kimball *et al.* (2020) found that pinfish abundance has increased in a South Carolina estuary over a 30 year period, potentially due to changes in climate including storm intensity and temperature. This suggests that future changes in climate may favor pinfish, although this depends on impacts to biogenic estuarine habitats. Pinfish are targeted as bait both commercially and recreationally (Ohs *et al.* 2018), but there is no evidence that the bait fishery impacts abundance. Faletti *et al.* (2019) noted that in Florida estuaries, pinfish populations in the northern part of the state were declining, while populations in the

southern estuaries were increasing. Camp *et al.* (2019) noted that forage fishes like pinfish are coupled with predatory fish abundance and that management of predatory fish could impact forage fish abundance. Population changes may be due to environmental factors (Faletti *et al.* 2019) or effects due to changes in predatory fish dynamics (Camp *et al.* 2019). Stratton *et al.* (2018) found that interannual abundance of pinfish on the nearshore continental shelf was negatively correlated with annual shrimp trawl effort. This negative response to trawling indicates that bycatch in the shrimp fishery has a substantial effect on this species.

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Pink shrimp - *Farfantepenaeus duorarum*

Overall Vulnerability Rank = Low ■

Habitat Sensitivity = Low ■

Climate Exposure = High ■

Data Quality = 90% of scores ≥ 2

<i>Farfantepenaeus duorarum</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	1.8	2.6		Low Moderate High Very High
	Prey Specificity	1.2	2.2		
	Adult Mobility	2.1	2.6		
	Dispersal of Early Life Stages	1.8	2.4		
	Early Life History Survival and Settlement Requirements	2.4	2.6		
	Complexity in Reproductive Strategy	2	2.8		
	Spawning Cycle	1.8	2.6		
	Sensitivity to Temperature	1.8	2.2		
	Sensitivity to Ocean Acidification	1.8	1.6		
	Population Growth Rate	1.2	2.2		
	Stock Size/Status	1.3	2.4		
	Other Stressors	2.5	2.4		
	Sensitivity Score	Low			
Exposure Factors	Air Temperature	4	3		
	Hypoxia	2.8	2.4		
	Ocean Acidification	4	2		
	Precipitation	1	3		
	Primary Productivity	1.5	2		
	Salinity	2.7	3		
	Sea Level Rise	3	2.6		
	Sea Surface Temperature	1	0		
	Exposure Score	High			
Overall Vulnerability Rank		Low			

Overall Climate Vulnerability Rank: **Low.** (93% bootstrap results in Low, 7% bootstrap results in Moderate).

Climate Exposure: **High.** The exposure factors contributing to pink shrimp's high climate exposure were air temperature (4.0, a proxy for estuarine temperatures), ocean acidification (4.0), and sea level rise (3.0). Hypoxia had an average score of 2.8 and salinity had an average of 2.7.

Biological Sensitivity: **Low.** The primary sensitivity attributes contributing to a low biological sensitivity score for pink shrimp were population growth rate (1.2), prey specificity (1.2), and stock size/status (1.3). Several sensitivity attributes had a mean score of 1.8 including habitat specificity, dispersal of early life stages, spawning cycle, sensitivity to temperature, and sensitivity to ocean acidification.

Distributional Vulnerability Rank: **High.** The top three attributes contributing to pink shrimp's high vulnerability to distribution shift ranking include moderate to low habitat specificity (1.8), moderate to low sensitivity to temperature (1.8), and highly to very highly dispersive early life stages (1.8). Adults were viewed as highly mobile (2.1).

Data Quality: All data quality scores were 2 or greater except sensitivity to ocean acidification (1.6). Ocean acidification was a very high exposure factor (4.0).

Climate Effects on Abundance and Distribution: Pink shrimp growth rates are sensitive to temperature and could be impacted during their juvenile life stage in the form of slower growth at higher temperatures. Heat stress could lead to increased mortality because preferred habitat is relatively shallow. However, shrimp are mobile and could seek deeper water. Mortality rates are size dependent, so slower growth would indirectly result in increased mortality due to longer durations spent in small size classes. One extensive and important Tortugas shrimp nursery area is Florida Bay, located within the Everglades National Park, where it is thought that environmental conditions control the number of shrimp on the Tortugas grounds (Costello *et al.* 1986). Costello *et al.* (1986) described increasing deleterious effects to the nursery habitat due to freshwater runoff and pollution. This could lead to habitat loss of the preferred seagrass habitat. Sea-level rise and habitat fragmentation could affect production of sub-adults from nurseries (Roth *et al.* 2008) Ocean Acidification effects are considered generally negative and include dissolution of calcified elements and reduced calcification rates (Taylor *et al.* 2015) causing indirect (diet items; molluscs and crustaceans) and direct (changes in shell transparency and exoskeleton function due to decreased pH).

Life History Synopsis: Pink shrimp occur along US Atlantic coast as far north as Chesapeake Bay to the Florida Keys and around the coast of the Gulf of Mexico to the Yucatan south of Cabo Catoche, Mexico. They're most abundant off southwestern Florida and the southeastern Gulf of Campeche. Highest densities are found at 11 - 65 m, on mud, sand bottoms (Costello *et al.* 1964). Spawning occurs offshore at depths ranging from four to 50 meters but spent adults have been caught as deep as 137 m (Costello *et al.* 1986). Spawning is temperature dependent, occurring between 19.6 and 30.6°C and occurs year round in the Dry Tortugas where it supports the multi-million dollar shrimp fishery (Upton *et al.* 1992). Spawning is limited to April through

September in northern latitudes. Pink shrimp likely spawn more than once, fertilization is external and eggs are demersal (Costello *et al.* 1986, Dall *et al.* 1990). Eggs hatch within 12 to 16 hours and proceed through several larval stages including five naupliar (demersal), three protozoal (pelagic with diel vertical migration) and three mysis (pelagic with diel vertical migration) stages before reaching postlarval stage at about 40 days old (Ewald 1965, Cook and Murphy 1969). At about six to 12 mm total length (TL), pink shrimp recruit into estuaries such as FLorida Bay, where they settle into seagrass (Costello *et al.* 1986) and spend several months as juveniles feeding and growing before leaving the bay, becoming part of the fishery (Costello and Allen 1966). Pink shrimp reside in estuaries for two to six months, growing 0.5 to 1 mm per day, and providing a linkage between the base of the food web and top consumers such as gray snapper and spotted seatrout (Costello and Allan 1970, Rutherford *et al.* 1982, 1983). At about 100 mm TL, early recruits begin offshore migration in the Fall and later recruits can overwinter and move offshore in the spring (Joyce 1965, Hughes 1969). Adults are found on calcareous mud and sand or sand-shell mixture at highest densities at depths of 11 - 36 m, reach sexual maturity at between six to eight months and likely have a maximum age of 16 to 20 months (Eldred *et al.* 1961).

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Red drum - *Sciaenops ocellatus*

Overall Vulnerability Rank = Low ■

Habitat Sensitivity = Low ■

Climate Exposure = High ■

Data Quality = 80% of scores ≥ 2

<i>Sciaenops ocellatus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	2.2	2.8		Low Moderate High Very High
	Prey Specificity	1.7	2.6		
	Adult Mobility	1.6	2.8		
	Dispersal of Early Life Stages	2.2	2.6		
	Early Life History Survival and Settlement Requirements	2.6	2.2		
	Complexity in Reproductive Strategy	1.8	2.2		
	Spawning Cycle	2.4	2.8		
	Sensitivity to Temperature	1.9	2.4		
	Sensitivity to Ocean Acidification	2	2.2		
	Population Growth Rate	2.4	2.4		
	Stock Size/Status	2.1	1.4		
	Other Stressors	1.8	1.8		
	Sensitivity Score		Low		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	2.2	2.5		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.5	2		
	Salinity	2.5	3		
	Sea Level Rise	2.3	2.6		
	Sea Surface Temperature	4	3		
	Exposure Score		High		
Overall Vulnerability Rank		Low			

Overall Climate Vulnerability Rank: **Low.** (67% bootstrap results in Low, 33% bootstrap results in Moderate).

Climate Exposure: **High.** The top exposure factors contributing to red drum's high climate exposure were sea surface temperature (4.0), and ocean acidification (4.0). Salinity was moderate to high (2.5), sea level rise (2.3) and hypoxia (2.2) were moderate. Primary productivity was low to moderate (1.5).

Biological Sensitivity: **Low.** The primary sensitivity attributes that contributed to a low biological sensitivity score for red drum were adult mobility (1.6), prey specificity (1.7), complexity in reproductive strategy (1.8), other stressors (1.8), and sensitivity to temperature (1.9).

Distributional Vulnerability Rank: **Moderate.** All attributes contributed to red drum's moderate vulnerability to distribution shift ranking. The top two were highly to very highly mobile adults (1.6), moderate sensitivity to temperature (1.9). Moderate habitat specificity (2.2) and moderately dispersive early life stages (2.2) had the same mean attribute score.

Data Quality: All data quality scores except other stressors (1.8) were 2 or greater.

Climate Effects on Abundance and Distribution: Few studies have examined the potential effects of climate change on red drum populations. Red drum are highly dependent on estuarine systems and therefore are likely to be susceptible to direct or indirect changes in habitat. For example, sea level rise may permanently inundate regularly flooded emergent vegetation such as salt marsh and mangrove, altering or eliminating these important edge habitats and access to benefits such as protection and foraging for small juvenile red drum. An important climate effect to consider is the reduction in freshwater inflow patterns to Gulf of Mexico (GOM) estuaries potentially leading to hypersaline conditions. Red drum are considered a euryhaline species; however, long-term or extreme shifts in the salinity regimes in estuarine nurseries may have adverse effects on the survival and growth of estuarine-dependent species such as red drum. It is also possible that both juvenile and adult red drum will be affected by ocean acidification since crustaceans such as blue crabs and shrimp are a primary component of their diet. Spawning of adults is temperature dependent and occurs in the fall as water temperatures decrease. Continued increases in water temperature may delay or disrupt the spawning season and subsequently affect early survival and growth of larval red drum.

Life History Synopsis: The red drum is an important estuarine and coastal sciaenid distributed throughout the entire GOM ranging from the southwest tip of Florida extending continuously along the Gulf coast into northern Mexico.

Red drum are gonochoristic and spawn in coastal waters near inlets and passes. Eggs and larvae are pelagic and spend approximately 20 days in the water column while they are transported by tidal currents into estuarine nursery habitats where they mature (Comyns *et al.* 1991). Settlement of larvae into seagrass habitat occurs between 15-20 mm in length (Rooker and Holt 1997). Differences in density, survival, and growth of newly settled red drum have been reported among

estuarine habitats (Rooker and Holt 1997, Rooker *et al.* 1988, Stunz *et al.* 2002a), and essential nursery habitats potentially vary ontogenetically (Bacheler *et al.* 2009) and among estuarine systems (Stunz *et al.* 2002b). Juveniles are estuarine-dependent and inhabit a variety of estuarine habitats including seagrass beds, salt marshes, oyster reefs, and mangroves for the first few years of life. These habitats provide protection from predators and prey items such as zooplankton, small crabs, and shrimp, expanding to include larger invertebrates and small fish as juvenile red drum grow.

Red drum typically reach adulthood and emigrate from estuarine to offshore waters between three and six years of age (Murphy and Taylor 1990). Adults are habitat generalists and commonly occur over sand and sandy mud bottoms in nearshore coastal waters, often aggregating in large schools near the water surface (Powers *et al.* 2012). Adults preferentially utilize deeper water at night but move into shallower areas for foraging, particularly nearshore seagrass beds. Red drum are opportunistic ambush predators with a diet consisting mostly of blue crabs (*Callinectes sapidus*), fish, and penaeid shrimp.

Spawning occurs in the fall as adult red drum aggregate near coastal inlets (Overstreet 1983), although spawning can also take place along the continental shelf and within some estuarine systems (Holt *et al.* 1985). Red drum spawning is temperature dependent and latitudinal variation in the timing of spawning has been documented along the Texas Gulf coast. Spawning is estimated to occur when coastal temperatures drop from 27-29°C to 24-25°C, corresponding to a spawning season beginning as early as late August and continuing through October and generally peaking in September and October (Simmons and Breuer 1962, Wilson and Nieland 1994, Rooker and Holt 1997, Dance and Rooker 2016).

Red drum are highly mobile although schooling behaviors and aggregations are commonly observed. Early genetic studies using nuclear and mitochondrial DNA indicate that red drum are genetically subdivided between the GOM and Atlantic (Gold and Richardson 1991). Recent analyses conducted on both inshore and offshore red drum in the GOM found no population structure along the inshore and offshore northern Gulf and revealed high levels of connectivity among populations (Michaelsen 2015). A recent stock assessment included a review of the stock structure of red drum and concluded that red drum in the GOM were a single unit stock (SEDAR 2016).

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Red grouper - *Epinephelus morio*

Overall Vulnerability Rank = Moderate ■

Habitat Sensitivity = Moderate ■

Climate Exposure = High ■

Data Quality = 90% of scores ≥ 2

<i>Epinephelus morio</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	2.7	3		Low Moderate High Very High
	Prey Specificity	1.7	2.6		
	Adult Mobility	2.6	2.6		
	Dispersal of Early Life Stages	1.9	2.6		
	Early Life History Survival and Settlement Requirements	2.4	2		
	Complexity in Reproductive Strategy	2.6	2.8		
	Spawning Cycle	2.6	2.8		
	Sensitivity to Temperature	2	2.6		
	Sensitivity to Ocean Acidification	2	2		
	Population Growth Rate	2.9	3		
	Stock Size/Status	2.9	2.5		
	Other Stressors	2.3	2.6		
	Sensitivity Score		Moderate		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	2.2	2		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.8	2		
	Salinity	3.5	3		
	Sea Level Rise	2.2	2.4		
	Sea Surface Temperature	4	3		
Exposure Score		High			
Overall Vulnerability Rank		Moderate			

Overall Climate Vulnerability Rank: **Moderate.** (48% bootstrap results in Moderate], 48% bootstrap results in High, and 5% bootstrap results in Very High).

Climate Exposure: **High.** A variety of factors are contributing to the high climate exposure score including ocean acidification (4.0), sea surface temperatures (4.0), and salinity (3.5). All are categorized as very high or high to very high.

Biological Sensitivity: **Moderate.** The primary sensitivity attributes contributing to a moderate biological sensitivity score for red grouper were dispersal of early life stages (1.9), sensitivity to temperature (2.0), sensitivity to ocean acidification (2.0), other stressors (2.3), and early life history survival and settlement garments (2.4).

Red Grouper are long lived (~30+ years), and do not reach peak reproductive activity in females until 812 years of age and for males the age is 10 years (Moe 1969). In the Gulf of Mexico, they have an average age at capture of 7.5 years, resulting in the elimination of many of the most effective reproducers in the population (Rose and Cowan 2003, Coleman and Koenig 2010). In general, recruitment of red grouper is considered to be low with intermittently high recruitment pulses (SEDAR 2019). The most recent stock assessment (SEDAR 61) found current red grouper stock status to be estimated as slightly below the target level of 30% SPR in 2017. However, uncertainty analyses accounting for recent red tide mortality in 2018-2019 found that the population may now be significantly below that target. This significant change from a single event highlights the biological sensitivity of this species (SEDAR 2019).

Red tide was discussed as an ‘other stressor’ and current research and stock assessments have shown that this is an important environmental factor to this species population and may become an increasingly frequent impactor in the future (SEDAR 2019).

Distributional Vulnerability Rank: **Low.** The top three attributes contributing to red grouper’s low vulnerability to distribution shift were moderate to high habitat specificity (2.7), moderate to high adult mobility (2.6), and moderate sensitivity to temperature (2.0).

Data Quality: All data quality scores were 2 or greater. Ocean acidification (2.0) is one of the most important factors that require further research going forward. Ocean acidification had a very high exposure score (4.0) for this species.

Climate Effects on Abundance and Distribution: Little is known about the relationship between the climate factors considered in this study and red grouper. Limited studies have been done in a laboratory setting with red grouper larvae. Colin *et al.* 1996, found that a salinity of at least 28 ppt or greater was required for newly spawned eggs to maintain positive buoyancy. As the eggs developed, the neutral buoyancy salinity threshold increased to 32 ppt (Colin *et al.* 1996). All eggs were negatively buoyant at 25 ppt salinity and very few were observed to hatch. Therefore, fluctuations in salinity could affect the recruitment numbers of this species.

Within the Gulf of Mexico, seasonally occurring harmful algal bloom events result in large areas of depleted oxygen (Coleman and Koenig 2010). This environmental condition is also commonly referred to as red tide and is believed to be notably impactful to red grouper populations (Walter III *et al.* 2015, SEDAR 2019). These events generally develop at deeper offshore depths (Steidinger and Vargo 1988)

and are carried by environmental factors such as tides and winds to shallower near-shore habitats (Steidinger and Haddad 1981). The most recent stock assessment (SEDAR 61) found that annual mortality from a red tide event can exceed all other sources of mortality combined and significantly reduce population abundance to concerning levels. The increasing frequency of mortality events identified in SEDAR 61 suggests that this could become a primary factor in the abundance of future Red grouper populations.

Life History Synopsis: Red grouper are a large-bodied grouper species distributed from North Carolina through southern Brazil, including Bermuda, throughout the Gulf of Mexico and Caribbean. In the Gulf of Mexico, populations are most abundant within the Eastern Gulf. These fish have a relatively long life expectancy with a maximum age of 30+ years (Beaumariage and Bullock 1976).

Red grouper are protogynous hermaphrodites, developing first as females and transitioning to males once they have reached at least 275 mm SL, consequently most individuals transition around 450-650 mm SL (Moe 1969). This sexual transformation is more closely correlated with oogenic and spawning activity than with age or size (Moe 1969). Females mature around the ages of 4-6 years, although it is believed that the females undergo vitellogenesis up to two years before they begin to spawn and don't reach peak reproductive activity until 8-12 years of age (Moe 1969). Males are most reproductively significant after the age of 10 years (Moe 1969). Red grouper spawn in relatively small polygynous groups and do not appear to form large aggregations (Coleman *et al.* 1996). Spawning activity of red grouper peaks in March and May when water temperatures fluctuate between 19-21 degrees C (Moe 1969, Johnson *et al.* 1998).

Little is known about the distribution of larval Red grouper. The eggs of the red grouper are small, <1mm, and contain a single oil droplet and hatch approximately 30 hours after spawning (Moe 1969). Larvae reared in a laboratory showed that the density of the eggs required a salinity of at least 28 ppt or greater to maintain positive buoyancy and as the eggs developed needed to maintain a salinity of 32 ppt for neutral buoyancy (Colin *et al.* 1996). The pelagic larvae spend between 4-9 weeks developing offshore (Coleman and Koenig 2010). It is believed that the juvenile red grouper leave the pelagic habitat for the benthos at or around 20-25mm SL (Beaumariage and Bullock 1976).

Juvenile diet consists mainly of demersal crustaceans while adults feed opportunistically on fishes, crustaceans such as portunid crabs, and mollusks such as squid and octopus (Longley and Hildebrand 1941, Moe 1969, Costello and Allen 1970).

Juveniles are particularly cryptic and can be found in crevices or ledges of shallow inshore hardbottom habitats for a period of 4-5 years (Harter *et al.* 2008, Coleman and Koenig 2010). Developmental migration to deeper offshore water occurs around the ages of 4 to 6 years (Moe 1969).

Adult red grouper prefer rocky bottom habitats with ledges as well as artificial hard bottom habitats like shipwrecks (Moe 1969).

Red grouper are excavators of the seafloor. As juveniles they excavate solution holes in the bays and shallow coastal waters of their territory (Coleman and Koenig 2010). As they become adults this behavior continues, exposing the carbonate rock, as they migrate to deeper habitat (Coleman and Koenig 2010). Once a solution hole has been excavated, both adults and juveniles will stay with the same hole for extended periods of time (>1 year) (Coleman and Koenig 2010).

Environmental conditions such a red tide are believed to be notably impactful to red grouper populations (Walter III *et al.* 2015, SEDAR 2019). These events generally develop at deeper offshore depths (Steidinger and Vargo 1988) and are carried by environmental factors such as tides and winds to shallower near-shore habitats (Steidinger and Haddad 1981).

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Red snapper - *Lutjanus campechanus*

Overall Vulnerability Rank = Moderate ■

Habitat Sensitivity = Moderate ■

Climate Exposure = High ■

Data Quality = 85% of scores ≥ 2

<i>Lutjanus campechanus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	1.4	3		Low Moderate High Very High
	Prey Specificity	1.2	3		
	Adult Mobility	1.8	2.8		
	Dispersal of Early Life Stages	1.7	3		
	Early Life History Survival and Settlement Requirements	2.1	3		
	Complexity in Reproductive Strategy	1.3	3		
	Spawning Cycle	2.1	3		
	Sensitivity to Temperature	1.4	2.6		
	Sensitivity to Ocean Acidification	1.5	2		
	Population Growth Rate	3	2.6		
	Stock Size/Status	2.8	2.8		
	Other Stressors	1.7	2.2		
	Sensitivity Score		Moderate		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	1.8	1.8		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.6	2		
	Salinity	2.9	3		
	Sea Level Rise	1.6	2		
	Sea Surface Temperature	4	3		
	Exposure Score		High		
Overall Vulnerability Rank		Moderate			

Overall Climate Vulnerability Rank: **Moderate.** (99% bootstrap results in Moderate, 1% bootstrap results in Low).

Climate Exposure: **High.** The top three exposure factors contributing to a high climate exposure score for red snapper were sea surface temperature (4.0), ocean acidification (4.0), and salinity (2.9). Sea level rise (1.6), primary productivity (1.6), and hypoxia (1.8) were all in the moderate to low range.

Biological Sensitivity: **Moderate.** The primary sensitivity attributes contributing to a moderate biological sensitivity score for red snapper were dispersal of early life stages (1.7), other stressors (1.7), adult mobility (1.8), early life history survival and settlement garments (2.1), and spawning cycle (2.1).

Distributional Vulnerability Rank: **High.** The top three attributes contributing to red snapper's high vulnerability to distribution shift ranking were low habitat specificity (1.4) and sensitivity to temperature (1.4), and highly dispersive early life stages (1.7). Adult red snapper are also highly mobile (1.8).

Data Quality: All data quality scores were 2 or greater. The lowest score was for sensitivity to ocean acidification (2.0) suggesting that further research in this area may be needed.

Climate Effects on Abundance and Distribution: Effects of changing climate on red snapper were ranked as moderate. The species had a fairly robust temperature range, and moderate temperature increases will not likely inhibit either distribution or fitness (the species is mobile and does have the ability to seek out deeper, cooler waters if necessary). Potential negative effects of ocean acidification on crustaceans occurring in their red snapper diets should be offset by their opportunistic and generalist feeding habits. Potential disruption of oceanic circulation patterns could affect the transport of larvae to appropriate settlement habitats.

Life History Synopsis: Red snapper is a large reef-associated fish species found in continental shelf waters from Cape Hatteras, North Carolina, to the Yucatan Peninsula (Hoese and Moore 1998).

Juvenile red snapper are found on open to low-relief natural (e.g., rocky, shell) and artificial reefs (e.g., concrete pyramids, tanks, ships) nearshore, whereas adult red snapper can be found on similar habitat types but across a much wider variety of depths (Galloway *et al.* 2009, Mitchell *et al.* 2014).

Red snapper are generalist predators and undergo ontogenetic shifts from eating zooplankton, mysids, and squid as juveniles to benthic crustaceans, cephalopods, and fishes as adults (Ouzts and Szedlmayer 2003, Szedlmayer and Lee 2004, Wells *et al.* 2008).

Adults can be highly mobile yet show high site fidelity in some places (Galloway *et al.* 2009, WilliamsGrove and Szedlmayer 2016), often loosely aggregating with conspecifics.

Red snapper have minimally complex reproduction and are thought to spawn around natural and artificial habitats throughout their geographic range in summer months (Collins *et al.* 1996, Farmer *et al.* 2017). Red snapper are gonochoristic and batch spawners, and the spawning season occurs from May to October, with a peak from June and July (Bradley and Bryan 1975; Collins *et al.* 1996).

Eggs hatch approximately 1 day after fertilization and the resulting larvae drift in currents up to hundreds of kilometers until settlement in nearshore benthic habitats approximately 20-30 days after hatching (Johnson *et al.* 2009). Wind-driven water currents appear to aid larval red snapper transport throughout the northern Gulf of Mexico (Johnson *et al.* 2009).

Red snapper occurs across a fairly wide range of temperatures within their geographic distribution, from approximately 19 to 29° C (Allen, 1985).

Red snapper may be somewhat affected by increased ocean acidification because they prey upon some invertebrate species (Ouzts and Szedlmayer 2003, Szedlmayer and Lee 2004, Wells *et al.* 2008) that may themselves be sensitive to ocean acidification.

Red snapper have a slow population growth rate, including an old maximum age (i.e., 52 years; Wilson and Nieland 2001), low natural mortality rate, and large maximum body size (SEDAR 2018).

The red snapper stock is considered to be recovering - it is not overfished and overfishing is not occurring (SEDAR 2018). Moreover, there appears to be some genetic differentiation between Gulf of Mexico and Atlantic populations of red snapper (Hollenbeck *et al.* 2015).

Other potential stressors for red snapper include possible coral bleaching, temperate reef degradation, and lionfish predation.

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Royal red shrimp - *Pleoticus robustus*

Overall Vulnerability Rank = Low ■

Habitat Sensitivity = Low ■

Climate Exposure = High ■

Data Quality = 30% of scores ≥ 2

<i>Pleoticus robustus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	2.3	2.2		Low Moderate High Very High
	Prey Specificity	1.7	0.8		
	Adult Mobility	2.2	1.6		
	Dispersal of Early Life Stages	2.1	0.8		
	Early Life History Survival and Settlement Requirements	2.3	0.8		
	Complexity in Reproductive Strategy	2	1		
	Spawning Cycle	2.2	0.6		
	Sensitivity to Temperature	2.1	1.6		
	Sensitivity to Ocean Acidification	2.1	1.4		
	Population Growth Rate	1.9	0.8		
	Stock Size/Status	1.9	0.8		
	Other Stressors	2.7	0.8		
	Sensitivity Score		Low		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	2.1	1.8		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.7	2		
	Salinity	3	3		
	Sea Level Rise	1.8	2		
	Sea Surface Temperature	4	3		
	Exposure Score		High		
Overall Vulnerability Rank		Low			

Overall Climate Vulnerability Rank: **Low.** (77% bootstrap results in Low, 23% bootstrap results in Moderate).

Climate Exposure: **High.** The top three exposure factors contributing to a high climate exposure score for royal red shrimp were sea surface temperature (4.0), ocean acidification (4.0), and salinity (3.0). Hypoxia had a mean score of moderate (2.1), Primary productivity was moderate to low (1.7), and sea level rise was low (1.8). Note that hypoxia, salinity, and sea level rise all had scores ranging from low to very high.

Biological Sensitivity: **Low.** The primary sensitivity attributes that contributed to a low biological sensitivity score for royal red shrimp were prey specificity (1.7), population growth rate in (1.9), and stock size/status (1.9). Most other sensitivity attribute means were approximately moderate.

Distributional Vulnerability Rank: **Moderate.** The top three attributes contributing to royal red shrimp's moderate vulnerability to distribution shift ranking were moderate sensitivity to temperature (2.1), highly dispersive early life stages (2.1), and highly to moderately mobile adults (2.2).

Data Quality: The only data quality score that was 2 or greater was habitat specificity indicating that all areas of royal red shrimp's life history require further research.

Climate Effects on Abundance and Distribution: No studies were found that specifically investigate the impact of climate factors on *P. robustus*, but broad statements can be made based on knowledge of range sensitivity and natural history. As a deep-water species, *P. robustus* has a preferred temperature range of 9-12 C and have been observed moving great distances in response to cold-water influxes (Bullis and Cummings 1963). It is likely that any prolonged changes in temperature at depth will alter the distribution and concentration of *P. robustus*. In addition, ocean acidification remains a major concern for calcifying organisms including shrimp.

Life History Synopsis: *Pleotucus robustus*, also known as the royal red shrimp, is a species of penaeid shrimp in the family Solenoceridae. Populations of *P. robustus* have been documented continuously along the upper continental shelf in the western Atlantic from Cape Hatteras to Brazil (Bullis and Cummins 1963). The population densities throughout this range can vary drastically, and population dynamics throughout this range have been of particular interest to commercial fishing operations. The highest concentrations of *P. robustus* are found in three primary locations: northeast Florida (St. Augustine shrimping grounds), south and southwest of the Dry Tortugas, and the Mississippi Delta (southeast of Mississippi Pass to Mobile, Alabama) where commercial fishing activities are performed (Perez-Farfante 1977, Reed and Farrington 2010).

Unlike other penaeid shrimp, *P. robustus* are a deep-water species, ranging in depths between 180-730m with the highest concentrations occurring between 250-500m (Anderson and Lindner 1971, Perez-Farfante 1977, Perry and Larsen 2004, McIntyre and Carpenter 2005, Paramo 2011). A depth and temperature relationship exists in regards to population concentrations such that

catch rates exceeding 25lbs/hour are confined to temperature ranges between 9-12° C (Bullis and Cummins 1963). During an influx of cold bottom water off the coast of Florida, *P. robustus* responded by moving inshore and reducing depths upwards of 40 fathoms within 2 days (Bullis and Cummins 1963, Perez-Farfante 1977). *Pleotucus robustus* have variable color patterns ranging from brick red to off-white (Anderson and Lindner 1971, Perez-Farfante 1977), but is known to display diurnal color patterns that primarily appear pink during the day and red at night (Perez-Farfante 1997). Benthic observations of *P. robustus* revealed that shrimp spend much of their time on mud, silt, and/or white calcareous mud habitats and forage by creating shallow grooves in the substrate (Anderson and Lindner 1971, Reed and Farrington 2010). Generally, *P. robustus* is sexually dimorphic with females ranging in median length between 173-183mm and males reaching median lengths of 138mm (Anderson and Lindner 1971, McIntyre and Carpenter 2005, Paramo and Saint-Paul 2012). There appears to be a correlation between size and latitudinal position, where larger individuals are found north of 29°39'N (Anderson and Lindner 1971). Females begin ovary development at 136mm in length and reach sexual maturity by 155mm, while males reach maturity at 125mm (Anderson and Lindner 1971, Perez-Farfante 1977). Sexual maturation is achieved around three years of age, and peak spawning occurs between January and May (Reed and Farrington 2010). Post-spawn, larvae are carried by the Gulf Stream along the Atlantic Coast (SAFMS 1998a) and may settle amongst deep sea coral reefs (Ross 2005). Little is known about recruitment patterns, but is speculated to occur when shrimp are less than 100mm in length and one year old (Reed and Farrington 2010). Unlike other shallow-water shrimp species that complete their life cycles relatively quickly, *P. robustus* is a long-living species that requires several years to reach reproductive age.

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Sandbar shark - *Carcharhinus plumbeus*

Overall Vulnerability Rank = High

Habitat Sensitivity = Moderate

Climate Exposure = Very High

Data Quality = 85% of scores ≥ 2

<i>Carcharhinus plumbeus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	1.3	2.8		Low Moderate High Very High
	Prey Specificity	1.4	2.6		
	Adult Mobility	1.1	2.8		
	Dispersal of Early Life Stages	1.2	2.8		
	Early Life History Survival and Settlement Requirements	1	2.2		
	Complexity in Reproductive Strategy	1.7	2		
	Spawning Cycle	1.9	2.6		
	Sensitivity to Temperature	1.2	2.8		
	Sensitivity to Ocean Acidification	1.3	2.4		
	Population Growth Rate	3.4	2.6		
	Stock Size/Status	3	2.8		
	Other Stressors	1.9	1.6		
	Sensitivity Score		Moderate		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	1.4	2.2		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.8	2		
	Salinity	3.6	3		
	Sea Level Rise	1.6	2.4		
	Sea Surface Temperature	4	3		
	Exposure Score		Very High		
Overall Vulnerability Rank		High			

Overall Climate Vulnerability Rank: **High.** (53% bootstrap results in High, 35% bootstrap results in Very High, 12% bootstrap results in Moderate).

Climate Exposure: **Very High.** The top three exposure factors contributed to the very high climate exposure score for sandbar shark were sea surface temperature (4.0), ocean acidification (4.0), and salinity (3.6). Primary productivity (1.8) was moderate, while hypoxia (1.4) and sea level rise (1.6) were both low to moderate.

Biological Sensitivity: **Moderate.** The primary sensitivity attributes that contributed to a moderate biological sensitivity score for sandbar shark were complexity in reproductive strategy (1.7), other stressors (1.9), and spawning cycle (1.9). Sandbar shark had a number of sensitivity attributes that were in the low category and two (population growth rate and stock size/status) that were in the high or very high category.

Distributional Vulnerability Rank: **Very High.** The top three attributes contributing to sandbar shark's very high vulnerability to distribution shift ranking were very highly mobile adults (1.1), very highly dispersive early life stages (1.2), and low sensitivity to temperature (1.2). Habitat specificity was also low (1.3). Data Quality: All data quality scores were 2 or greater except other stressors (1.6). Complexity in reproduction, ocean acidification, and primary productivity all had a data quality score of 2.0.

Climate Effects on Abundance and Distribution: Few studies examined the effect of climate drivers on temporal changes in the distribution and abundance of sandbar sharks (Peterson *et al.* 2017, Crear *et al.* 2019, 2020). Peterson *et al.* (2017) found a correlation between sandbar shark abundance and North Atlantic Oscillation (NAO), and suggested that positive NAO conditions may lead to restricted northward migrations of the sandbar shark. Crear *et al.* (2020) reported that juvenile sandbar shark habitat was negatively influenced by future increases in water temperature. Though the amount of suitable bottom decreased, when incorporating the entire water column, projected suitable habitat increased, suggesting a behavioral shift will be needed to avoid non-preferred conditions (Crear *et al.* 2020). Additionally, Crear *et al.* (2019) revealed that overall swimming performance of juvenile sandbar sharks declined with increasing temperatures and decreasing dissolved oxygen, suggesting that continued water temperature increases would lead to a reduction in nursery habitat.

Life History Synopsis: Sandbar shark enjoys a wide distribution, found in the tropical/temperate offshore waters of the western Atlantic from Massachusetts to Florida, through the Gulf of Mexico and Yucatan, and including the Bahamas and Cuba and Bahamas, and to Argentina (Bigelow and Schroeder 1948, Springer 1960, Castro 2011).

Adult sandbar sharks are considered highly migratory and occur in offshore waters' whereas juveniles are most common in coastal areas (associated with sandy/muddy flats, bays, estuaries, and harbors) during the summer months (Springer 1960, 1967). Juveniles are commonly found in coastal nursery areas that they use for feeding and predator avoidance (Springer 1967, Branstetter 1990, Carlson 1999).

Sandbar sharks are diet generalists, with neonates feeding on crabs and other large crustaceans, with teleost fishes making up an increasing proportion of diet with increasing age (Medved *et al.* 1985, Ellis and Musick 2007). Adults feed on a diverse array of teleosts, rajiids, and cephalopods (Stevens and McLoughlin 1991, Stillwell and Kohler 1993). Increasing ocean acidification may potentially affect young sandbar sharks, who feed on crabs and other crustaceans, but they likely are able to switch to other diet items, if necessary.

Sandbar sharks are highly mobile, with a tagging study finding one individual moving 3000 km (Kohler and Turner 2001). A recent tagging study in the Gulf of Mexico revealed a round trip long-distance movement of a sandbar shark out of the Gulf and into waters off the U.S. east coast up to the South Carolina coast and back, resulting in a nearly 3,800 km movement (Altobelli and Szedlmayer 2020). The species is not limited in its mobility either behaviorally or physically.

This species is viviparous with a yolk sac placenta. Gestation has been estimated at 9-12 months in the Northwest and Western Central Atlantic Ocean (Springer 1960, Baremore and Hale 2012), with a mean brood size of eight pups per female. Sandbar shark ovarian cycle is at least biennial, although there is evidence that some females have a triennial cycle in the Gulf of Mexico, and pupping is thought to occur during summer months (Baremore and Hale 2012).

Sandbar sharks exhibit a slow population growth rate (2-12%, Sminkey 1994), and life history characteristics of a moderately old maximum age 31 years (Casey *et al.* 1985, Andrews *et al.* 2011), a large maximum length, an age at maturity of 12-16 years (Casey *et al.* 1985, Sminkey and Musick 1985), a low fecundity and a low growth coefficient ($k = 0.03-0.11$: Casey *et al.* 1985, Sminkey and Musick 1985, Hale and Barramore 2013, Romine *et al.* 2013). Given these characteristics, the species is considered vulnerable to recovery from population depletions such as overfishing.

SEDAR 54 found SSF-2015/SSF-MSY ranged from 0.61-0.58 for different model runs, indicating the stock was overfished (SEDAR 2017). F-2015/F-MSY ranged from 0.71-0.85, indicating the stock was not currently undergoing overfishing. International Union for the Conservation of Nature lists the species as vulnerable to overfishing (Musick *et al.* 2009). There was no evidence that genetic variation has been compromised (Musick *et al.* 2009).

Fishing pressure remains the most concerning stressor. There is also some concern about anthropocentric impacts (development, pollution) on potential estuarine nursery areas, which might be used by some neonates and juveniles.

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Scalloped hammerhead shark - *Sphyrna lewini*

Overall Vulnerability Rank = Very High ■

Habitat Sensitivity = High ■

Climate Exposure = Very High ■

Data Quality = 85% of scores ≥ 2

<i>Sphyrna lewini</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	1.3	2.8		Low Moderate High Very High
	Prey Specificity	1.6	2.8		
	Adult Mobility	1.1	2.8		
	Dispersal of Early Life Stages	1.2	2.8		
	Early Life History Survival and Settlement Requirements	1	2.2		
	Complexity in Reproductive Strategy	2	2.6		
	Spawning Cycle	1.8	2.6		
	Sensitivity to Temperature	1.2	2.8		
	Sensitivity to Ocean Acidification	1.3	2.4		
	Population Growth Rate	3.2	2.2		
	Stock Size/Status	3.2	0.8		
	Other Stressors	2.6	2.2		
Sensitivity Score		High			
Exposure Factors	Air Temperature	1	0		
	Hypoxia	1.5	2.2		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.8	2		
	Salinity	3.6	3		
	Sea Level Rise	1.4	2.6		
	Sea Surface Temperature	4	3		
Exposure Score		Very High			
Overall Vulnerability Rank		Very High			

Overall Climate Vulnerability Rank: **Very High.** (70% bootstrap results in Very High, 28% bootstrap results in High, and 3% bootstrap results in Moderate).

Climate Exposure: **Very High.** Three exposure factors that contributed to a very high climate exposure score for scalloped hammerhead shark were sea surface temperature (4.0), ocean acidification (4.0), and salinity (3.6). Hypoxia, primary productivity, and sea level rise were all low to moderate.

Biological Sensitivity: **High.** The primary sensitivity attribute contributes to a high biological sensitivity score for scalloped hammerhead shark were population growth rate in (3.2), stock size/status (3.2), and other stressors (2.6).

Distributional Vulnerability Rank: **Very High.** The top three attributes contributing to scalloped hammerhead shark's very high vulnerability to distribution shift ranking were very highly mobile adults (1.1), very highly dispersive early life stages (1.2), and low sensitivity to temperature (1.2). Scalloped hammerhead sharks were also scored as habitat generalists (1.3).

Data Quality: All data quality scores were 2 or greater except stock size/status which was 0.8 suggesting that more information is needed on this aspect of the life history.

Climate Effects on Abundance and Distribution: No studies have directly investigated the impact of climate on scalloped hammerhead sharks. However, the species' use of climate-sensitive habitats suggests a potential for food chain impacts (Miller *et al.* 2013) Temperature changes cue females to move north for parturition, where they are found during the warmer months. Chin *et al.* (2010) assessed the climate change risk of elasmobranchs at the Great Barrier Reef, Australia, including the scalloped hammerhead shark. The scalloped hammerhead was ranked as having a low overall vulnerability to future climate change, owing to a low sensitivity to individual stressors and low 'rigidity' in habitat and diet preferences.

Life History Synopsis: The scalloped hammerhead shark (*Sphyrna lewini*) is a moderately large-bodied (up to 3 meters), partly migratory, coastal-pelagic shark species (Compagno 1984). In the GOM, Animals mature at 9-10 years (male) and 15 years (female) (Piercy *et al.* 2007). Large, sexually segregated aggregations are observed, with sexual segregation potentially for reproductive purposes. Pups are born late spring to summer after a 9 to 12-month gestation, with females reproducing every year or two years. The Von Bertalanffy K is 0.09 for females and 0.13 for males (Piercy *et al.* 2007), and the intrinsic rate of population increase has been estimated as 0.11 to 0.29 (Hayes *et al.* 2009).

Juveniles prefer coastal areas such as estuaries and bays. These shallow inshore/nearshore nursery areas may be prone to development or disturbance from human use, as well as fishing activity (Holland *et al.* 1993). One study identified an open-water nursery area (i.e., not in an estuary) off the shore of Cape Canaveral, FL, indicating some flexibility (Adams and Paperno 2007). Large individuals of both sexes occur in relatively shallow water and are regularly caught in the SEFSC bottom longline survey. Adults use offshore/midwater areas, although females migrate to coastal waters for pupping (Branstetter 1987, Klimley 1987). They are caught in most

directed shark fisheries, and as bycatch, throughout their range (Baum *et al.* 2007). Offshore areas are vulnerable to fishing pressure, evidenced by declines in US pelagic longline data by 89% between 1986 and 2000 for all hammerhead species.

Benthic reef fish, demersal fish, and crustaceans are the primary food source for juveniles (Compagno 1984, Branstetter 1987, Stevens and Lyle 1989). The wide range of prey items suggests these individuals may be able to expand their diet. Adults primarily feed on mesopelagic fish, squids, stingrays, and benthic and epipelagic fishes (Compagno 1984, Branstetter 1987, Stevens and Lyle 1989). As with juveniles, this wide range of prey items suggests these individuals may expand their diet if preferred species are not available.

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Scamp grouper - *Mycteroperca phenax*

Overall Vulnerability Rank = Moderate ■

Habitat Sensitivity = Moderate ■

Climate Exposure = High ■

Data Quality = 60% of scores ≥ 2

<i>Mycteroperca phenax</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	2.8	3		Low Moderate High Very High
	Prey Specificity	1.6	2.2		
	Adult Mobility	2.5	2		
	Dispersal of Early Life Stages	1.8	1.6		
	Early Life History Survival and Settlement Requirements	2.4	1.2		
	Complexity in Reproductive Strategy	2.8	2.8		
	Spawning Cycle	2.7	2.6		
	Sensitivity to Temperature	2	2.4		
	Sensitivity to Ocean Acidification	1.9	1.8		
	Population Growth Rate	3.3	2.6		
	Stock Size/Status	2.3	1		
	Other Stressors	2.3	2		
Sensitivity Score		Moderate			
Exposure Factors	Air Temperature	1	0		
	Hypoxia	2	1.4		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.8	2		
	Salinity	3	3		
	Sea Level Rise	1	0		
	Sea Surface Temperature	4	3		
Exposure Score		High			
Overall Vulnerability Rank		Moderate			

Overall Climate Vulnerability Rank: **Moderate.** (79% bootstrap results in Moderate, 21% bootstrap results in High).

Climate Exposure: **High.** Three exposure factors contributed to a high climate exposure score for scamp: sea surface temperature (4.0), ocean acidification (4.0), and salinity (3.0). Hypoxia (2.0) and primary productivity (1.8) were moderate.

Biological Sensitivity: **Moderate.** The primary sensitivity attributes contributing to a moderate biological sensitivity score for scamp grouper were dispersal of early life stages in (1.8), sensitivity to ocean acidification (1.9), sensitivity to temperature (2.0), stock size/status (2.3), other stressors (2.3), and early life history survival and settlement requirements (2.4).

Distributional Vulnerability Rank: **Moderate.** Three attributes indicate that scamp have a moderate potential for distribution shift: high adult mobility (2.5) as evidenced by tagging studies (Wilson and Burns 1996), widespread dispersal of early life stages (1.8), and moderately specific habitat preferences (2.8, rocky ledges or pinnacles of high relief: Koenig *et al.* 2000). The species is possibly limited by a narrow preferred temperature range (20-27°C: Fishbase).

Data Quality: Eight data quality scores were 2 or greater, while four (early life stage dispersal, early life history survival and settlement requirements, sensitivity to ocean acidification, and stock size/status) were less than 2.0. Early life history settlement and survival requirements and other stressors were both identified as data- deficient as well as being high-sensitivity attributes.

Climate Effects on Abundance and Distribution: Few studies examined the effect of climate factors on the population productivity of scamp grouper. A somewhat narrow temperature preference may suggest that sea surface temperature increases will result in changes in abundance and distribution, not that scamp had a moderate potential for distributional change.

Life History Synopsis: Scamp is distributed in the western Atlantic from North Carolina south along the U.S., throughout the Gulf of Mexico except Cuba and in the Caribbean from Colombia to Tobago. It has also been recorded from southern Belize (Robertson and Van Tassell 2015). Its depth range is 0-100 metres, but usually occurs deeper than 30 m.

Juveniles are found in shallow water at jetties and in mangrove areas, as well as on reefs at depths of 15-25 m (Koenig and Coleman 2013). Adults are associated with reefs and are found over ledges and high-relief rocky bottom in the eastern Gulf of Mexico, and low-profile hardbottom ledges at depths of 30 to 100 meters off North Carolina. Scamp are the most abundant grouper found on or near living *Oculina* banks off the east coast of Florida, areas of pinnacles at depths of 70-100 m. Scamp have been observed on pavement, low relief outcrops, moderate relief outcrops, and rock rubble as well.

No differentiation has been reported between juvenile and adult diet. Fish are primary prey, but scamp also feed on cephalopods and crustaceans. Five most frequently occurring food in one

study (Matheson et al 1986) were unidentified fish, round scad, tomtate, unidentifiable serranids, and vermillion snapper.

Scamp are capable of significant migrations. In one study from the Gulf of Mexico, Wilson and Burns (1996) reported 52.6% of recaptured scamp moved >9 km, with one individual being recaptured 255 km away from its tagging site.

This species is a protogynous hermaphrodite that forms small, transient spawning aggregations of tens to a few hundred individuals on high-relief, offshore reefs along the shelf edge in depths of 50 - 100 m (Gilmore and Jones 1992, Coleman *et al.* 2011, Farmer *et al.* 2017). Spawning occurs from the end of January through June in the Gulf of Mexico with a peak in March to mid-May (Coleman *et al.* 1996, Lombardi-Carlson *et al.* 2012, Lowerre-Barbieri *et al.* 2020). Males exhibit high site fidelity to specific spawning sites and defend territories, while females move amongst a larger range of multiple spawning sites (Gilmore and Jones 1992). Spawning locations and time of spawning overlaps with those of gag. The genus *Mycteroperca* normally has an egg phase lasting two days, and a larval phase that lasts on average 43 days (D'Agostino *et al.* 2015). *Mycteroperca* larvae display high tolerance to environment variability with salinities ranging from 20 to 50 ppt and temperatures between 20°C and 30°C (GraciaLopez *et al.* 2004). Scamp could be affected by increasing ocean acidification, as juvenile scamp include crustaceans in their diet. Adults consume some crustaceans but seem more able to switch to fish as a primary diet component.

Scamp are vulnerable due to their slow population growth rate, based on a high maximum age (34 years; SEDAR 2020), moderate natural mortality rate of 0.15, low growth coefficient of 0.13-0.14, a large maximum body size of greater than 1000 mm FL (SEDAR 2020). Age of 50% maturity of females is 3.4 years, but the age of 50% males in the populations was 10.8 years mean (Lowerre-Barbieri *et al.* 2020).

A SEDAR stock assessment for scamp has not been completed, although one is currently underway, with the data workshop completed in 2020. A microsatellite study of genetic variation in scamp found genetic homogeneity between populations in the Gulf of Mexico and Atlantic coast of the U. S. (Zatcoff *et al.* 2004).

Other potential stressors for scamp could include degradation of nursery habitat (jetties and mangrove areas) coral bleaching, temperate reef degradation (including destruction of *Oculina* coral habitat), lionfish predation, and exposure to red tide events.

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Sheepshead - *Archosargus probatocephalus*

Overall Vulnerability Rank = Low ■

Habitat Sensitivity = Low ■

Climate Exposure = High ■

Data Quality = 85% of scores ≥ 2

<i>Archosargus probatocephalus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	1.8	2.8		Low Moderate High Very High
	Prey Specificity	1.8	2.8		
	Adult Mobility	1.8	2.6		
	Dispersal of Early Life Stages	1.9	2.6		
	Early Life History Survival and Settlement Requirements	2	2.2		
	Complexity in Reproductive Strategy	2.3	2.6		
	Spawning Cycle	2.2	2.4		
	Sensitivity to Temperature	1.4	2.5		
	Sensitivity to Ocean Acidification	2.3	2.4		
	Population Growth Rate	2.3	2		
	Stock Size/Status	1.9	1.8		
	Other Stressors	2.4	2.2		
	Sensitivity Score		Low		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	2.3	2.4		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.8	2		
	Salinity	3	3		
	Sea Level Rise	2.4	2.6		
	Sea Surface Temperature	4	3		
	Exposure Score		High		
Overall Vulnerability Rank		Low			

Overall Climate Vulnerability Rank: **Low.** (90% bootstrap results in Low, 10% bootstrap results in Moderate).

Climate Exposure: **High.** Three exposure factors contributed to a high score for sheepshead: sea surface temperature (4.0), ocean acidification (4.0), and salinity (3.0). Sheepshead use estuarine and coastal habitats during all life stages, but cool weather triggers winter/spring spawning movements. Hardshelled organisms that function as critical prey resources (mollusks, echinoderms, and barnacles; Jennings 1985; Sedberry 1987) and habitats (oyster bars; Jennings 1985) for Sheepshead are especially vulnerable to ocean acidification.

Biological Sensitivity: **Low.** The primary sensitivity attributes contributed to a low biological sensitivity score for sheepshead were sensitivity to temperature (1.4), habitat specificity (1.8), prey specificity (1.8), adult mobility (1.8), and dispersal of early life stages (1.9).

Distributional Vulnerability Rank: **High.** The top three attributes contributing to sheepshead's high vulnerability for distribution shift were low sensitivity to temperature (1.4), moderate to low habitat specificity (1.8), and high to very high adult mobility (1.8). Sheepshead also have highly dispersive early life stages (1.9).

Data Quality: All data quality scores were 2 or greater except stock size/status suggesting that this aspect of their life history needs further research. Only two states conduct assessments of stock size or status in the Gulf of Mexico, and no Gulf-wide estimates of stock status are available.

Climate Effects on Abundance and Distribution: Little is known regarding potential impacts of climate factors on the abundance, distribution, and population productivity of Sheepshead. Given their broad geographic distribution (Caldwell 1965, Randall *et al.* 1978, Jennings 1985) and tolerance of a wide range of environmental conditions (Springer and Woodburn 1960), it is unlikely that warming temperatures will have any significant impacts on the overall distribution and range of Sheepshead.

Life History Synopsis: Sheepshead are broadly distributed in estuarine and coastal waters throughout the western Atlantic, ranging from Nova Scotia to Brazil (Caldwell 1965, Randall *et al.* 1978, Jennings 1985).

Sheepshead grow rapidly during their first 6 - 8 years of life (Beckman *et al.* 2001, Winner *et al.* 2017), reaching a maximum age of 12 - 20 years and a maximum size of approximately 62 cm (Beckman *et al.* 1991, Dutka-Gianelli and Murie 2001). Sheepshead are gonochoristic with females beginning to mature at about age 2, although the proportion of mature females at age appears lower off Florida than in the north-central Gulf (Tucker 1987, Render and Wilson 1992).

Spawning occurs primarily in coastal waters (Music and Pafford 1984, Render and Wilson 1992), although there is some evidence of spawning within estuaries. Sheepshead spawn during late winter/early spring (Render and Wilson 1992). Females are batch-spawners (Render and Wilson 1992, Wenner and Archambault 2006, Liao *et al.* 2009, McDonough *et al.* 2011), with older,

larger females producing more, larger batches of eggs than younger, smaller females (Wenner and Archambault 2006).

Larval sheepshead are found in nearshore waters and within estuaries (Jennings 1985, Parsons and Peters 1989). The pelagic larval stage lasts for 30 - 40 days prior to metamorphosis at about 8 mm SL (Parsons and Peters 1989, Tucker and Alshuth 1997). Juvenile sheepshead are most abundant in grass flats or over mud bottom (Springer and Woodburn 1960, Odum and Heald 1972, Jennings 1985), migrating to more structured habitats such as oyster bars, piers, breakwaters, seawalls, and artificial reefs as they grow (Jennings 1985). Adult sheepshead move in schools to offshore spawning grounds with the onset of cool weather and return to inshore waters in the spring. Sheepshead tolerate a wide range of environmental conditions; in Tampa Bay, juveniles have been collected in salinities and temperatures ranging from 5 - 35 psu and 12.8 - 32.5°C, respectively (Springer and Woodburn 1960).

Juvenile sheepshead generally feed on mixed invertebrates including ostracods, gammarids, copepods, and polychaetes (Hildebrand and Cable 1938, Springer and Woodburn 1960, Castillo-Rivera *et al.* 2007). At about 50 mm, juvenile sheepshead begin feeding on hard-shelled organisms such as mollusks, echinoderms, and barnacles (Jennings 1985, Sedberry 1987). Sheepshead are thought to be omnivorous, feeding on whatever is available, thereby showing adaptations towards maximizing the use of trophic resources (Overstreet and Heard 1982, Wenner and Archambault 2006, Castillo-Rivera *et al.* 2007).

Little is known regarding potential predators of sheepshead, although they have been identified in the stomach contents of some sharks (Snelson *et al.* 1984). In Florida and Louisiana,

Sheepshead are neither overfished or undergoing overfishing (Munyandorero *et al.* 2017, West *et al.* 2020).

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Smalltooth sawfish - *Pristis pectinata*

Overall Vulnerability Rank = High ■

Habitat Sensitivity = High ■

Climate Exposure = High ■

Data Quality = 70% of scores ≥ 2

<i>Pristis pectinata</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	2.9	2.8		Low Moderate High Very High
	Prey Specificity	1.9	3		
	Adult Mobility	1.8	2.8		
	Dispersal of Early Life Stages	1.3	3		
	Early Life History Survival and Settlement Requirements	1	2.2		
	Complexity in Reproductive Strategy	2.3	1.8		
	Spawning Cycle	2.6	1.8		
	Sensitivity to Temperature	1.7	2.6		
	Sensitivity to Ocean Acidification	1.2	2.4		
	Population Growth Rate	3.6	2.4		
	Stock Size/Status	3.2	1		
	Other Stressors	2.9	1.8		
	Sensitivity Score		High		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	2.1	2.2		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.3	2		
	Salinity	2	3		
	Sea Level Rise	2.5	2.6		
	Sea Surface Temperature	4	3		
	Exposure Score		High		
Overall Vulnerability Rank		High			

Overall Climate Vulnerability Rank: **High.** (96% bootstrap results in High, 4% bootstrap results in Moderate).

Climate Exposure: **High.** The two primary exposure factors contributing to a high climate exposure score for smalltooth sawfish were sea surface temperature (4.0) and ocean acidification (4.0). Sea level rise (2.5) was moderate to high. Salinity (2.0) and hypoxia (2.1) were moderate, primary productivity (1.3) was low to moderate.

Biological Sensitivity: **High.** The primary sensitivity attributes contributing to a high biological sensitivity score for small tooth sawfish were population growth rate (3.6), stock size/status (3.2), other stressors (2.9), habitat specificity (2.9), and spawning cycle (2.6).

Distributional Vulnerability Rank: **High.** The top three attributes contributing to smalltooth sawfish's high vulnerability to distribution shift were very highly dispersive early life stages (1.3), moderate to low sensitivity to temperature (1.7), and highly to very highly mobile adults (1.8). Habitat specificity was high (2.9) suggesting particular habitat requirements.

Data Quality: Several data quality scores were less than two: complexity in reproductive strategy (1.8), spawning cycle (1.8), stock size/status (1.0) and other stressors (1.8).

Climate Effects on Abundance and Distribution:

There is relatively little information available regarding climate effects on smalltooth sawfish. Their restricted range, low population growth rates and slow rates of evolution make them particularly vulnerable to changing conditions (Field *et al.* 2009, Chin *et al.* 2010). Poulakis *et al.* (2011) documented mortalities of juvenile Smalltooth sawfish in south Florida following the passage of strong cold fronts, but other evidence shows the species to be relatively resilient to abrupt changes in salinity and tropical weather events (Brame *et al.* 2019). Juvenile sawfish have been observed to move away from their core area during strong weather events but return within days of the storm passing (G. R. Poulakis and J. K. Carlson unpublished data). Encounter data and tagging data show adult smalltooth sawfish migrate seasonally northward up the Florida peninsula (NMFS 2009, Papastamatiou *et al.* 2015), suggesting that temperature may act as a cue to seasonal migrations. The effects of climate change are predicted to be most severe in coastal areas, which smalltooth sawfish depend heavily upon. Importantly, the location and extent of red mangrove habitat - which act as important nursery grounds (Wiley and Simpfendorfer 2010) - are shifting in range and size as results of climate change (Osland *et al.* 2013, Ellison 2015). Although harmful algal blooms (HABs) have been reported in the core range of the smalltooth sawfish, so far, no HAB induced mortalities have been observed.

Life History Synopsis:

In the U.S.A., the smalltooth sawfish historically ranged from North Carolina to Texas, with the core population(s) occurring in peninsular Florida (Bigelow and Schroeder 1953, Brame 2019). Today, bycatch-induced mortality and habitat loss have largely reduced the range of the population to southwest Florida, primarily from Charlotte Harbor to the Florida Keys (Seitz and Poulakis 2002, Poulakis and Seitz 2004).

Smalltooth sawfish are found in shallow coastal habitats such as estuaries, river mouths, and bays, with habitat types varying from un-vegetated mud to sand bottoms and along mangrove shorelines (Seitz and Poulakis 2002, Poulakis *et al.* 2011, Norton *et al.* 2012). Small juveniles favor salinities between 18 and 30 parts per thousand (ppt) and shallow water depths (<1 m), and have affinities for warm water temperatures (>30°C) and moderate dissolved oxygen concentrations (>6 mg/L) (Poulakis *et al.* 2011). They are often found in close association with red mangrove shorelines, though have also been observed miles up from the river mouth (Poulakis *et al.* 2010, 2011, 2013, Simpfendorfer *et al.* 2011, Hollensead *et al.* 2016, Huston *et al.* 2017). They exhibit strong site fidelity to restricted areas within the nursery and gradually increase their home range with size (Simpfendorfer *et al.* 2010, 2011, Hollensead *et al.* 2016, Scharer *et al.* 2017). While habitat use patterns vary widely between nurseries (Poulakis *et al.* 2011, Simpfendorfer *et al.* 2011, Scharer *et al.* 2017), juveniles are thought to move as a result of food availability, water temperature, salinity and/or weather events (Poulakis *et al.* 2013, 2016, Hollensead *et al.* 2016, 2018, Scharer *et al.* 2017).

Large juveniles and adults spend the majority of their time in shallow, coastal waters, though they have been observed in deeper, shelf waters (Poulakis and Seitz 2004, Simpfendorfer *et al.* 2010, 2011, Wiley and Simpfendorfer 2010, Poulakis *et al.* 2013, Waters *et al.* 2014, Carlson *et al.* 2014). While adults have on rare occasions been seen in waters 32–34°C (Carlson *et al.* 2014), they favor temperatures between 22 and 28°C (Papastamatiou *et al.* 2015). Temperatures below 8–12°C can be lethal depending on exposure time and water depth (Poulakis *et al.* 2011, Schraer *et al.* 2017).

Encounter data and tagging data suggest that adult smalltooth sawfish migrate seasonally northward up the Florida peninsula (NMFS 2009, Papastamatiou *et al.* 2015), though it is unclear if these migrations occur consistently, year after year.

Smalltooth sawfish grow relatively rapidly, compared with other sharks and rays; juveniles double in length in the first year, exceeding 200 cm stretched total length (STL) by their second year and reaching sizes of about 500 cm STL as adults (Simpfendorfer *et al.* 2008). Little is known regarding maximum age, though they are thought to reach at least 30 years of age in the wild (Simpfendorfer 2015).

Smalltooth sawfish are late maturing (7–11 years of age) and produce a small number (7–14) of live young (Carlson and Simpfendorfer 2015, Feldheim *et al.* 2017). Females have biennial reproductive cycles with one-year gestation cycles (Feldheim *et al.* 2017). Sexual maturity is reached at four to five years of age for males; it takes longer for females but precise timing remains unknown (Simpfendorfer *et al.* 2008). In Charlotte Harbor, pregnant females give birth between November and July (peaking between April and May) (Poulakis *et al.* 2011), while farther south in the Ten Thousand Islands and Everglades National Park, births occur in all months except for September (peaking between March and July). Smalltooth sawfish were recently discovered producing young through parthenogenesis (reproduction without fertilization from a male) (Fields *et al.* 2015). While the young were viable, it is unclear, as of yet, whether or not they will be able to reproduce and contribute to population growth. It also remains unclear

whether or not asexual reproduction comes as a response to low population size for this species. In addition, to date, five functional males have been necropsied and all contained both female and male reproductive organs (J. Gelsleichter and G. R. Poulakis unpubl. data) suggesting that a rudimentary form of hermaphroditism is common for this species.

Little is known about the smalltooth sawfish diet, though they are thought to feed primarily on teleost and elasmobranch fishes at all life stages (Poulakis *et al.* 2017). Direct observations in the field indicate they feed on school fish (i.e., clupeids, carangids, mugilids, elopids, sparids, belonids), elasmobranchs (dasyatids), and the pinfish *Lagodon rhomboides* and pink shrimp *Farfantepenaeus duorarum* (used as bait) (Poulakis *et al.* 2013, 2017).

While there is currently no estimate of smalltooth sawfish population size, it is clear that the population suffered large declines during the 20th century. However, more recently, the population is thought to have stabilized throughout its core range and even shown slight increases in certain areas like Everglades National Park (Carlson *et al.* 2007). While the historical declines and range contraction are concerning for the conservation of the population, Chapman *et al.* (2011) found the population to be genetically healthy and exhibit no evidence of a genetic bottleneck. Carlson and Simpfendorfer (2015) constructed an age-structure Leslie matrix model for the US population and concluded that the population could potentially recover to higher levels as long as fishing-related mortality is kept low.

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Snook - *Centropomus undecimalis*

Overall Vulnerability Rank = High ■

Habitat Sensitivity = Moderate ■

Climate Exposure = Very High ■

Data Quality = 85% of scores ≥ 2

<i>Centropomus undecimalis</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	Low Moderate High Very High
Sensitivity Attributes	Habitat Specificity	2.1	2.8	<	

Overall Climate Vulnerability Rank: **High.** (97% bootstrap results in High, 2% bootstrap results in Moderate, 1% bootstrap results in Very High).

Climate Exposure: **Very High.** The three exposure factors that contributed to a very high climate exposure score for snook were sea surface temperature (4.0), ocean acidification (4.0), and salinity (3.8). Primary productivity (2.0) and sea level rise (2.3) were both moderate.

Biological Sensitivity: **Moderate.** The primary sensitivity attributes contributing to a moderate biological sensitivity score for snook were habitat specificity (2.1), adult mobility (2.1), early life history survival and settlement requirements (2.2), dispersal of early life stages (2.4), and sensitivity to ocean acidification (1.8).

Distributional Vulnerability Rank: **Moderate.** The top three attributes contributing to snook's moderate vulnerability to distribution shift were moderate habitat specificity (2.1), moderate to high sensitivity to temperature (2.3), and highly to moderately dispersive early life stages (2.4).

Data Quality: All data quality scores were 2 or greater. The lowest data quality scores were found in stock size/status and other stressors, both of which were 2.0. Ocean acidification and primary productivity also had data quality scores of 2.0.

Climate Effects on Abundance and Distribution: Two recent studies have associated the effect of warming temperatures on the abundance and distribution of snook in the Gulf of Mexico. Purtlebaugh *et al.* (2020) documented the northward shift in West Florida. Anderson *et al.* (2020) characterized the increased abundance in Texas. Fewer "cold kill" extreme winter temperatures may allow snook to expand their range further northward.

Life History Synopsis: Snook is a large subtropical marine/estuarine species distributed in the southeastern U. S. from northeastern Florida south along the U.S., Bermuda, in the Gulf of Mexico from the Florida Keys north to the Suwanee River (Florida) and from Matagorda Bay, Texas down along the Mexican coast to northwestern Cuba, throughout the Caribbean Sea except the Cayman Islands, and along South America to Santa Catarina State, Brazil.

Small juveniles (<150 mm SL) are tolerant of low oxygenated waters and are found in the lower portions of rivers (especially riverine backwaters), tidal tributaries, and in coastal wetland ponds. These types of habitats are under threat as they lie at the interface with urbanization and human land use. Larger juveniles (151-350 mm standard length), which are not as tolerant to low dissolved oxygen and presumably need larger prey, start to leave the nursery habitat and are found in lower portions of rivers, the mouths of tidal tributaries, and among coastal wetland island networks (McMichael *et al.* 1989, Stevens *et al.* 2007, Stevens *et al.* 2010). Adults could be considered a habitat generalist, as they are a euryhaline species that prefers coastal waters, mangrove-fringed estuarine habitats. Their wide salinity tolerance allows utilization of a variety of habitats from freshwater to marine. After maturation, distribution is broad and includes open estuarine shorelines, seagrass shoals, beaches, rivers (up to 100 km), and nearshore reefs (<10km from shore) (Stevens *et al.* 2018, Winner *et al.* 2010).

In freshwater and coastal wetland nursery habitats of Florida, juveniles feed on palaemonid shrimp, microcrustaceans and mosquitofish (McMichael *et al.* 1989, Adams *et al.* 2009, Ferreira *et al.* 2019). Adults are opportunistic carnivores with diets reflective of prey commonly found in the environment. In southwestern Florida, diet in the estuary was comprised of pinfish, anchovies, and pink shrimp, whereas diet in rivers was comprised of crayfish and brown hoplos (Blewett *et al.* 2006). In coastal rivers of southeastern Florida, adults ate a variety of estuarine fish, swimming crabs, shrimp, and xanthid crabs, reflecting the strong marine influence in these rivers. Diet in the rivers of the coastal Everglades were dominated by sunfishes. Adults capitalize on "prey pulses" such as when prey is forced into the main channels of rivers as freshwater marshes recede in the dry season (Stevens *et al.* in press).

Adults are mobile but behavior mediates distances moved. Gulf coast snook inhabit a single estuary their entire lives while Atlantic snook move greater distances. Seasonal movements occur as snook move into rivers to capitalize on a prey pulse or towards inlets and passes during the spawning season (Trotter *et al.* 2012, Young *et al.* 2014, 2016, Stevens *et al.* 2018).

Snook are protandric hermaphrodites, with female gonads maturing directly from male gonads after spawning occurs. This is likely socially mediated, initiated by lack of females in the population. Snook are obligate marine spawners requiring salinities of >24 ppt for critical egg buoyancy and sperm activation. Spawning occurs when water temperatures warm to 24°C and is usually linked to times of increased rainfall (Gilmore *et al.* 1983, Hill 2005, Taylor *et al.* 1998). Spawning season is protracted, from April to October, with peak spawning on the east coast occurring in July and August. Snook form large spawning aggregations in high salinity waters near the mouths of coastal rivers, inlets and lower estuaries. Snook are broadcast spawners.

While few larval snook have been collected, Peters *et al.* (1998) documented that newly hatched larvae spend about 2.5 weeks in the upper few meters of the water column in high-salinity water prior to their arrival in shallow-water nursery sites, likely transported by favorable tidal stream transport. While eggs and larvae are found in polyhaline and euryhaline waters near estuarine passes or adjacent river mouths, small juveniles prefer low-energy shallow waters that provide abundant prey and a respite from larger predators, including tidal ponds and creeks.

Snook are most commonly found in waters of temperatures between 25 - 31 °C. Mass mortality of snook occurs as water temperatures fall below 10 °C. Historically, the primary distribution of Gulf snook was on the west coast of Florida, from the Dry Tortugas north to Cedar Key. Long-term fisheries independent monitoring has shown that in recent years, snook have increased in abundance and expanded its northern range in West Florida (Purtlebaugh *et al.* 2020). Recent studies have also reported expanded ranges and increased abundance of snook along the coast of Texas (Anderson *et al.* 2020). While snook normally utilizes coastal shallow habitat (<3 m), they are known to make move into warmer (~2 °C) sheltered waters at southerly latitudes. At the species range limit, movements into warm springfed rivers or other temperature refugia occur as winter approaches.

Snook are likely to be affected by increasing ocean acidification, as larval and small snook eat copepods and microcrustaceans and larger snook eat shrimp, crayfish and crabs.

Snook in the east Gulf have a slow population growth rate, as indicated by a large maximum body size (95 cm), a moderately slow growth coefficient ($K=0.18$), an extended longevity (20 years), a low natural mortality rate ($M=0.25$), and an age of 5 years where 50% of the fish of a given year class will be mature females (males mature at age-1, mature males transition to mature females) (Muller *et al.* 2015, Taylor *et al.* 2000). These characteristics make the species vulnerable to population disruptions.

Spawning stock biomass has been decreasing on the Atlantic coast of Florida since the mid-1990s and has been generally increasing on the Gulf coast. Muller *et al.* (2015) found that for the Gulf coast of Florida, SPR is well above the objective of above 40%, fishing mortality was below the fishing mortality expected at 40% SPR, and SSB was larger than SSB expected at 40% SPR. Gulf of Mexico and Atlantic populations of snook are genetically distinct and are managed as different stocks.

Coastal wetland habitat is being lost to development. Snook are negatively impacted by mosquito control efforts throughout Florida. High freshwater flows in rivers are needed to inundate floodplains to produce prey pulses and these are being diverted to reservoirs. Microplastics could be an issue. Harmful algal blooms could impact snook populations negatively as well.

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Southern flounder - *Paralichthys lethostigma*

Overall Vulnerability Rank = Low ■

Habitat Sensitivity = Low ■

Climate Exposure = High ■

Data Quality = 85% of scores ≥ 2

<i>Paralichthys lethostigma</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	Low Moderate High Very High
Sensitivity Attributes	Habitat Specificity	2.1	2.9		

Overall Climate Vulnerability Rank: **Low** (96% bootstrap results in Low 4% bootstrap results in Moderate).

Climate Exposure: **High.** Two exposure factors contributed to a high climate exposure score for southern flounder: sea surface temperature (4.0) and ocean acidification (4.0). Exposure to both factors is likely during multiple life stages. Southern flounder use estuarine habitats, but cool weather triggers winter spawning movements offshore. Primary productivity (1.4) was low to moderate, sea level rise (2.4), salinity (2.4), and hypoxia (2.4) were all ranked moderate to high. Hypoxia and salinity had scores ranging from low to very high.

Biological Sensitivity: **Low.** The primary sensitivity attribute to a low biological sensitivity score for southern flounder were sensitivity to temperature (1.4), sensitivity to ocean acidification (1.7), dispersal of early life stages in (1.7), and prey specificity (1.8).

Distributional Vulnerability Rank: **Moderate.** The top three attributes contributing to southern flounder's moderate vulnerability to distribution shift ranking were low sensitivity to temperature (1.4), highly dispersive early life stages (1.7), and low to high habitat specificity (2.1). Adult mobility (2.3) was also viewed as high to very high.

Data Quality: All data quality scores except stock size/status (1.6) were 2 or greater. Only Louisiana and Alabama have conducted assessments of stock status, both of which indicate that southern flounder stocks are not healthy.

Climate Effects on Abundance and Distribution: Little is known regarding potential impacts of climate factors on the abundance, distribution, and population productivity of Southern Flounder. Given existing gaps in the spatial distribution of southern flounder in south Florida, it is likely that increasing temperatures may result in a northward shift in their distribution and, in the Gulf of Mexico, a potential contraction in quantity of suitable habitat.

Life History Synopsis: Southern Flounder are found from northern Mexico to Virginia, although there is a distributional break in southern Florida (Springer and Woodburn 1960). Southern Flounder grow quickly as juveniles (Fitzhugh *et al.* 1996), although growth becomes sexually-dimorphic and highly variable by age-1 and age-2 (Fitzhugh *et al.* 1996, Midway *et al.* 2015). Females reach 50% maturity by 30 - 35 cm TL and age 1 - 2 (Monaghan and Armstrong 2000, Midway and Scharf 2012, Corey *et al.* 2016).

Spawning occurs primarily in coastal waters during the fall and winter (Music and Paffort 1984; Monaghan 1996; Smith *et al.* 2009). Females spawn approximately every 3 - 12 days, with average batch fecundity around 50,000 eggs per batch (Fischer 1999). Southern flounder larvae are pelagic (Benson 1982), eventually entering inlets or interior coastal waters (Peters *et al.* 1995) prior to moving to shallow estuarine environments post-settlement (Walsh *et al.* 1999). Juvenile southern flounder are found in waters above mud bottom, along the edge of saltmarsh habitats, near areas with shell bottom substrate, and submerged aquatic vegetation (Pattillo *et al.* 1997, Minello 1999, Walsh *et al.* 1999, Peterson *et al.* 2003). Juveniles are euryhaline (Deubler

1960, Stickney and White 1973) and can tolerate temperatures as low as 2 - 4 ° C (Williams and Deubler 1968). Southern flounder remain within estuarine nurseries for a year or more before migrating offshore in association with falling water temperatures (Shepard 1986, Wenner *et al.* 1990, Patillo *et al.* 1997, Craig *et al.* 2015).

Tagging studies indicate that mature adults generally migrate in a southerly direction (Monaghan 1996, Smith *et al.* 2009, Craig *et al.* 2015), although many fish are recaptured within the same estuary in which they were tagged. Larval southern flounder feed on zooplankton (Daniels 2000).

As juveniles, southern flounder consume epifauna including mysids, amphipods, and calanoid copepods (Powell and Schwartz 1977, Burke 1995). Adults are primarily piscivorous, although they will also consume shrimp (Powell and Schwartz 1977, Fitzhugh *et al.* 1996).

A 2020 assessment of the Louisiana stock indicates that southern flounder are currently overfished (West *et al.* 2020), whereas the Alabama stock is not overfished but is currently experiencing overfishing (Powers *et al.* 2018).

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Southern stingray - *Dasyatis americana*

Overall Vulnerability Rank = High 

Habitat Sensitivity = Moderate 

Climate Exposure = Very High 

Data Quality = 80% of scores ≥ 2

<i>Dasyatis americana</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	1.6	2.8		Low Moderate High Very High
	Prey Specificity	1.4	3		
	Adult Mobility	1.8	2.8		
	Dispersal of Early Life Stages	1.4	2.6		
	Early Life History Survival and Settlement Requirements	1	2.2		
	Complexity in Reproductive Strategy	1.9	2.2		
	Spawning Cycle	1.9	2.6		
	Sensitivity to Temperature	1.3	2.6		
	Sensitivity to Ocean Acidification	2.1	2.4		
	Population Growth Rate	2.7	1.6		
	Stock Size/Status	1.7	0.8		
	Other Stressors	2.5	2		
	Sensitivity Score		Moderate		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	2.2	2.4		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.8	2		
	Salinity	3.5	3		
	Sea Level Rise	2.3	2.4		
	Sea Surface Temperature	4	3		
	Exposure Score		Very High		
Overall Vulnerability Rank		High			

Overall Climate Vulnerability Rank: **High.** (50% bootstrap results in Moderate, 30% bootstrap results in High, 20% bootstrap results in Low).

Climate Exposure: **Very High.** The three exposure factors contributing to a very high climate exposure score for southern stingray were sea surface temperature (4.0), ocean acidification (4.0), and salinity (3.5). Sea level rise (2.3) and hypoxia (2.2) were moderate to high. Primary productivity (1.8) was moderate to low.

Biological Sensitivity: **Moderate.** The primary sensitivity attributes that contribute to a moderate biological sensitivity score for southern stingray were stock size/status in (1.7), adult mobility (1.8), complexity in reproductive strategy (1.9), spawning cycle (1.9), and sensitivity to ocean acidification (2.1).

Distributional Vulnerability Rank: **High.** The top three attributes contributing to southern stingray's high vulnerability to distribution shift were low sensitivity to temperature (1.3), very highly to highly dispersive early life stages (1.4), and low to moderate habitat specificity (1.6).

Data Quality: All data quality scores except stock size/status (0.8) and population growth rate (1.6) were 2 or greater.

Climate Effects on Abundance and Distribution: No studies have directly examined the effect of climate change on the abundance and distribution of the southern stingray, although simulation studies have been performed examining the effects of climate change on closely related species associated with the Great Barrier Reef in Australia (Chin *et al.* 2010). Given their neritic distribution (to approximately 80m; Jones *et al.* 2020) and association with both seagrass and coral reef habitats (Last *et al.* 2016) over a portion of their range, warming of coastal waters and associated factors affecting these habitats (such as ocean acidification), could potentially impact the distribution and abundance of southern stingrays in the northern Gulf of Mexico. In addition, as this species is known to inhabit nearshore and estuarine environments (Schmid *et al.* 1988, McEachran and Fechtelm 1998), factors associated with sea level rise and increased storm activity, leading to freshwater input and eutrophication could change distribution patterns and local abundances. However, while localized changes in distribution and abundance could be an expected effect of climate change, given the broad range of habitats this species inhabits, potential phenotypic plasticity in life history characteristics (often correlated with differences in water temperature in other batoids; Frisk 2010), and opportunistic generalist feeding strategy and diet (Gilliam and Sullivan 1993), the overall impact of climate change on the Southern stingray in the northern Gulf of Mexico region is expected to be low.

Life History Synopsis: Very little research is available concerning the life history characteristics of the southern stingray. Growth in wild populations has not been estimated, although they have been reported to reach a maximum observed age of 17yrs in the wild (off southwest Florida; Hayne *et al.* 2018), with maximum verified ages observed in captivity being similar for both sexes (Henningsen and Leaf 2010). However, disc widths (DW) reported at these ages (between 1100-1200mm; Hayne 2018) are significantly smaller than the observed maximum disc width in the wild (1500mm to 1640mm; Bigelow and Schroeder 1953 and Ramírez-Mosqueda *et al.* 2012 respectively), indicating maximum age could be significantly older. Furthermore, Henningsen

and Leaf (2010) report individuals, captured as adults and held in captivity, living up to 17 and 19 additional years for females and males respectively, post capture. Bigelow and Schroeder (1953) estimated size at maturity to be 510mm for males and between 750-800mm for females. Henningsen and Leaf (2010) and Ramírez-Mosqueda *et al.* (2012) suggested similar estimates (520mm for males and 750-800mm for females; 517mm for males and 764mm for females respectively). If we assume mature individuals raised in captivity were on the small end of these ranges, and utilizing age at DW suggested in both Henningsen and Leaf (2010) and Hayne *et al.* (2018), longevity in excess of 20yrs is highly probable. One individual female reported by Henningsen and Leaf (2010) was captured at 1000mm and grew to 1300mm over the next 15 years. Again utilizing DW at age reported in the two previously mentioned studies, this individual could have been between 22 and 28yrs old at the time of reporting.

Bigelow and Schroeder (1953) estimated size at birth to be approximately 200mm DW, from measurements of wild caught embryos. In his study of captive southern stingrays, Henningsen (2000) reported newborns ranging in size from 200-340mm DW. Although estimates from captive populations are not normally considered to be representative of conditions in the wild, the fact that these estimates are similar (although captive bred individuals slightly larger, which is to be expected) would seem to reinforce the ~200mm estimate. Furthermore, Henningsen and Leaf (2010) indicated that of the neonates examined during their study, females were born at significantly larger median DW than males, which could also account for some of the disparity between wild caught and captive specimens. Litter sizes have been reported as ranging from 2-10 individuals (average ~4) with male to female ratios not significantly different from 1:1 (Bigelow and Schroeder 1953, Henningsen and Leaf 2010, Ramírez-Mosqueda *et al.* 2012). Both Henningsen and Leaf (2010) and Ramírez-Mosqueda *et al.* (2012) indicated increasing litter sizes with increasing maternal DW.

Gestation has been variably been reported as 4.5-7.5 months with a biannual reproductive cycle in captivity (Henningsen 2000) to 7-8 months with an annual reproductive cycle in the southern Gulf of Mexico (Ramírez-Mosqueda *et al.* 2012). Ramírez-Mosqueda *et al.* 2012 also indicated that the female reproductive cycle in the southern Gulf of Mexico is asynchronous, with ovulation and parturition occurring year round. While there has been agreement in many life history estimates between studies focused on wild caught and captive populations, reproductive cycle and gestation period appear to be a case where there is significant divergence, indicating that these characteristics are highly plastic with respect to environmental stability. While it has been proposed that temperature may play a significant role in the variability of reproductive characteristics (Henningsen *et al.* 2004, Ramírez-Mosqueda *et al.* 2012), it is also probable that the availability and consistency of food plays an important role. Female southern stingrays provide significant nutritional input for their embryos in later stages of development, utilizing villiform trophonemata of the uterus to deliver a nutrient dense histotroph (Musick and Ellis 2005). It stands to reason therefore that maternal nutrition would affect embryonic growth.

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Spanish mackerel - *Scomberomorus maculatus*

Overall Vulnerability Rank = Low ■

Habitat Sensitivity = Low ■

Climate Exposure = High ■

Data Quality = 80% of scores ≥ 2

<i>Scomberomorus maculatus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	1.9	2.6		Low Moderate High Very High
	Prey Specificity	1.6	2.2		
	Adult Mobility	1.4	2.8		
	Dispersal of Early Life Stages	2.2	2		
	Early Life History Survival and Settlement Requirements	1.6	1.6		
	Complexity in Reproductive Strategy	1.7	2.2		
	Spawning Cycle	2.1	2.2		
	Sensitivity to Temperature	1.6	2.6		
	Sensitivity to Ocean Acidification	1.6	2		
	Population Growth Rate	2	2		
	Stock Size/Status	1.4	2.6		
	Other Stressors	1.6	1.8		
	Sensitivity Score		Low		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	1.7	2.4		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.5	2		
	Salinity	3.1	3		
	Sea Level Rise	1.6	2.8		
	Sea Surface Temperature	4	3		
	Exposure Score		High		
Overall Vulnerability Rank		Low			

Overall Climate Vulnerability Rank: **Low.** (96% bootstrap results in Low, 4% bootstrap results in Moderate).

Climate Exposure: **High.** The exposure factors led to a high climate exposure score for Spanish mackerel: sea surface temperature (4.0), ocean acidification (4.0), and salinity (3.1). Ocean acidification likely affects adult life stages. Increases in sea surface temperature could be considered to negatively impact habitat quality of juveniles. Spanish mackerel uses coastal and nearshore habitats during juvenile stages, but also utilizes offshore areas for spawning and feeding migrations.

Biological Sensitivity: **Low.** The primary sensitivity attributes contributing to a low biological sensitivity score for Spanish mackerel were stock size/status (1.4), adult mobility (1.4), prey specificity (1.6), sensitivity to temperature (1.6), and sensitivity to ocean acidification (1.6). All of the sensitivity scores ranged from 1.4 to 2.2 with the mean score of 1.7. Spanish mackerel are a medium-lived fish with relatively high growth rates, are able to utilize a variety of habitats and utilize multiple prey types including small fishes but also crustacean, these characteristics considered adaptive in being able to respond to possible changes in habitat and/or food quality from climate changes.

Distributional Vulnerability Rank: **High.** The top three attributes contributing to Spanish mackerel's high vulnerability to distribution shift ranking were very high to high adult mobility (1.4), low to moderate sensitivity to temperature (1.6), moderate habitat specificity (1.9). Early life stage dispersal (2.2) was also viewed as moderate.

Data Quality: All data quality scores except early life history survival and settlement requirements (1.6) and other stressors (1.8) were 2 or greater. Generally, the life history and population dynamics are reasonably studied. However, very little information exists with which to quantify population growth (r) or natural mortality, thus adding uncertainty to some components.

Climate Effects on Abundance and Distribution: There are no known studies that definitively document how climate will affect long term productivity of Spanish mackerel populations in the southeastern US. Changes in distribution associated with warming along northeastern US have been predicted for northeastern stocks (Hare *et al.* 2019). This predicted change in species distribution has been characterized as being positive for the Spanish mackerel stocks along the NE US however is associated with moderate uncertainty. Masami *et al.* (2019) reported increased occupancy and range expansion for juvenile Spanish mackerel off Texas, from a fishery independent assessment utilizing bag seines. This observed increase in occupancy was thought to be associated with increasing salinity which has been reported for many of the bays along the Texas coast.

Life History Synopsis: Spanish mackerel are mainly a continental, pelagic species ranges along the Atlantic coast most commonly from Cape Hatteras southward; in the Gulf of Mexico (GoM) from the Florida Keys to the Yucatan Peninsula, Mexico (Erdman 1949, Collette *et al.* 1978, Godcharles and Murphy 1986, Sutherland and Fable 1980, Johnson 1981). The species undergoes distinct seasonal migrations; movements are generally believed to be temperature

dependent (Moe 1972, Powell 1975, Bensen 1982). During the spring and summer months, the species frequents the Atlantic coast as far north as New York and occasionally moves into colder Gulf of Main waters. During fall and summer the species is commonly observed between North Carolina and Florida. The main areas of abundance are off the Atlantic coast of Florida (Dwinell and Futch 1973, Trent and Anthony 1979, Fable *et al.* 1987).

Larvae occur most frequently in offshore surface waters, with temperature and salinity ranging from 19.6-29.8°C with 28.3-37.4 ppt. In the GoM, larvae are often found in nearshore shallow-water habitats from Florida to south Texas (Wollam 1970, Dwinell and Futch 1973). Juveniles commonly inhabit high salinity nearshore coastal and beachfront waters; sometimes also entering estuarine areas. Juveniles are believed to prefer sandy habitats (Bensen 1982). Juveniles are collected from low salinity (12.8 - 19.7 ppt) estuaries as well as from high salinity beaches, suggesting that at least some Spanish mackerel utilize estuaries as nursery grounds (Springer and Woodburn 1960).

Adult Spanish mackerel are pelagic and oceanodromous, and are found near the edge of the continental shelf to shallow coastal waters. The species is also found in drop-offs and shallow/gently sloping reef/lagoon waters. Adults are schooling pelagic carnivores that feed primarily on estuarine-dependent species such as menhaden (*Brevoortia* sp.) and anchovies (*Anchoa*), with squid being the most abundant invertebrate (Godcharles and Murphy 1986). Juveniles are primarily piscivorous, with anchovies, menhaden, Spanish sardines, and Atlantic thread herring constituting the bulk of the diet. Less common prey types are mullets (*Mugil* spp.) and sciaenids.

The species is not limited behaviorally or physically in their movement, beyond their preference for water temperatures between from 21 - 31°C.

Spanish mackerel are gonochoristic. They spawn in the open ocean, at depths of 12-35 m over the inner continental shelf (McEachran *et al.* 1980). Spawning varies slightly latitudinally with NC-GA spawning occurring May-August, and spawning in Florida Atlantic waters occurring April-Sept, and as late as October (Powell 1975). They are broadcast spawners. Pelagic eggs are buoyant and hatching occurs approximately 25 hours after fertilization at water temperatures averaging 26°C (Smith 1907). Larvae and early juveniles grow 1.9 mm per day for approximately the first 23 days of life. From 23 - 40 days, growth is accelerated, with young fishes growing as much as 5 mm per day. Thereafter, growth slows to approximately 2.1 mm per day (Schmidt *et al.* 1993, Peters and Schmidt 1997).

Spanish mackerel have a high growth coefficient showing particularly rapid growth during through juvenile life stage, an early age-at-maturity of age 2, a moderately low longevity of about 12 years, a moderate maximum body size, and high rate of natural mortality. These characteristics indicate the species has a high population growth rate and should be able to recover from population depletions fairly quickly.

Larvae feed on a wide variety of readily available larval fish species, indicating a mismatch of prey with larval emergence should not be a factor. Generally adult and juvenile diets are similar.

Spanish mackerel are rarely reported from waters cooler than 18°C. They are typically collected from waters ranging from 21 - 31°C. Water temperatures in excess of 25°C triggers spawning in Spanish mackerel (Beaumariage 1970). They utilize depths from 0-35 m in the water column.

Spanish mackerel should not be affected by increased ocean acidification as their diet consists primarily of schooling fishes.

Spanish mackerel are not obligate estuarine users, although larvae and juveniles that do use inshore nursery areas could be subject to anthropogenic impacts (habitat degradation/alteration, pollution) felt by many other species. Adults using nearshore coastal waters could be affected by pollution.

Based on a 2012 SEDAR stock assessment, Gulf Spanish mackerel were not considered overfished nor undergoing overfishing (SEDAR 2012). Various studies have found conflicting evidence of genetic connectivity between Atlantic and Gulf of Mexico populations of Spanish mackerel.

Given the highly migratory nature of this species, possible mixing of pelagic eggs, and low number of individuals needed to homogenize the genetic signal, it is not surprising that mitochondrial and nuclear DNA differences were not detected.

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Speckled hind - *Epinephelus drummondhayi*

Overall Vulnerability Rank = High ■

Habitat Sensitivity = High ■

Climate Exposure = High ■

Data Quality = 55% of scores ≥ 2

<i>Epinephelus drummondhayi</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	2.6	2.2		Low Moderate High Very High
	Prey Specificity	1.6	1.8		
	Adult Mobility	2.6	2		
	Dispersal of Early Life Stages	2.1	1.2		
	Early Life History Survival and Settlement Requirements	2.5	0.6		
	Complexity in Reproductive Strategy	2.9	2.2		
	Spawning Cycle	2.4	2		
	Sensitivity to Temperature	2.5	2.6		
	Sensitivity to Ocean Acidification	1.8	2		
	Population Growth Rate	3.6	2.6		
	Stock Size/Status	3.6	1.6		
	Other Stressors	1.6	1.6		
	Sensitivity Score		High		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	2	1.6		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.5	2		
	Salinity	2.5	3		
	Sea Level Rise	1	0		
	Sea Surface Temperature	4	3		
Exposure Score		High			
Overall Vulnerability Rank		High			

Overall Climate Vulnerability Rank: **High.** (100% bootstrap results in High).

Climate Exposure: **High.** The two main exposure factors that contributed to a high climate exposure score for speckled hind were sea surface temperature (4.0) and ocean acidification (4.0). Salinity (2.5) was moderate to high, and hypoxia (2.0) was moderate. Primary productivity (1.5) was low to moderate.

Biological Sensitivity: **High.** The primary sensitivity attributes that contribute to high biological sensitivity score for speckled hind were habitat specificity (2.6), adult mobility (2.6), early life history survival and settlement requirements (2.5), sensitivity to temperature (2.5), population growth rate (3.6), and stock size/status (2.6).

Distributional Vulnerability Rank: **Low.** The top three attributes contributing to speckled hind's low vulnerability to distribution shift were high habitat specificity (2.6), high to moderate sensitivity to temperature (2.6), and moderate to high adult mobility (2.6). Early life stage dispersal (2.1) was moderate.

Data Quality: All data quality scores were 2 or greater except early life history survival and settlement requirements (0.6), dispersal of early life stages (1.2), stock size/status (1.6), other stressors (1.6). and hypoxia (1.6).

Climate Effects on Abundance and Distribution: There is limited understanding of the spatial distribution and abundance of Speckled Hind in the Gulf of Mexico, and therefore, the potential impacts of climate effects. While an index of abundance was derived from the SEAMAP Reef Fish Video Survey which samples offshore reef habitat throughout the Gulf of Mexico (Campbell *et al.* 2016), limited sample sizes and low occurrence precluded its recommendation for use in the 2016 SEDAR 49 U.S. Gulf of Mexico data-limited stock assessment for this species (SEDAR 2016). Reef type was a significant predictor in abundance, which may suggest a link between Speckled Hind presence and habitat.

Life History Synopsis: Speckled hind is a rare member of the deep-water grouper complex (Farmer *et al.* 2016) and is infrequently encountered in the eastern and northern Gulf of Mexico (Heemstra and Randall 1993) and off Campeche Bank (Brule *et al.* 2000, Murawski *et al.* 2018). This species occurs between 25-183 m but is most common at 60-120 m depth, with juveniles found in shallower regions (GMFMC 2004). Adults are selective about habitat and typically inhabit rocky bottom areas (McEachran and Fechhelm 2006, Farmer and Karnauskas 2013) and moderate relief outcrops (Harter and David 2010). Juveniles may be found on hard bottom habitat in shallower water (Ross 1988).

Reproductive characteristics of speckled hind in the Gulf of Mexico are currently lacking. A single study investigated reproductive life history for speckled hind from the U.S. South Atlantic (Ziskin *et al.* 2011). Ziskin *et al.* (2011) used data collected from histologically staged gonads to calculate size and age at 50% maturity, which were 532 mm TL and 6.6 years, respectively. Speckled hind is a protogynous hermaphrodite that spawns in late spring or summer at known spawning locations in the Gulf of Mexico (Bullock and Smith 1991, Brule *et al.* 2000, Ziskin *et al.* 2011). Speckled hind undergo 50% transition at 627 mm TL and 6.9 years (GMFMC 2016).

The courtship behavior of this species has been observed on deep, *Oculina* coral reefs where gag and scamp are known to aggregate for spawning (Gilmore and Jones 1992). While much of their life history remains unknown, speckled hind larvae are thought to be pelagic with a duration of 40-60 d (Sosa-Cordero and Russell 2018). Settlement requirements for larval speckled hind are unknown, though it is possible that larvae use chemical and/or auditory cues to locate suitable habitat. Speckled hind are thought to aggregate to spawn, though this suggestion is unconfirmed (Heyman *et al.* 2019).

Speckled hind consume crustaceans and ray-finned fishes (Bullock and Smith 1991; McEachran and Fechhelm 2006). Juveniles and adults alike consume fishes, molluscs, and crustaceans (Heemstra and Randall 1993, Sosa-Cordero and Russell 2018), and are known to be aggressive apex predators within their reef community (Huntsman *et al.* 1999). Speckled Hind are slow-growing and long-lived, with a maximum reported age of at least 40 years in the South Atlantic (Ziskin *et al.* 2011). A recent validation study by Andrews *et al.* (2013) using radiocarbon to validate the timing of band deposition provided evidence that Speckled hind had been underaged in earlier literature (e.g., Ziskin *et al.* 2011). Andrews *et al.* (2013) concluded longevities up to 60 – 80 years. Stevens *et al.* (2019) recommended an L_{∞} of 888 mm TL, von Bertalanffy K of 0.12, and theoretical age at length zero of -1.80 years for speckled hind during the 2016 SEDAR 49 U.S. Gulf of Mexico data-limited stock assessment for this species. During that assessment, a maximum age of 45 years was recommended due to the difficulties in interpreting band increments in thin-sectioned sagittal otoliths and the results of the radiometric dating validation study (SEDAR 2016).

The Gulf of Mexico speckled hind stock, considered a single unit stock given the lack of information on stock structure in the Gulf of Mexico, was scheduled for assessment during the 2016 SEDAR 49 U.S. Gulf of Mexico data-limited stock assessment. Ultimately, data limitations precluded the application of datalimited approaches for determining stock status (SEDAR 2016). As a result, stock status remains unknown. Speckled hind fall within Tier 3B of the Gulf of Mexico's Acceptable Biological Catch control rule, which is reserved for stocks where current fishing levels may not be sustainable over time (GMFMC 2011). Since juveniles remain in shallower water, habitat destruction as a result of trawling may impact this life stage.

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Spiny lobster - *Panulirus argus*

Overall Vulnerability Rank = Moderate ■

Habitat Sensitivity = Moderate ■

Climate Exposure = High ■

Data Quality = 85% of scores ≥ 2

<i>Panulirus argus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	2.4	2.6		Low Moderate High Very High
	Prey Specificity	1.5	2.4		
	Adult Mobility	2.5	2.6		
	Dispersal of Early Life Stages	1.1	2.4		
	Early Life History Survival and Settlement Requirements	2.8	2.8		
	Complexity in Reproductive Strategy	2.6	2.8		
	Spawning Cycle	1.8	2.6		
	Sensitivity to Temperature	1.4	2.4		
	Sensitivity to Ocean Acidification	2.6	2.2		
	Population Growth Rate	2.1	2		
	Stock Size/Status	2	1.4		
	Other Stressors	2.7	2.6		
	Sensitivity Score		Moderate		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	2.2	2.8		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.5	2		
	Salinity	2.8	3		
	Sea Level Rise	2.6	2.8		
	Sea Surface Temperature	4	3		
	Exposure Score		High		
Overall Vulnerability Rank		Moderate			

Overall Climate Vulnerability Rank: **Moderate.** (99% bootstrap results in Moderate, 1% bootstrap results in High).

Climate Exposure: **High.** Two exposure factors contributed to this score: sea surface temperature (4.0) and ocean acidification (4.0). All life stages are at risk relating to ocean acidification. Spiny lobster have a hard shell covering their cephalothorax and rely on prey species with calcium carbonate exoskeletons or shells (snails, crabs, clams, urchins) as both juveniles and adults (MyFWC). Spiny lobster depend on water temperature to signal spawning with an optimum temperature of 24 degrees C (Crawford 1921). Decreases in temperature initiate mass migration offshore in both sexes (Davis 1977, Hernkind 1982, Kanciruk and Hernnkind 1978, Marx and Hernkind 1986) so changes in sea surface temperature can affect timing of movement and spawning aggregations. Additionally, increased sea surface temperature could affect the larval survival rates as spiny lobster have a long planktonic larval stage up to 10 months (Chavez 2012).

Biological Sensitivity: **Moderate.** The primary sensitivity attributes contributing to a moderate biological sensitivity score for spiny lobster were spawning cycle (1.8), stock size/status (2.0), population growth rate (2.1), habitat specificity (2.4), and adult mobility (2.5). No sensitivity attributes scored above 3.0. Spiny lobster occupy many different habitats from larvae through maturity. Beginning with a planktonic larval stage, secondary larvae move to nearshore seagrass and algal habitats, then grass flats and coral reefs as juveniles, and finally to offshore reefs as late-stage juveniles and adults (MyFWC). Other stressors that could negatively affect spiny lobster include PaV1 disease, which causes mortality in juveniles and has the potential to be exacerbated by climate change.

Distributional Vulnerability Rank: **Moderate.** The top three attributes contributing to spiny lobster's moderate vulnerability to distribution shift were very highly dispersive early life stages (1.1), low to moderate sensitivity to temperature (1.4), and moderate to high habitat specificity (2.4). Spiny lobster has a long planktonic larval stage along with different habitat requirements for each subsequent life stage: seagrass beds, nearshore coral reefs, and then offshore deep reefs (Moe 1991, Alfonso *et al.* 1991, Marx and Hernkind 1985, Hernkind 1980).

Data Quality: All data quality scores were 2 or greater, except stock size/status (1.4).

Climate Effects on Abundance and Distribution: Several studies have examined the effects of climate change and habitat loss for Caribbean spiny lobster populations. Using ecological niche models, BoavidaPortugal *et al.* 2018 projected losses of suitable habitat for coastal lobster populations, with highest losses in diversity projected for spiny lobster in the tropical zone. In addition to the effects of ocean acidification on shell development and prey species with calcium bicarbonate shells, Ross & Behringer, 2019 found that climate driven changes in temperature, salinity, and pH negatively affect the chemosensory driven shelter response in spiny lobster off Florida Bay. Climate change is also projected to affect productivity of the spiny lobster fisheries even when overexploitation is not a factor (Chavez and Garcia-Cordova 2011).

Life History Synopsis: Caribbean spiny lobster occupy warmer waters from North Carolina to the Gulf of Mexico and the Caribbean. They prefer temperatures greater than 20°C and are bottom dwellers utilizing rocks, coral reefs and seagrass beds up to 90m in depth (Holthuis 1991, Butler *et al.* 2011).

Adults remain in their dens during daylight hours to avoid predation and forage under dark nighttime conditions (MyFWC). Spiny lobster feed on snails and crabs as juveniles, then expand their diet to include clams and urchins as they reach maturity, though adults will eat almost anything (MyFWC).

Sexual maturity occurs at two years of age (Chavez 2001, Butler *et al.* 2011). Depending on water temperatures, spawning can occur from April through October, with mass migration and spawning in offshore reefs (Kanciruk and Herrnkind 1978, Marx and Herrnkind 1986).

Females carry eggs on their underside until they hatch (MyFWC). Spiny lobster have the longest larval duration of any marine animal, remaining planktonic for 6-12 months (Moe 1991) and drifting for up to thousands of miles before settling in coastal areas, seagrasses, and algae beds (MyFWC). Larvae are predated upon by many pelagic fish species but their high fecundity levels offset this predation (Phillips and Sastry 1980).

Mangroves and grass flats are used as coastal nursery habitat and are at risk due to coastal development and runoff (Butler *et al.* 1995). Additionally, adult reef habitat can be degraded by upstream sewage outflows (Butler *et al.* 1995). Sponge loss in adult habitat and climate change impacts have also shown to increase disease and impact resilience to diseases (M. Butler pers. comm. 2009, Butler *et al.* 2011).

Much is unknown about the status of the stock and its genetic variation. Maximum age is estimated to be around 12 years old, with documentation of some individuals reaching up to 20 years of age though causes of mortality are unknown (Chavez 2001, Erhardt 2005, Butler *et al.* 2011).

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Stone crab - *Menippe adina*

Overall Vulnerability Rank = Low ■

Habitat Sensitivity = Low ■

Climate Exposure = High ■

Data Quality = 85% of scores ≥ 2

<i>Menippe adina</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	2	2.6		Low Moderate High Very High
	Prey Specificity	1.3	2.4		
	Adult Mobility	2.5	2.6		
	Dispersal of Early Life Stages	1.8	2.4		
	Early Life History Survival and Settlement Requirements	2.3	2.4		
	Complexity in Reproductive Strategy	1.9	2.8		
	Spawning Cycle	2	2.4		
	Sensitivity to Temperature	1.8	2.4		
	Sensitivity to Ocean Acidification	2.4	2.2		
	Population Growth Rate	1.6	2.2		
	Stock Size/Status	1.9	1		
	Other Stressors	2.6	2.2		
	Sensitivity Score		Low		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	2.5	2.4		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.4	2		
	Salinity	2.6	3		
	Sea Level Rise	2.7	2.6		
	Sea Surface Temperature	4	3		
	Exposure Score		High		
Overall Vulnerability Rank		Low			

Overall Climate Vulnerability Rank: **Low.** (52% bootstrap results in Low, 48% bootstrap results in Moderate).

Climate Exposure: **High.** Two exposure factors contributed to a high climate exposure for stone crab: sea surface temperature (4.0) and ocean acidification (4.0). Sea level rise (2.7), salinity (2.6), and hypoxia (2.5) were high to moderate. Primary productivity (1.4) was low to moderate.

Biological Sensitivity: **Low.** The primary sensitivity attribute to a low biological sensitivity score for stone crab were prey specificity (1.3), population growth rate (1.6), dispersal of early life stages (1.8), sensitivity to temperature (1.8), and stock size/status (1.9).

Distributional Vulnerability Rank: **High.** The top three attributes contributing to stone crab's high vulnerability to distribution shift were moderate sensitivity to temperature (1.8), highly dispersive early life stages (1.8), and moderate habitat specialization (2.0). Stone crab was on the border between moderate and high vulnerability to distribution shift in the overall rankings.

Data Quality: All data quality scores were 2 or greater, except stock size/status (1.0) indicating that a good deal is known about stone crab life history.

Climate Effects on Abundance and Distribution: Studies examining climate effects suggest that stone crab may be vulnerable to ocean acidification and increased seawater temperatures. Hatching success rate has been shown to reduce in lower pH seawater and increased temperature and $p\text{CO}_2$ reduced larval survivorship. However, a variability among broods in acidic treatments compared to a control group proposes the possibility that stone crab may adapt to future seawater pH changes (Gravinese *et al.* 2018, Gravinese 2018). Wilber and Herrnkind (1986) documented stone crab use of subtidal regions during the winters suggests that distribution may shift with warming seawater temperatures. Thus, likely influencing energy intake and expenditure in stone crab because of an altered environment (Hancock and Griffen 2017).

Life History Synopsis: Two stone crab species, *Menippe mercenaria* and *Menippe adina* and their hybrid forms are found in the Gulf of Mexico, yet there is little evidence of genotypic variance in terms of reproduction, molting, or mating behavior, and the stone crab fishery in Florida is managed as *Menippe spp.* (Gerhart and Bert 2008, Gandy *et al.* 2016, Crowley *et al.* 2019).

The Florida fishery for stone crab comprises 98.3% of the total U.S. landings, and is among the most valuable in Florida, particularly in southwest Florida where catch is highest (Bert and Stevely 1989, Gandy *et al.* 2018, Crowley *et al.* 2019). Stone crabs are carnivorous and exhibit sexual dimorphism (Bert and Stevely 1989).

Functional maturity is reached in stages beginning with morphological growth in size and shape, followed by physiological development of gonads and finally by exhibiting behaviors necessary for mating (Gerhart and Bert 2008). Size at maturity varies between male and female crabs ranging from 34-37 mm carapace width (CW) and 41-44mm CW, respectively (Crowley *et al.* 2018).

Juvenile crabs molt frequently, especially in warmer months, while larger, mature crabs time their molts based on opportunities for reproduction. Mature females molt primarily in fall months and can only mate after molting when their carapace is soft (Gerhart and Bert 2008). Conversely, males must be in their intermolt phase to mate, so peak molting occurs in winter when chances of mating are lowest (Gerhart and Bert 2008, Bert *et al.* 2016b).

Spawning in Florida's Gulf of Mexico population peaks between April and May through September or October and lasts even longer in Florida's southernmost Gulf waters where water temperatures are higher (Bert *et al.* 2016b, Crowley *et al.* 2019). Females can spawn multiple times after a single mating event and store sperm from multiple male crabs from multiple mating events (Bert *et al.* 2016b, Crowley *et al.* 2018).

Females produce up to 1 million eggs with an average of 4 egg masses per mating event (Gerhart and Bert 2008, Krimsky and Gravinese *et al.* 2009). Fecundity is positively correlated with female size (Crowley *et al.* 2019) however there is an inverse relationship between clutch size and egg size depending on season and water temperature. One study found that clutch sizes were small, but eggs were larger early in the spawning season when temperatures were 27°C or less (Bert *et al.* 2016a). Larger eggs produce higher quality larvae leading to higher survival rates and are better equipped at later metamorphic stages.

Laboratory rearing studies indicate that water temperature of 30°C and salinity of 30 ppt is optimal for larval survival while juvenile stone crabs thrive best 15-30°C and 20-40 ppt (Brown *et al.* 1992, Brown and Bert 1993).

Metamorphosis includes 5-6 zoeal stages and one megalopal stage and can take up to 28 days (Brown *et al.* 1992). Stone crab larvae are released primarily in relation to the diel cycle and spawning begins during the day and continues after dark (Krimsky and Gravinese *et al.* 2009). Information on larval dispersal is lacking, but behavioral studies suggest that early-stage zoeae are dispersed offshore by surface waters followed by a vertical descent in later zoeal stages facilitates transport by bottom currents towards suitable nursery habitats (Gravinese 2007, Krimsky and Gravinese *et al.* 2009).

Juveniles first settle in nearshore and estuarine waters and occupy many sessile invertebrates for shelter, from barnacles and encrusting bryozoans to sponges and oysters. Mature crabs are most found over rock bottoms amongst mud or sand substrates offshore and occupy sandy burrows nearshore (Bert and Stevely 1989, Geiger and Bert, 2006).

Stone crabs have evolved large, powerful claws relative to their carapace size which they use to crush and consume gastropods and bivalves. (Crowley *et al.* 2018). They can regenerate claws and legs after injury however this is predicated on their ability to obtain quality prey to meet energy demands (Crowley *et al.* 2018).

A 2011 stock assessment reported that stone crabs are being overfished, citing a lack of increase in commercial landings while the number of commercial traps has more than doubled (Muller *et al.* 2011). The commercial fishery is regulated by a seasonal closure, minimum claw size, and prohibition of claw harvest from egg-bearing females.

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Tiger shark - *Galeocerdo cuvier*

Overall Vulnerability Rank = High

Habitat Sensitivity = Moderate

Climate Exposure = Very High

Data Quality = 70% of scores ≥ 2

<i>Galeocerdo cuvier</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)		
Sensitivity Attributes	Habitat Specificity	1.2	2.8		Low Moderate High Very High	
	Prey Specificity	1.2	3			
	Adult Mobility	1.1	2.8			
	Dispersal of Early Life Stages	1.2	3			
	Early Life History Survival and Settlement Requirements	1	2.4			
	Complexity in Reproductive Strategy	1.7	2.8			
	Spawning Cycle	2	2.4			
	Sensitivity to Temperature	1.2	2.6			
	Sensitivity to Ocean Acidification	1.2	2.4			
	Population Growth Rate	3.2	2.4			
	Stock Size/Status	2.7	1.4			
	Other Stressors	1.8	1.6			
	Sensitivity Score		Moderate			
	Exposure Factors	Air Temperature	1	0		
Hypoxia		1.5	1.9			
Ocean Acidification		4	2			
Precipitation		1	0			
Primary Productivity		1.8	2			
Salinity		3.5	3			
Sea Level Rise		1	0			
Sea Surface Temperature		4	3			
Exposure Score		Very High				
Overall Vulnerability Rank		High				

Overall Climate Vulnerability Rank: **High.** (51% bootstrap results in High, 45% bootstrap results in Moderate, 4% bootstrap results in Low, 1% bootstrap results in Very High).

Climate Exposure: **Very High.** The three exposure factors contributing to a very high climate exposure score for tiger shark were sea surface temperature (4.0), ocean acidification (4.0), and salinity (3.5). Hypoxia (1.5) and primary productivity (1.8) were in the low to moderate range.

Biological Sensitivity: **Moderate.** The primary sensitivity attributes that contributed to a moderate biological sensitivity score for tiger shark were spawning cycle (2.0) complexity in reproductive strategy (1.7), and stock size/status (2.7). Note that the majority of the sensitivity attributes at a low mode in several had very high scores.

Distributional Vulnerability Rank: **Very High.** The top three attributes contributing to tiger shark's very high vulnerability to distribution shift were very highly dispersive of early life stages (1.2), very highly mobile adults (1.1), and low to moderate to sensitivity temperature (1.2). Habitat specificity was also low (1.2).

Data Quality: All data quality scores were 2 or greater, except stock size/status (1.4) and other stressors (1.6). Stock size/status had a moderate to high sensitivity score. Hypoxia also had a data quality score of 1.9.

Climate Effects on Abundance and Distribution: Tiger sharks may be one of the few species to benefit from climate change as they have a diverse diet and could adapt to changing prey abundance and currently migrate in response to changing SSTs, which may extend their range poleward (Payne *et al.* 2018, Holland *et al.* 2019).

Life History Synopsis: Tiger sharks have a worldwide distribution and occur in the tropical and warm temperate waters of the western Atlantic Ocean from Cape Cod, Massachusetts to Uruguay (Bigelow and Schroeder 1948, Castro 2011).

In the northern Gulf of Mexico, juvenile and adult tiger sharks occur in nearshore and deeper continental shelf and offshore waters throughout the year (Branstetter 1981, Branstetter *et al.* 1987, Driggers *et al.* 2008, Ajemian *et al.* 2020). Tiger sharks apparently lack well-defined nursery areas (Springer 1967) as catch per unit effort data revealed that young-of-the-year and juvenile tiger sharks were widely distributed in waters <100 m along the continental shelf of the Gulf of Mexico and southeastern U.S. (Driggers *et al.* 2008).

Tiger sharks have the most omnivorous diet for a shark species, as their diet ranges from small crabs to small migrating land birds that fall into the ocean to larger sea turtles, sharks and mammals (Bigelow and Schroeder 1948). They exhibit an ontogenetic shift in diet with smaller sharks feeding primarily on molluscs, with teleost fishes, reptiles, elasmobranchs and mammals becoming more important to their diet with increasing age (Lowe *et al.* 1996, Aines *et al.* 2017). The trophic role of tiger sharks is context and habitat-dependent, consistent with a generalist, opportunistic diet at the populations level (Ferreira *et al.* 2017). The opportunistic diet of the tiger shark and the flexibility of its trophic ecology allows them to explore multiple habitats and

food webs which will be advantageous for this species to continue to find prey in the face of future climate change.

Tiger sharks are highly mobile, and tag-recapture and satellite tagging studies have shown adults have the ability to make long-distance basin-wide movements (Hammerschlag *et al.* 2012, Lea *et al.* 2015, Kohler and Turner 2019). A 52-year tag-recapture study showed numerous individuals moving among the US Atlantic coast, Gulf of Mexico, Caribbean Sea and offshore waters of the greater North Atlantic Ocean (Kohler and Turner 2019). Recent satellite tagging studies in the western North Atlantic revealed large home ranges and extensive seasonal migrations (Hammerschlag *et al.* 2012, Lea *et al.* 2015, Ajemian *et al.* 2020).

Tiger sharks are aplacentally viviparous and one of the more fecund species within the family Carcharhinidae, capable of giving birth to reportedly in excess of 80 young (Bigelow and Schroeder 1948). More common brood sizes range from 18-70 pups per brood (Castro 2011). Females reproduce at a minimum biennially and gestation is thought to last for one year before giving birth during summer months (Castro 2011). Several areas pupping areas have been identified in US waters of the western North Atlantic Ocean, including off South Carolina, northeastern Florida/southeastern Georgia and western central Florida (Natanson *et al.* 1999, Driggers *et al.* 2008). Female and male tiger sharks are thought to mature at an age of 10 years and growth is relatively slowly ($k = 0.12$ and 0.13 for females and males, respectively (Kneebone 2008).

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Tomtate - *Haemulon aurolineatum*

Overall Vulnerability Rank = Low ■

Habitat Sensitivity = Low ■

Climate Exposure = High ■

Data Quality = 80% of scores ≥ 2

<i>Haemulon aurolineatum</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	1.4	3		Low Moderate High Very High
	Prey Specificity	1.5	3		
	Adult Mobility	1.9	2		
	Dispersal of Early Life Stages	2.1	2		
	Early Life History Survival and Settlement Requirements	1.8	1.6		
	Complexity in Reproductive Strategy	1.7	2.8		
	Spawning Cycle	2.1	2.8		
	Sensitivity to Temperature	1.7	2.8		
	Sensitivity to Ocean Acidification	2	2		
	Population Growth Rate	1.6	2.4		
	Stock Size/Status	1.4	1.6		
	Other Stressors	2.3	2.6		
	Sensitivity Score		Low		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	1.8	2.2		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.8	2		
	Salinity	3.5	3		
	Sea Level Rise	2.2	2.6		
	Sea Surface Temperature	4	3		
	Exposure Score		High		
Overall Vulnerability Rank		Low			

Overall Climate Vulnerability Rank: **Low.** (53% bootstrap results in Low, 47% bootstrap results in Moderate).

Climate Exposure: **High.** The three exposure factors that contributed to tomtate's high climate exposure ranking were sea surface temperature (4.0), ocean acidification (4.0), and salinity (3.5). Hypoxia (1.8), primary productivity (1.8), and sea level rise (2.2) were all moderate. Exposure to all three main factors occurs during the all life stages. Tomtate are an abundant species that inhabits coastal and nearshore habitats during all life stages (Lingo and Szedlmayer 2006, Kells and Carpenter 2011, Patterson *et al.* 2014).

Biological Sensitivity: **Low.** The primary sensitivity attributes that contributed to a low biological sensitivity score for tomtate were habitat specificity (1.4), stock size/status (1.4), prey specificity (1.5), population growth rate (1.6), and complexity in reproductive strategy (1.7). Tomtate is an abundant species that is relatively short-lived fish with moderate population growth rates. Tomtate are generalist predators consuming plankton, invertebrates, and smaller fishes (Norberg 2015). Juveniles and adults are found in similar habitats that broadly encompass everything from sand to natural structure to artificial structure (Lingo and Szedlmayer 2006, Kells and Carpenter 2011, Patterson *et al.* 2014).

Distributional Vulnerability Rank: **High.** The top three attributes contributing to tomtate's high vulnerability to distribution shift were low habitat specificity (1.4), low to moderate sensitivity to temperature (1.7), and highly mobile adults (1.9).

Data Quality: All data quality scores except stock status/size (1.8) were 2 or greater. Generally, data is moderate for this species specifically or as part of the grunt complex. However, tomtate received a very high sensitivity score for Ocean Acidification exposure and data quality was described as moderate for this attribute.

Climate Effects on Abundance and Distribution: Tomtate are dispersed from South America, Caribbean, Gulf of Mexico, to the Western Atlantic (Chesapeake Bay). Their vast range coupled with their generalist prey and habitat preferences suggests that tomtate may be well suited to expand their range with climate changes.

Life History Synopsis: Tomtate, *Haemulon aurolineatum*, is a small, abundant reef-associated schooling species (Lingo and Szedlmayer 2006, Kells and Carpenter 2011, Patterson *et al.* 2014). Tomtate is widely distributed in the western Atlantic from the Chesapeake Bay south along the U.S. coast, Bermuda, the Bahamas, throughout the Gulf of Mexico and Caribbean Sea, and along the South American coast to southern Brazil (Kells and Carpenter 2011). This species resides in warm (23-28°C), shallow waters ranging from 1 to 40 meters (fishbase.org).

Juvenile and adult tomtate occupy similar habitats that includes seagrass beds, sand flats, and natural hard-bottom habitats such as rocky outcroppings and coral reefs, as well as small (e.g., concrete blocks, wire cages) to large (e.g., oil and gas platforms and liberty ships) artificial reefs (Holt and Arnold 1980, Manooch and Barans 1982, McEachran and Fechtel 2005, Lingo and Szedlmayer 2006, Dance *et al.* 2011, Mudrak and Szedlmayer 2012). Some of their preferred habitats, such as coral reefs and seagrasses, have undergone considerable degradation from

human activity and water quality fluctuations, and are susceptible to climate changes (e.g., ocean acidification, sea level rise, and salinity).

Juvenile tomtates predominantly consume zooplankton (e.g., copepods, Alheit and Schiebel 1982). As they increase in size, their diet expands to that of a generalist carnivore consuming a variety of prey species including small benthic invertebrates such as crustaceans and mollusks, zooplankton, and smaller fishes (Anderson *et al.* 2015, Courtenay and Sahlman 1978, Norberg 2015). All of these shellforming invertebrate prey species (e.g., crustaceans and mollusks) are highly sensitive to ocean acidification.

There is limited literature on tomtate movements. It is known that within a given habitat, individuals undergo diel migrations for feeding (e.g., from shallow/refuge areas under rocks, to deeper mudflats at night, Alheit and Scheibel 1982). However, large-scale migratory movements, home ranges, and site fidelity remain unknown. There is no evidence to suspect that these fishes are mobility-limited either behaviorally or physically, but this alone does not confirm that they make larger movements.

Tomtate spawning has not been documented in detail in the Gulf of Mexico. In the US Southeast shelf (Atlantic), protracted spawning has been reported from May to July (Herrema *et al.* 1985, Sedberry *et al.* 2006). Spawning females appeared to preferentially select middle and outer-shelf reefs where water temperatures ranged from 20 to 28°C and depths ranged from 15 to 54 meters (Sedberry *et al.* 2006). In the Caribbean, it has been proposed that tomtate may spawn year round (Munro *et al.* 1973).

Similarly, little information exists on tomtate early life history. Generally, grunts produce spherical pelagic eggs with a single oil droplet, eggs hatch 1-2 days after fertilization, and larvae remain in the water column relying on tidal currents for transport for approximately 15 days. Young fishes then settle onto nursery habitats such as seagrass beds or artificial reefs (McFarland 1980, Brothers and McFarland 1981, Mudrak and Szedlmayer 2012).

Tomtate have a moderate to high population growth rate. Low vulnerability life history attributes include an earlier maximum age and age-at-maturity, and smaller maximum length (12 inches and 1 pound, safmc.net), they have a moderate vulnerability for their growth coefficient statistic (Manooch and Barans 1982). Collectively, tomtate's small size and faster growth has resulted in the IUCN listing them as a species of least concern (5-6 years generation length, Anderson *et al.* 2015).

Presently, fisheries managers do not formally assess tomtate populations. It is believed that this species is not overfished and overfishing is not occurring (GMFMC 1997). However, peer-reviewed literature has suggested that this species is landed by fishers in some areas (Smith *et al.* 2011, Norberg 2015) although, as one of the smallest grunts they are not highly desired by fishers throughout their range (safmc.net). Tomtates are a common prey item of piscivorous fishes (e.g., snappers and groupers among others) and populations could be inhibited by high

predator densities (Dance *et al.* 2011). No information is available on genetic population structure of tomtate.

Other potential stressors for tomtate include: dredge-and-fill activities, which directly impact settlement stage nursery habitats by burying nearshore hardbottom (Lindeman and Snyder 1999), canal discharges resulting in prolonged low-salinity regimes and loss of seagrass and bivalve habitats, leading to degradation of shelter and prey of various grunt species in the St. Lucie Inlet system in east Florida (T. Gibson pers. comm. 1999), impacts of harmful algal blooms in estuarine nursery areas, predation by invasive lionfish (Munoz *et al.* 2011).

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White shrimp - *Litopenaeus setiferus*

Overall Vulnerability Rank = Low ■

Habitat Sensitivity = Low ■

Climate Exposure = High ■

Data Quality = 90% of scores ≥ 2

<i>Litopenaeus setiferus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	1.8	2.4		Low Moderate High Very High
	Prey Specificity	1.1	2.4		
	Adult Mobility	1.7	2.6		
	Dispersal of Early Life Stages	1.8	2.4		
	Early Life History Survival and Settlement Requirements	2.2	2.4		
	Complexity in Reproductive Strategy	1.8	2.6		
	Spawning Cycle	1.7	2.6		
	Sensitivity to Temperature	1.9	2.2		
	Sensitivity to Ocean Acidification	1.8	1.6		
	Population Growth Rate	1.2	2.2		
	Stock Size/Status	1.2	2.2		
	Other Stressors	2.6	2.4		
	Sensitivity Score		Low		
Exposure Factors	Air Temperature	4	3		
	Hypoxia	2.8	2.6		
	Ocean Acidification	4	2		
	Precipitation	1	3		
	Primary Productivity	1.3	2		
	Salinity	2.2	3		
	Sea Level Rise	2.8	2.6		
	Sea Surface Temperature	1	0		
	Exposure Score		High		
Overall Vulnerability Rank		Low			

Overall Climate Vulnerability Rank: **Low.** (100% bootstrap results in Low).

Climate Exposure: **High.** The three exposure factors contributing to a high exposure score for white shrimp were air temperature (4.0, a proxy for estuarine temperatures), ocean acidification (4.0), and hypoxia (2.8).

Biological Sensitivity: **Low.** The primary sensitivity attribute that contributed to a low biological sensitivity score for white shrimp were prey specificity (1.1), population growth rate (1.2), and stock size/status (1.2). Only one sensitivity attribute (other stressors) had very high expert scores, and all but two (early life history survival and settlement requirements and other stressors) were less than 2.0.

Distributional Vulnerability Rank: **High.** The top three attributes contributing to white shrimp's high vulnerability to distribution shift ranking were highly to very highly mobile adults (1.7), moderate to low habitat specificity (1.8), and highly to very highly dispersive early life stages (1.8).

Data Quality: All data quality scores except sensitivity to ocean acidification (1.6) were 2 or greater.

Climate Effects on Abundance and Distribution: White shrimp growth rates are especially sensitive to temperatures and could be impacted during their juvenile life stage in the form of slower growth at higher temperatures. Heat stress could lead to increased mortality because preferred habitat is relatively shallow. However, shrimp are mobile and could seek deeper water. Mortality rates are size dependent, so slower growth would indirectly result in increased mortality due to longer durations spent in small size classes. Habitat loss due to sea-level rise and marsh fragmentation would affect production of sub-adults from nurseries (Roth *et al.* 2008) Ocean Acidification effects are considered generally negative and include dissolution of calcified elements and reduced calcification rates (Taylor *et al.* 2015) causing indirect (diet items; molluscs and crustaceans) and direct (changes in shell transparency and exoskeleton function due to decreased pH).

Life History Synopsis: White shrimp are a commercially important penaeid shrimp found on the US Atlantic coast as far north as New York, throughout the Gulf and along the Atlantic coast of Mexico from Tamaulipas to Campeche. Spawning occurs offshore between depths of eight to 55 meters (Dall *et al.* 1990, Lindner and Cook 1970) Spawning generally takes place from March to October with a peak during June and July (Lindner and Anderson 1956, Weymouth *et al.* 1933, Temple and Fisher 1968). White shrimp are broadcast spawners of externally fertilized (via spermatophore) semi-buoyant eggs (Dall *et al.* 1990) The eggs hatch within 10-12 hours and within 30 days, white shrimp progress through five naupliar (demersal), 3 protozoal (pelagic), and 3 mysis (pelagic) stages before becoming postlarvae (Lindner and Cook 1970, Dall *et al.* 1990). At approximately 10 mm total length (TL), postlarvae recruit into estuaries where they settle on shallow mud bottoms and in shallow vegetation (Zein-Eldin and Griffith 1969, Baker and Minello 2010) They reside in the estuarine nurseries for two to three months during which time they grow rapidly (about 1 mm TL per day (Baker and Minello 2009, 2011). When they

reach a size range of 100 to 120 mm TL, white shrimp begin to move offshore in September to December, and peak emigrations are driven by cooling water temperatures (Lindner and Cook 1970). As white shrimp progress from sub-adult to adulthood, they begin moving offshore in a generally westward and deeper direction but return to nearshore and inshore shelf waters as water temperatures increase (April - May) (Lindner and Anderson 1956). Females reach sexual maturity at about 140 mm TL while males mature at about 120 mm TL (Lindner and Anderson 1956, Burkenroad 1934). White shrimp have a likely maximum age of two years while some species in the lab have lived three to four years.

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Yellow stingray - *Urobatis jamaicensis*

Overall Vulnerability Rank = Moderate ■

Habitat Sensitivity = Low ■

Climate Exposure = Very High ■

Data Quality = 75% of scores ≥ 2

<i>Urobatis jamaicensis</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	2.3	2.6		Low Moderate High Very High
	Prey Specificity	1.5	2.6		
	Adult Mobility	1.8	2.4		
	Dispersal of Early Life Stages	1.4	3		
	Early Life History Survival and Settlement Requirements	1	2.2		
	Complexity in Reproductive Strategy	2.1	2		
	Spawning Cycle	2	2.6		
	Sensitivity to Temperature	1.9	2.4		
	Sensitivity to Ocean Acidification	1.6	2.4		
	Population Growth Rate	2.5	1.4		
	Stock Size/Status	1.9	1.2		
	Other Stressors	2.4	1.8		
	Sensitivity Score		Low		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	2.3	2		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.8	2		
	Salinity	3.5	3		
	Sea Level Rise	2.4	2.6		
	Sea Surface Temperature	4	3		
	Exposure Score		Very High		
Overall Vulnerability Rank		Moderate			

Overall Climate Vulnerability Rank: **Moderate.** (56% bootstrap results in Moderate, 36% bootstrap results in Low, 8% bootstrap results in High).

Climate Exposure: **Very High.** *Describe the drivers of the exposure score. Example, if the species is a High, list all the exposure factors that are High or Very High. Also mention any interesting distributional overlap with the projection. (NEVA Example: Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Air Temperature (4.0). Exposure to all three factors occur during the life stages. Tuatog uses coastal and nearshore habitats during all life stages, but makes offshore movements into the winter.)*

Biological Sensitivity: **Low.** The primary sensitivity attributes contributing to a low biological sensitivity score for yellow stingray were early life history survival and settlement requirements (1.0), dispersal of early life stages (1.4), prey specificity (1.5), and sensitivity to ocean acidification (1.6).

Distributional Vulnerability Rank: **High.** The top three attributes contributing to yellow stingray's high vulnerability to distribution shift ranking were very highly to highly dispersive early life stages, highly to very highly mobile adults, and moderate sensitivity to temperature.

Data Quality: 75% of the data quality scores were 2 or greater. *(Identify any interesting data gaps like attributes that have high sensitivity as well as low data quality)*

Climate Effects on Abundance and Distribution: No specific studies have been conducted concerning the impact of climate on the Yellow stingray. Given that this species inhabits shallow coastal waters (to ~30m in depth), including bays and estuaries (Bigelow and Schroeder 1953, McEachran and Fechhelm 1998, Spieler *et al.* 2013, Last *et al.* 2016), the probability of exposure to environmental factors affected by climate change is high. Furthermore, because the species utilizes a wide variety of habitats, including seagrass and coral reefs, effects of climate change (such as coral bleaching and ocean acidification) could degrade important habitat features. In addition, while the yellow stingray has been shown to exhibit tolerance and adaptiveness to reductions in salinity (Sulikowski and Maginniss 2001), reductions in temperature have been shown to have a significant detrimental effect on embryonic development (Lesniak *et al.* 2015). While generally reported to inhabit a relatively wide geographical range (North Carolina to southern Caribbean, Bigelow and Schroeder 1953, McEachran and Fechhelm 1998, Last *et al.* 2016), the yellow stingray appears to only be commonly reported from particular localities within this range, being relatively rare throughout much of the remainder (Spieler *et al.* 2013). This indicates that habitat specific and localized effects of climate change could have a more pronounced effect on the distribution and abundance of this species.

Life History Synopsis: Spieler *et al.* (2013) provide a very thorough review of the current knowledge of the biology of the yellow stingray. The yellow stingray reaches a maximum size of approximately 480mm total length (TL), although larger individuals have been

reported (up to ~700mm TL, Bigelow and Schroeder 1953, McEachran and Fechhelm 1998, Last *et al.* 2016), possibly based on a misinterpretation of data or a misidentification, with maximum observed ages of between 7 and 8 years (Spieler *et al.* 2013). Females are generally larger than males (Spieler *et al.* 2013). Data suggests that males mature between 200mm TL (Yanez-Arancibia and Amezcua-Linares 1979) to 265mm TL (LaMarca 1964).

Preliminary data suggests females may mature at slightly larger sizes (smallest gravid female ~295mm TL, Spieler *et al.* 2013). The Yellow stingray exhibits a biennial reproductive cycle off southeastern Florida, with ovulation occurring from January to April and again from August to September (Fahy *et al.* 2007). Gestation is relatively rapid, lasting only 5 to 6 months, with parturition occurring from June to September for Spring reproductive events, and November to January for the Fall (Fahy *et al.* 2007).

Comprehensive studies from other localities throughout the proposed range of this species are required to determine if the biennial cycle is universal or local (Spieler *et al.* 2013). Lesniak *et al.* (2015) indicated that pregnancies subjected to lower temperatures (22°C) resulted in embryo resorption and reproductive failure in all cases, as compared to higher temperatures (27°C) which resulted in a combination of reproductive failures (resorptions and a single stillbirth) and successful live births. Brood sizes were observed to increase proportionally to maternal size, being larger in the Spring/Summer (1-7 embryos) than in the Fall/Winter (1-3 embryos) (Fahy *et al.* 2007).

Movement and tracking data from southeastern Florida suggest that this species preferentially utilizes hard bottom substrates, with no apparent seasonal migrations (Fahy 2004, Spieler *et al.* 2013). Their diet predominantly consists of infauna excavated from the sediment (Quin 1996, Spieler *et al.* 2013).

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Yellowedge grouper - *Hyporthodus flavolimbatus*

Overall Vulnerability Rank = High ■

Habitat Sensitivity = High ■

Climate Exposure = High ■

Data Quality = 45% of scores ≥ 2

<i>Hyporthodus flavolimbatus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	1.9	2.4		Low Moderate High Very High
	Prey Specificity	1.5	1.8		
	Adult Mobility	2.5	1.4		
	Dispersal of Early Life Stages	1.9	1.2		
	Early Life History Survival and Settlement Requirements	2.3	0.6		
	Complexity in Reproductive Strategy	2.8	1.4		
	Spawning Cycle	2.4	2.4		
	Sensitivity to Temperature	2.1	2.4		
	Sensitivity to Ocean Acidification	1.9	1.8		
	Population Growth Rate	3.8	2.6		
	Stock Size/Status	3	2.4		
	Other Stressors	1.6	1.6		
Sensitivity Score		High			
Exposure Factors	Air Temperature	1	0		
	Hypoxia	1.9	1.8		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.8	2		
	Salinity	3.5	3		
	Sea Level Rise	1	0		
	Sea Surface Temperature	4	3		
Exposure Score		High			
Overall Vulnerability Rank		High			

Overall Climate Vulnerability Rank: **High.** (50% bootstrap results in High, 30% bootstrap results in Very High, and 20% bootstrap results in Moderate).

Climate Exposure: **High.** The three exposure factors that contributed to a high climate exposure score for yellowedge grouper were sea surface temperature (4.0), ocean acidification (4.0), and salinity (3.5). Hypoxia (1.9) and primary productivity (1.8) were both moderate.

Biological Sensitivity: **High.** The primary sensitivity attributes contributing to a high biological sensitivity score for yellowedge grouper and were complexity in reproductive strategy (2.8), stock size/status (3.0), and population growth rate (3.8).

Distributional Vulnerability Rank: **High.** The top three attributes contributing to yellowedge grouper's high vulnerability to distribution shift ranking were highly dispersive early life stages (1.9), moderate sensitivity to temperature (2.1), and moderate to low habitat specificity (1.9).

Data Quality: Seven attributes and one exposure factor had data quality scores less than 2.0. These were prey specificity (1.8), adult mobility (1.4), dispersal of early life stages (1.2), early life history survival and settlement requirements (0.6), complexity in reproductive strategy (1.4), sensitivity to ocean acidification (1.8), other stressors (1.6), and hypoxia (1.8).

Climate Effects on Abundance and Distribution: There is limited understanding of the potential impacts of climate effects on the spatial distribution and abundance of yellowedge Grouper in the Gulf of Mexico.

Life History Synopsis: Yellowedge grouper are found in the western Atlantic from North Carolina to southern Florida, the entire Gulf of Mexico, Cuba, the West Indies, off the coasts of Central America, and the northern coast of South America to Brazil. Within the Gulf of Mexico, this species is primarily distributed between 50 to 300 m (Cook 2007). Ontogenetic habitat shifts have been observed for this species, with smaller fish (<400 mm TL) generally occurring in shallower waters between 35-125 m and larger fish found in deeper waters up to 300 m (Cook 2007). Adult yellowedge grouper prefer soft substrate throughout the western and central GOM (Cook 2007), but have also been found at the shelf edge on mud, sand, sand-shell and hard bottom areas (Jones *et al.* 1989, Heemstra and Randall 1993).

Reproductive characteristics of yellowedge grouper in the Gulf of Mexico were evaluated in preparation for the 2011 stock assessment. Size and age at 50% maturity of females were 547 mm TL and age 8 years, respectively (SEDAR 2011). Yellowedge grouper is a protogynous hermaphrodite (transitions from female to male) that exhibits an extended spawning season from February to November, with peak development in March through September (SEDAR 2011). Yellowedge grouper form spawning aggregations (Heyman *et al.* 2019). The size and age at 50% sexual transition was 815 mm TL and 22 years, respectively. There is a paucity of understanding the larval stage of yellowedge grouper because this species is indistinguishable from snowy grouper (Richards 1999).

Yellowedge grouper consume a wide variety of invertebrates and fishes (Bullock and Smith 1991, Heemstra and Randall 1993).

Yellowedge grouper are slow-growing and long-lived, with a maximum reported age of at least 85 years in the Gulf of Mexico (SEDAR 2011). This age estimate was validated using radiocarbon dating (Cook *et al.* 2009). The growth parameters for the stock assessment were estimated by sex because of notable differences, with females predicted to grow faster but obtain a smaller asymptotic size than males (male: $L_{\infty} = 1043.2$ mm, $k = 0.054$, $t_0 = -5.531$; female: $L_{\infty} = 843.0$ mm, $k = 0.095$, $t_0 = -3.051$).

The Gulf of Mexico yellowedge grouper stock was last assessed in 2011 during the SEDAR 22 Gulf of Mexico stock assessment. At 2009, the last year of data included in the assessment, the stock was not overfished and not undergoing overfishing (SEDAR 2011). However, the stock has not been assessed since and therefore the current stock status is uncertain.

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Yellowmouth grouper - *Mycteroperca interstitialis*

Overall Vulnerability Rank = Very High ■

Habitat Sensitivity = High ■

Climate Exposure = Very High ■

Data Quality = 45% of scores ≥ 2

<i>Mycteroperca interstitialis</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	2.3	2.6		■ Low ■ Moderate ■ High ■ Very High
	Prey Specificity	1.5	1.8		
	Adult Mobility	2.6	1.4		
	Dispersal of Early Life Stages	2	1.4		
	Early Life History Survival and Settlement Requirements	2.8	0.8		
	Complexity in Reproductive Strategy	2.6	2		
	Spawning Cycle	2.1	2		
	Sensitivity to Temperature	2.2	2.6		
	Sensitivity to Ocean Acidification	2.1	1.6		
	Population Growth Rate	3.4	2.4		
	Stock Size/Status	3	1.8		
	Other Stressors	1.9	1.8		
Sensitivity Score		High			
Exposure Factors	Air Temperature	1	0		
	Hypoxia	1	0		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.9	2		
	Salinity	3.7	3		
	Sea Level Rise	1	0		
	Sea Surface Temperature	4	3		
Exposure Score		Very High			
Overall Vulnerability Rank		Very High			

Overall Climate Vulnerability Rank: **Very High.** (58% bootstrap results in Very High, 39% bootstrap results in High, and 3% bootstrap results in Low).

Climate Exposure: **Very High.** The three exposure factors that contributed to a very high climate exposure score for yellowmouth grouper were sea surface temperature (4.0), ocean acidification (4.0), and salinity (3.5). Hypoxia (1.9) and primary productivity (1.8) were both moderate.

Biological Sensitivity: **High.** The primary sensitivity attribute contributing to a high biological sensitivity score for yellowmouth grouper were adult mobility (2.6), complexity in reproductive strategy (2.6), early life history survival and settlement requirements (2.8), stock size/status (3.0), and population growth rate (3.4).

Distributional Vulnerability Rank: **Moderate.** The top three attributes contributing to yellowmouth grouper's moderate vulnerability to distribution shift ranking were highly dispersive early life stages (1.9), moderate habitat specificity (1.9), and moderate sensitivity to temperature (2.1).

Data Quality: Seven sensitivity attributes and one exposure factor had data quality scores less than 2.0. These were prey specificity (1.8), adult mobility (1.4), dispersal of early life stages (1.2), early life history survival and settlement requirements (0.6), complexity in reproductive strategy (1.4), sensitivity to ocean acidification (1.8), other stressors (1.6), and hypoxia (1.8).

Climate Effects on Abundance and Distribution: There is limited understanding of the spatial distribution and abundance of yellowmouth grouper in the Gulf of Mexico, and therefore, the potential impacts of climate effects. While an index of abundance was derived from the SEAMAP Reef Fish Video Survey which samples offshore reef habitat throughout the Gulf of Mexico (Campbell *et al.* 2016), limited sample sizes and low occurrence precluded its recommendation for use in the 2016 SEDAR 49 U.S. Gulf of Mexico data-limited stock assessment for this species (SEDAR 2016). Reef type was a significant predictor in abundance, which may suggest a link between yellowmouth grouper presence and habitat.

Life History Synopsis: Yellowmouth grouper is a shallow-water grouper of the family Serranidae that occurs between 20 and 150 m in the western Atlantic from North Carolina and Bermuda to southern Brazil as well as the Gulf of Mexico and Caribbean (Bullock and Murphy 1994, McEachran and Fechhelm 2006). In the Gulf of Mexico, this species has been reported from the Florida Middle Ground in the eastern Gulf (Smith *et al.* 1975), from the Flower Garden Banks off Texas (Dennis and Bright 1988), and off the Campeche Banks, Mexico (Smith 1971). While this species generally occurs at depths greater than 30 m in the eastern Gulf of Mexico, it may be found at shallower depths in Bermuda and the Florida Keys (Bardach *et al.* 1958, Bullock and Smith 1991). Adults are found on coral reefs and rocky bottoms (McEachran and Fechhelm 2006), whereas juveniles commonly occur in shallow waters such as mangrove lined lagoons (GMFMC 2004).

A single study reporting reproductive characteristics for yellowmouth grouper in the Gulf of Mexico classified reproductive phases for males, females and transitional fish using

histologically prepared gonad tissue (Bullock and Murphy 1994). This study estimated 50% size and age at maturity of females as between 400 – 450 mm TL and 2 - 4 years, respectively.

Yellowmouth grouper are protogynous hermaphrodites, with transition taking place around 505-643 mm TL and 5-14 years (GMFMC 2016). Spawning aggregations may occur during peak spawning in April and May, and smaller-group matings may occur throughout the year (Bullock and Murphy 1994). Settlement requirements for larval yellowmouth grouper are unknown, though larvae are considered water column associated (GMFMC 2016). It is possible that larvae use chemical and/or auditory cues to locate suitable habitat.

Yellowmouth grouper feed upon ray-finned fishes as both juveniles and adults (Randall 1967, Bullock and Murphy 1994).

One study investigated the age and growth of yellowmouth grouper from the Gulf of Mexico (Bullock and Murphy 1994). This study collected yellowmouth grouper caught by recreational vessels fishing on the Florida Middle Grounds between 1978 and 1992 and recommended an L-infinity of 828 mm TL, von Bertalanffy K of 0.08, and theoretical age at length zero of -7.50 years, which was used during the 2016 SEDAR 49 U.S. Gulf of Mexico data-limited stock assessment for this species. During that assessment, a maximum age of 28 years was recommended based on the maximum age observed (SEDAR 2016).

The Gulf of Mexico yellowmouth grouper stock, considered a single unit stock given the lack of information on stock structure in the Gulf of Mexico, was scheduled for assessment during the 2016 SEDAR 49 U.S. Gulf of Mexico data-limited stock assessment. Ultimately, data limitations precluded the application of data-limited approaches for determining stock status (SEDAR 2016). Specifically, there were concerns raised regarding the identification of yellowmouth grouper in both commercial and recreational fisheries as this species can easily be confused with scamp (*Mycteroperca phenax*) due to similarity in body color and markings (Heemstra and Randall 1993). As a result, stock status remains unknown. Yellowmouth grouper fall within Tier 3A of the Gulf of Mexico's Acceptable Biological Catch control rule, which is reserved for stocks that are unlikely to be undergoing overfishing (GMFMC 2011).

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Yellowtail snapper - *Ocyurus chrysurus*

Overall Vulnerability Rank = Low ■

Habitat Sensitivity = Low ■

Climate Exposure = High ■

Data Quality = 80% of scores ≥ 2

<i>Ocyurus chrysurus</i>		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)	
Sensitivity Attributes	Habitat Specificity	2.4	3		Low Moderate High Very High
	Prey Specificity	1.6	2.8		
	Adult Mobility	2.2	2.8		
	Dispersal of Early Life Stages	1.9	2.6		
	Early Life History Survival and Settlement Requirements	2.3	2.4		
	Complexity in Reproductive Strategy	1.6	2.6		
	Spawning Cycle	1.4	2.8		
	Sensitivity to Temperature	1.8	2		
	Sensitivity to Ocean Acidification	2	2		
	Population Growth Rate	2	2.2		
	Stock Size/Status	1.2	2.2		
	Other Stressors	2.1	1.6		
	Sensitivity Score		Low		
Exposure Factors	Air Temperature	1	0		
	Hypoxia	1.5	2		
	Ocean Acidification	4	2		
	Precipitation	1	0		
	Primary Productivity	1.8	2		
	Salinity	3.5	3		
	Sea Level Rise	1	0		
	Sea Surface Temperature	4	3		
	Exposure Score		High		
Overall Vulnerability Rank		Low			

Overall Climate Vulnerability Rank: **Low.** (52% bootstrap results in Low, 47% bootstrap results in Moderate).

Climate Exposure: **High.** The three exposure factors contributing to a high climate exposure score for yellowtail snapper were sea surface temperature (4.0), ocean acidification (4.0), and salinity (3.5). Hypoxia (1.9) and primary productivity (1.8) were moderate. Yellowtail snapper are often observed swimming in schools above the substrate (Grimes 1976) and are commonly found in salinities ranging from brackish estuarine to open ocean values (16 to 35 ppt, Fishbase.org). Juveniles inhabit shallow coastal waters including back reefs and seagrasses (Flaherty-Walia *et al.* 2017, Swanson *et al.* 2019). Adults are generally observed on hard-bottom and coral reef habitats (up to 70m, Hoese and Moore, 1998, GMFMC 2013, Herbig *et al.* 2019). Yellowtail snapper's preferred temperature range is 21.7 to 27.9°C (Fishbase.org) and their upper lethal temperature limit is 34.0°C (Wallace 1977).

Biological Sensitivity: **Low.** The primary sensitivity attributes contributing to a low biological sensitivity score for yellowtail snapper were stock size/status (1.2), spawning cycle (1.4), prey specificity (1.6), and complexity in reproductive strategy (1.6). There were no very high expert scorers for yellowtail snapper sensitivity attributes.

Yellowtail snapper are not overfished and overfishing is not occurring (SEDAR 2020). This species has a longer spawning season (April to August in Florida, Allen 1985) and is known to form spawning aggregations at Riley's Hump near the Dry Tortugas (Lindeman *et al.* 2000). Yellowtail snapper have a diverse diet that shifts from plankton when they are juveniles to a more generalist adult diet consisting of cephalopods, worms, crabs, shrimp, fishes, crustaceans, and gastropods (Randall 1967, Allen 1985, Barbieri and Colvocoresses 2003).

Distributional Vulnerability Rank: **Moderate.** The top three attributes contributing to yellowtail snapper's moderate vulnerability to distribution shift ranking were moderate sensitivity to temperature (2.1), highly dispersive early life stages (1.9), and highly to moderately mobile adults (2.5). Habitat specificity (1.9) was also moderate.

Data Quality: Seven sensitivity attributes and one exposure factor has data quality scores less than 2. These were prey specificity (1.8), adult mobility (1.4), dispersal of early life stages (1.2) early life history survival and settlement requirements (0.6), complexity on reproductive strategy (1.4), sensitivity to ocean acidification (1.8), other stressors (1.6), and hypoxia (1.8). Yellowtail snapper received a very high sensitivity score for ocean acidification (4.0) exposure and the sensitivity to ocean acidification (1.8) with data quality score of 1.8 suggests more research is needed.

Climate Effects on Abundance and Distribution: Few studies have directly examined the effect of climate factors on yellowtail snapper however, degradation to preferred coral reef and seagrass habitats and warming waters due to climate changes will likely affect abundance and distribution of this species. In addition, yellowtail snapper abundance and

distribution can already be affected by episodic events including red tide blooms and cold snaps.

Life History Synopsis: Yellowtail snapper, *Ocyurus chrysurus*, is a coastal and estuarine species widely distributed from Massachusetts to Brazil, including Bermuda, the Bahamas, and throughout the Gulf of Mexico and Caribbean Sea (Fischer 1979, Kaschner *et al.* 2010). The U.S. mainland population is centralized in the Florida Keys and Southeastern Florida (McClellan and Cummings 1998, Acosta and Beaver 1998, SEDAR 2012). In the Gulf of Mexico, this species is much more common along Florida's west coast from the Dry Tortugas to Escambia County (eastern Gulf, SEDAR 2012), although, observations have been reported in the western Gulf, notably at the Flower Garden Banks located off the coast of Texas (Johnston *et al.* 2015). Yellowtail snapper is easily identified due to its extended yellow lateral stripe and deeply forked yellow tail (SEDAR 2020).

This species is considered ubiquitous using many habitat types during its life (SEDAR 2020). Juveniles inhabit shallow, inshore seagrass beds, hardbottom, and backreef habitats, and mangroves in some regions (Rooker and Dennis 1991, Nagelkerken *et al.* 2000, Flaherty-Walia *et al.* 2017, Swanson *et al.* 2019). In contrast, adults inhabit clear coastal waters, mostly around hard-bottom and coral reefs (up to 70m, Hoese and Moore, 1998, Nagelkerken *et al.* 2009, GMFMC 2013, Herbig *et al.* 2019ab). Yellowtail snapper have also been observed on shallow water artificial reefs (e.g., jetties, pilings, oil and gas platforms, etc.). In some areas, the use of artificial reefs has allowed this species to expand its range into areas where traditional early life habitat was previously unavailable (FGBNMS 2008).

Yellowtail snapper regularly form schools above the seafloor (Grimes 1976) and have been described as semi-pelagic wanderers over reef habitats (Moe 1972). However, for a mobile species, adults tend to remain in an area once they have become established (Beaumariage 1969, Bortone and Williams 1986). Acoustic tracking of tagged yellowtail snapper estimated an average home range of about 4.17 km² to 5.45 km² in the Dry Tortugas, Florida (Farmer and Ault 2011, Herbig *et al.* 2019b). Regular smaller movements included diel habitat shifts and foraging and larger movements included seasonal migrations (Friedlander *et al.* 2013, Farmer and Ault 2011, Herbig *et al.* 2019ab).

Diet studies have shown that larval and juvenile yellowtail snapper feed primarily on plankton. Larger sub-adults and adults have a generalist diet consisting of crustaceans (e.g., shrimp and crabs), fishes, worms, gastropods, and cephalopods (Randall 1967, Allen 1985, Barbieri and Colvocoresses 2003). Documented foraging during dawn, dusk, day, and night hours likely allows yellowtail snapper to access this large array of prey species (Thompson and Munro 1974, Cummings 2004, Friedlander *et al.* 2013, Herbig *et al.* 2019).

Yellowtail snapper have a protracted spawning season with seasonal peaks in activity (Erdman 1976). During May through July, large spawning aggregations have been reported to form at Riley's Hump near the Dry Tortugas in the Gulf of Mexico (Lindeman *et al.*

2000). Peak spawning is from April to August in the Florida Keys (Allen 1985), although year-round spawning has been reported (McClellan and Cummings 1998). Spawning is believed to occur in open waters over high-relief hard bottom areas such as coral reefs, banks, and shelf areas, but has not been directly observed.

Little is known about their larval stage. Eggs are pelagic (Bortone and Williams 1986) and hatch after approximately 20 hours. Larvae likely rely on tidal currents (0 to 25m, D'Alessandro *et al.* 2010) for transport to seagrass nursery habitats. Settlement of larvae occurs around 3-4 weeks after hatching (Bortone and Williams 1986) at about 33 mm SL in the Dry Tortugas (Flaherty-Walia *et al.* 2017, Swanson *et al.* 2019).

Longevity is moderate, estimated between 13 to 17 years for yellowtail snapper from the Atlantic (SERO 2011) and a maximum age of 20 years has been reported in Florida (SEDAR 2020). The species matures fairly quickly, with females from south Florida waters attaining 50% maturity at an average age of 1.7 years (Muller *et al.* 2003). Sex ratios are approximately equal (SEDAR 2020). Maximum size is reported to be 810 mm, but most specimens captured are much smaller than this, and maximum weight is 10.19 pounds (4.62 kilograms, Ft. Myers, Florida). Natural mortality was reported as 0.19 (SEDAR 2020). Combined, these characteristics indicate yellowtail snapper may be vulnerable to recovering from population disruptions or exploitations.

Other stressors likely to impact yellowtail snapper include environmental alterations of their nursery habitat due to development (dredge/spoil disposal), pollution, harmful algal blooms, cold snaps, and lionfish predation on juveniles.

From a fisheries perspective, yellowtail snapper are caught by both recreational and commercial fisheries in the Gulf of Mexico. Genetic linkages between the South Atlantic and Gulf of Mexico stocks are unknown however, limited data suggests they should be treated as a single stock for management (Hoffman *et al.* 2003, Saillant *et al.* 2012) by the South Atlantic Fisheries Management Council, Gulf of Mexico Fisheries Management Council, and the State of Florida. Recent stock assessments of yellowtail snapper completed by Florida Fish and Wildlife Conservation Commission showed that the stock was not overfished and overfishing was not occurring (SEDAR 2012, SEDAR 2020).

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