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A CLIMATE VULNERABILITY ASSESSMENT FOR FISH AND INVERTEBRATES IN THE UNITED STATES SOUTH ATLANTIC LARGE MARINE ECOSYSTEM

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Abstract

Climate change is occurring in most geographic regions, affecting marine fishery resources and the communities that rely on them for livelihood. Effects include changes in distribution, abundance, and productivity. Managers need to understand which species are most vulnerable, as these changes are likely to intensify in the future. Traditional quantitative approaches require a large amount of resources and generally are not applicable to multiple species at once. A recently developed methodology for climate vulnerability assessments allows for the assessment of a wide range of species and uses both existing information and expert opinion to assess both the exposure of species to various climate stressors as well as the inherent biological sensitivity of species to that same stressor. The combination of exposure and sensitivity yields an overall climate vulnerability estimate. Here we conduct a climate vulnerability assessment on 71 species of commercially, recreationally, or ecologically important fish and invertebrate species found in riverine, estuarine, nearshore, and offshore waters of the southeast US Atlantic coast. Climate vulnerability refers to reduced productivity or abundance due to a changing climate. We determined that overall climate vulnerability is high or very high for almost two-thirds of species assessed, and the most impacted functional groups of species included deepwater reef fishes, diadromous fishes and invertebrates. Sea surface temperature, sea surface salinity, and ocean acidification were determined to be the exposure factors with the greatest impact on species. Slightly more than half of species assessed have a high or very high potential for a change in geographic distribution due to climate change. Negative effects of climate change were predicted for only 18% of species, while 31 species were expected to be positively affected. These results will aid scientists in focusing research efforts on the most vulnerable species and help fishery managers incorporate climate change into their decisions.

Contents

Introduction

Anthropogenic climate change is of increasing concern to managers of living marine resources throughout the world. Climate change is projected to impact marine organisms in all geographic regions and across all trophic levels. Phytoplankton populations are affected by warming oceans, with implications for higher trophic levels [1]. Climate-influenced decreases to sea ice extent and chlorophyll-a concentrations in the southwest Atlantic Ocean led to corresponding decreases in krill abundance and the potential replacement of krill by salps, which are more tolerant of warmer seawater [2]. Climate-mediated changes to the environment have been shown to affect vital processes of fishes, including development [3], timing of reproduction [4, 5], and respiration and fitness [6, 7]. Timing of migratory movements of marine and anadromous fish stocks are subject to alteration in a changing climate [8, 9]. Additionally, there are many examples of marine species changing their geographic distribution in response to a warming thermal environment [10–14].

Until recently, most studies of climate effects on living marine resources involved linking single-species population models to climate models [15]. These mechanistic studies often showed the impact of a changing climate on populations, but were difficult to conduct due to the large amount of labor and resources they require, even for a single species. An alternative that has arisen in recent years is the trait-based climate vulnerability assessment. Climate vulnerability is defined as a reduction in abundance or productivity of a species due to climate change. This method relies on the participation of experts to score both the biological attributes of the species that may make them resilient or sensitive to climate change and the magnitude of exposure of the species to the environmental variables expected to change as a result of future climate. A standard methodology for conducting climate vulnerability assessments (CVA) on large groups of marine species [16] has been used by the National Marine Fisheries Service (NMFS) to assess the climate vulnerability of marine fishes and invertebrates in multiple geographic regions [17-19].

While the effects of a changing climate may be more pronounced in more northerly areas such as Alaska or the northeast United States, changes have been observed in the southeast United States (SEUS) as well. A recently-completed ecosystem status report for the region noted changing trends in several climate-related environmental variables: increasing annual and decadal sea surface temperature, a decreasing trend in upwelling-favorable winds since 2016, accelerated rates of sea level rise since 2010, and an increasing trend in the amount of $p\mathrm{CO}_2$ in the atmosphere since 2010 [20]. Recent meta-analyses have examined the potential effects of a changing climate on the distribution of marine species in the SEUS [12, 14].

Our objective in this study was to conduct a CVA on recreationally, commercially and ecologically important species of fish and invertebrates found along the SEUS Atlantic coast. Studies such as CVAs can be valuable to resource managers responsible for preventing overfishing [21, 22], as well as for climate resilience planning [23]. In addition to overall climate vulnerability, we assessed each species' potential for changing its geographic distribution due to climate change, as well as the overall directional effect (positive, negative, or neutral) climate change would have on each species. A secondary but favorable outcome of the CVA process is the identification of a data quality metric, generated during the expert scoring process, that will help identify data gaps and potential research needs going forward.

Materials and Methods

This study utilized a systematic methodology [16] that included the following steps: 1) defining the study area, 2) selecting species for inclusion in the assessment, 3) defining the biological sensitivity attributes used to assess the ability of a species to respond to climate change, 4) identifying climate exposure factors to include in the assessment, 5) recruiting a panel of expert scorers with knowledge of biology of each species, 6) constructing biological profiles of species to be assessed to assist the expert scorers, 7) developing species distribution maps, 8) scoring of climate exposure factors, 9) expert scoring of biological sensitivity attributes, 10) assessing uncertainty in overall climate vulnerability scoring using bootstrap analyses, 11) assessing the potential for each species to change its distribution, and 12) assessing the overall directional effect of climate change on each species.

The CVA methodology uses life-history traits as biological sensitivity attributes and environmental variables as climate exposure factors, with assessment of both being classified in bins of low, moderate, high, or very high. The potential for species to alter their geographic distribution in response to a changing climate is also classified as low, moderate, high, or very high. The overall directional effect of climate change is characterized as positive, neutral, or negative. Informed expert judgment was used to arrive at scores for biological sensitivity attributes, overall directional effect of climate change, and data quality. Climate exposure factors for which data were available to download from NOAA's Earth Systems Research Laboratory (ESRL) data portal in Boulder, Colorado [24] were scored directly using the climate model data. Two climate exposure factors, Gulf Stream-induced upwelling and sea level rise, for which data were unavailable for download from the ESRL data portal, were scored using informed expert opinion based on qualitative exposure factor descriptions developed by an expert scorer using current scientific literature.

Study Area

The geographic area included in this CVA extended from Cape Hatteras, North Carolina, through the Florida Keys in the SEUS, and includes the area extending from the river basins and estuaries to the seaward margins of continental shelves and the outer boundaries of the major current systems (Fig. 1). This area is known as the South Atlantic Large Marine Ecosystem (LME). While our primary focus was on fishes and invertebrates in marine waters of the SEUS continental shelf, estuarine and adjacent riverine systems were included due to the inclusion in our assessment of diadromous and estuarine-dependent species.

Species Included in Assessment

The primary goal of this CVA was to examine the vulnerability of a suite of marine fishes and invertebrates that occur throughout the LME. Criteria used to select assessed species included: 1) importance of the species in recreational or commercial fisheries landings, 2) whether the species was currently assessed by federal or state fisheries stock assessments or managed under fisheries management plans (e.g., NMFS Southeast Data Assessment and Review (http://sedarweb.org), Atlantic States Marine Fisheries Commission's Interjurisdictional Fisheries Management Plans, state-managed species), 3) if the species occupies ecologically important niches (e.g., forage species), and 4) if the species is listed as threatened (e.g. Nassau grouper) or endangered (Atlantic sturgeon) by definitions laid out in the Endangered Species Act. The candidate list was screened by a core group of three fisheries scientists from the National Marine Fisheries Service's Southeast Fisheries Science Center for consensus concerning inclusion in the assessment. These scientists had an opportunity to add or remove species from the candidate list, and this initial process resulted in a total of 67 species selected for assessment. Outreach was conducted to other relevant management bodies (Councils, Commissions, and state agencies), and an additional four species were added, bringing the total assessed species to 71 (Table 1). The 71 species were divided into nine functional groups: Coastal Fish (*n* = 10), Coastal Pelagic Fish (*n* = 7), Diadromous Fish (*n* = 5), Elasmobranchs (*n* = 6), Invertebrates (*n* = 9), Forage Fish (*n* = 3), Pelagic Fish (*n* = 3), Reef Fish (*n* = 23), and Deepwater Reef Fish (*n* = 5). Species were assigned to functional groups based on life history characteristics as well as habitat preferences. Functional groupings were useful in assigning species to expert scorers, as well as providing an opportunity to assess the vulnerability of functionally similar species to climate change.

Climate Exposure Factors

Exposure is defined as the degree to which an organism will experience change in a particular environmental variable during a changing climate scenario. Environmental variables selected to serve as climate exposure factors were determined to have a potential impact on the survival, productivity, or distribution of the species. The climate exposure factors used in a climate vulnerability assessment are a simplified subset of the complete suite of environmental variables influencing a population. We examine these factors individually in this assessment, but there are often complex **interactive relationships between factors, such as the reduced oxygen carrying capacity of seawater in a warming ocean environment [6], or the interaction with other stressors such as ocean acidification or hypoxia.** The climate exposure factors, selected by a core group of participants as relevant for the SEUS LME, used were sea surface temperature, sea surface salinity, air temperature (proxy for estuarine and freshwater temperature), precipitation, sea surface pH (proxy for ocean acidification), sea level rise, and Gulf Stream-induced upwelling (Table 2). Sea surface temperature is an important environmental variable and has been linked to both productivity and geographic distribution [25, 12, 26]. Changes in sea surface salinity are likely to affect productivity by increasing energetic costs [27], or increasing mortality of early life stages of estuarine and riverine species due to increasing salinity in their nursery habitat [28]. While bottom temperature would be more appropriate than sea surface temperature for deepwater reef fishes, the spatial resolution of current climate models is too low for this variable to be useful. Similarly, we used air temperature as a proxy for estuarine and riverine water temperatures due to lack of spatial resolution in climate models in these areas. Effects of increasing ocean acidification include negative effects on survival and productivity of marine shellfish [29-31], direct effects on survival and productivity of fishes [32], indirect effects on fishes such as decreased prey quality [33], and negative effects on vital habitat (e.g., species that rely on scleractinian corals for both food and habitat; [34]. We used precipitation as a proxy for streamflow, an important input for diadromous and estuarine species. Effects of climate-mediated changes to ocean currents was incorporated into our assessment in the form of a Gulf Stream-induced upwelling exposure factor. Many species rely on a variety of ocean currents, both large- and small-scale, for transport and dispersal of larval stages [35]. Sea level rise was also included as a climate exposure factor. Sea level rise is now increasing an average 3.4 mm/yr globally [36] and will likely influence the population dynamics of fishes and invertebrates via alteration of marsh, seagrass, mangrove, coral, and estuary habitats.

Biological Sensitivity Attributes

A complex of 12 biological sensitivity attributes was used to judge the ability of each species to respond to a changing climate based on its inherent life history traits. The attributes used in this study were the default attributes identified in the NMFS CVA methodology [16] and have been used in all NMFS CVAs to date: habitat specificity, prey specificity, adult mobility, dispersal of early life stages, early life survival and settlement requirements, complexity in reproductive strategy, spawning cycle, sensitivity to temperature, sensitivity to ocean acidification, population growth rate, stock size status, and other stressors (Table 2). These 12 sensitivity attributes address characteristics across the full life history, from larval survival through fishery removal or natural mortality. Each sensitivity attribute has clearly defined end points to assist the expert scorers. For example, the spectrum of Adult Mobility was defined as ranging from ‘High Mobility’ to ‘Low Mobility’. A life history trait for mobility could fall anywhere across the spectrum defined by those end points. In the example of eastern oyster, a sessile invertebrate, mobility would be scored as low, and vulnerability to climate change for this sensitivity attribute would likely be judged as very high. Conversely, dolphinfish have extremely high adult mobility and might be expected to move to avoid adverse environmental conditions, thus climate vulnerability due to limited mobility for this species would thus be judged as low. A more detailed description of each of the 12 sensitivity attributes is compiled in Appendix A, along with recommendations to the experts on how to score the attributes.

Expert Scorers

Expert scorers were recruited from throughout the southeast region study area. Scorers were solicited from NOAA Fisheries Southeast Fisheries Science Center, NOAA Fisheries Southeast Regional Office, and the state marine fisheries management agencies for North Carolina, South Carolina, Georgia, and Florida. Academic researchers as well as retired scientists with relevant experience in the region were also recruited. Participants were asked to participate based on their knowledge of one or more functional groups of species. Other participants from the South Atlantic Fishery Management Council and the Atlantic States Marine Fisheries Commission recommended potential scorers, provided input on which species to include in the assessment, and participated in a weeklong workshop where sensitivity and exposure scores were discussed in person.

Preparation of Species Profiles

Profiles summarizing biological and ecological information on the 71 species assessed in the study were developed to assist experts in assigning scores for biological sensitivity attributes. These profiles described multiple aspects (33 total) of the 12 sensitivity attributes evaluated for each species' response to changing climate. The profiles were developed by consolidating available information from multiple sources, including scientific literature, stock assessment reports, and species information sheets developed by the Atlantic States Marine Fisheries Commission. In addition to a description of the life history traits of each species, the species profiles include a score for data quality, described in Table 3. The goal of the data quality metric is to identify attributes for which information may be absent or insufficient, thus providing information about data gaps and direction for future research.

Species Distributions

Initial geographic distributions of the 62 fish species assessed were obtained from the IUCN Red List distributional maps [37]. These were selected as starting points as they were a rigorously reviewed source of consistent spatial information. These IUCN distribution maps were imported into MATLAB [38] as ArcGIS shapefiles for analyses. Locations of ESRL data nodes were then layered into the distribution maps. Initial distributions of the nine invertebrate species were manually constructed using information from the scientific literature and commercial landings information from NMFS, and available grid nodes from the ESRL data portal were layered into the maps. After these initial distributions were generated for all species, an expert consultation ensued in which three core panel members discussed each distribution map to determine whether any data grid nodes should be added to or excluded from the final distribution based on local expert knowledge and scientific literature. Final maps with species distribution represented by the included data grid nodes were then generated. A species distribution map for red snapper is presented as an example in Fig. 2.

Scoring of Biological Sensitivity Attributes/Qualitative Exposure Factors and Expert Certainty

Sixteen scorers were assigned species based on their expertise within a specific functional group(s). Each scorer was asked to evaluate between 18 and 24 species, and each species was scored by five experts. Experts assigned scores for all 12 sensitivity attributes and the two qualitative exposure factors, for each assigned species. Species were scored across a spectrum of vulnerability, consisting of possible ratings of low, moderate, high, or very high vulnerability. Scorers were asked to account for any uncertainty in vulnerability scores by distributing their scores across the spectrum of vulnerabilities using a five-tally system. In the case of absolute certainty, a scorer could place all five tallies in a single vulnerability bin (e.g., eastern oyster would have very high vulnerability for adult mobility, thus a scorer would likely put all five tallies in the very high bin). In a more common case of uncertainty, tallies could be spread across multiple bins. Initial scoring was done using an online portal over several weeks. Scores were then tabulated and summaries of scores by species × attribute/factor were generated. An in-person workshop was then held where scorers discussed all scores as a group and were given the opportunity to change their scores based on group discussions. Discussions were cordial and collegial and consensus was not expected nor required.

The sea level rise climate qualitative exposure factor, described in Appendix B, was developed by examining contemporary rates of sea level rise and those projected through 2050 (https://tidesandcurrents.noaa.gov/sltrends/sltrends.html [36,39]). The projections consider a number of climate and non-climate factors such as thermal expansion of seawater due to increasing temperature, melting of land ice in Greenland and Antarctic glaciers, vertical land movement due to global isostatic adjustment, sediment compaction, changes in metocean processes that alter sea surface heights (e.g., shifts in ocean currents, winds, air pressure), fossil fuel and groundwater withdrawals. The net result of these analyses is sea level is rising across the entire southeast U.S. coast, with the highest rates of increase, 9-10 mm/yr, found along the coasts of North Carolina and South Carolina [39]. Experts were asked to score individual species for exposure to sea level rise, based on their life history traits and projected sea level rise in their range, along a continuum ranging from low (not dependent on marsh, seagrass, mangrove, coral, or estuary habitats) to very high (rely on marsh, seagrass, mangrove, coral, or estuary habitats, and the relative sea level trends within their range are ≥ 9 mm/yr). Species with some dependency on affected habitats and residing in an area with projected sea level rise of 0-9 mm would be scored as having moderate or high exposure.

Exposure to changes in Gulf Stream-induced upwelling was assessed by expert scorers with the aid of a descriptive account of the subject (Appendix C) developed after an extensive literature search. The Gulf Stream is the dominant oceanographic feature in the SEUS and is instrumental in transporting both nutrients and heat along the entire SEUS coast. Macronutrients (nitrate, phosphate, silicate) necessary for marine phytoplankton growth are delivered along the eastern continental margin of the United States from the Straits of Florida to Cape Hatteras [40] by Gulf Stream-associated upwelling events of nutrient-rich North Atlantic Central Water (NACW). The Gulf Stream is part of the upper north-flowing limb of the Atlantic Meridional Overturning Circulation (AMOC), a large-scale circulation system that is a major transporter of heat from the tropics to the North Atlantic, carrying warm, near-surface waters (via the Gulf Stream) into far-northern latitudes and returning cold deep waters southward into the South Atlantic [40-42]. The Gulf Stream appears to be weakening along with the AMOC [43-47], and future climate change scenarios predict further weakening [48], which may have implications for regional primary and secondary productivity patterns if it results in declines in the magnitude, duration or frequency of Gulf Stream-related upwelling events. Scorers were instructed to use their expert knowledge of a species' distribution to determine the extent to which overlap with the Gulf Stream occurs. Species that have a high overlap with the Gulf Stream and upwelling should have a higher exposure score than species that have low overlap. Exposure was then assigned on a continuum ranging from low (distributions overlap almost exclusively with inner shelf conditions) to high (distributions overlap almost exclusively with conditions on the middle or outer continental shelves, where changes in Gulf Stream transport, eddy propagation, and upwelling are expected to be experienced). For a species spending some of its life cycle in an area with nearshore currents or seaward where upwelling events occur, it was scored between low and high. If a species had a particular critical life stage, experts could weight their scores based on the areas where critical life stages occur.

Scoring of Quantitative Exposure Factors using Climate Model Projections

Climate data for sea surface temperature, sea surface salinity, pH (representing ocean acidification), air temperature and precipitation were downloaded from NOAA's ESRL 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 (CMIP5) using the Representative Concentration Pathway 8.5 (RCP 8.5) scenario, or the high emissions "business as usual" scenario, assuming little to no stabilization of greenhouse gases by 2100 [49]. Data for air temperature and precipitation were generated using 35 different models, sea surface temperature and sea surface salinity were derived from 25 models, and information on pH was derived from 11 models. Climate data from the ESRL Climate Change Portal were available as 1° gridded arrays containing mean fields and standard deviations for the periods of 1956-2005 (historical time frame) and 2006-2055 (future time frame). Climate exposure data were prepared and analyzed in MATLAB [37]. Climate data were transformed into a standard deviation format (standardized anomaly) using the formula:

$(\text{mean}_{2006\text{-}2055} - \text{mean}_{1956\text{-}2005})/\text{standard deviation}_{1956\text{-}2005}$.

An example of the sea surface temperature climate model output showing future climate projections and the difference in historical vs future periods (standard anomaly) for the South Atlantic LME is shown in Fig. 3, and full model output plots for other exposure factors can be found in Appendix D.

Assessment of Overall Climate Vulnerability and Bootstrap Analysis

Overall climate vulnerability was estimated by first assigning each scorer's component (sensitivity attribute or exposure factor) a numerical value: 1 for Low, 2 for Moderate, 3 for High, 4 for Very High. Weighted mean component scores were then calculated across scorers' tallies using the following formula [16]:

$$Mean = \frac{(L \times 1) + (M \times 2) + (H \times 3) + (VH \times 4)}{25}$$

where L = number of low vulnerability tallies from scorers

M = number of moderate vulnerability tallies

H = number of high vulnerability tallies

VH = number of very high vulnerability tallies

A logic rule (Table 4) was then used to convert weighted mean component scores into overall sensitivity and exposure scores for each species. For example, any species with three sensitivity or exposure weighted means ≥ 3.5 was given a Very High sensitivity or exposure score of 4, and species with two or more weighted means ≥ 3.0 were given a High score of 3.0. A logic model is used in lieu of simple averaging because the latter minimizes the importance of high scores. Finally, an overall vulnerability score is calculated by multiplying the overall sensitivity score by the overall exposure score. Overall climate vulnerability ranking is determined by the following scale: 1-3 Low climate vulnerability, 4-6 Moderate climate vulnerability, 8-9 High climate vulnerability, 12-16 Very High climate vulnerability.

Uncertainty in overall climate vulnerability scores was assessed using bootstrap analysis. Scores across all experts for a given sensitivity attribute or exposure factor were drawn randomly, with replacement 5,000 times for the 12 sensitivity attributes and the two qualitative exposure factors. Overall vulnerability was calculated for each iteration, the outcomes of these iterations were recorded, and the proportion of the 5,000 iterations that scored in each overall vulnerability bin was enumerated.

Species Distribution Change Potential

Potential for species to change their geographic distribution in response to climate change was assessed as a function of four relevant sensitivity attributes: adult mobility, dispersal of early life stages, habitat specificity, and sensitivity to temperature. Highly mobile, thermally tolerant species with widely dispersed larval stages that are habitat generalists are more likely to be successful in adapting to a changing climate by shifting their distributions than sessile or low-mobility specimens with specific habitat requirements and restricted dispersal of larval stages [50]. To assess the distribution change potential of each species, we reversed the scores for the Habitat Specificity, Dispersal of Early Life Stages, and Adult Mobility attributes and applied the same logic rule we used in the overall vulnerability assessment to arrive at an overall potential ranking.

Directional Effects of Climate Change

Scorers assessed the directional effect of climate change for individual species by distributing four tallies across three bins: positive, negative or neutral (no effect). Five scorers assessed each species, and the scores were converted into numeric values: positive = 1, negative = −1, and neutral = 0. A weighted mean was then calculated across scorers and a final directional effect was assigned as follows: weighted means ≥ 0.333 were positive, weighted means ≤ -0.33 were negative, and $-0.33 \leq$ weighted means ≤ 0.33 were scored as neutral, or having no effect.

Leave-One-Out Sensitivity Analysis

We re-estimated the overall vulnerability score for each species by leaving out the scores for each sensitivity attribute or exposure factor, one at a time. Resulting distributions of numbers of changes in vulnerability ranks by attribute or factor provide insight into which ones are most influential in determining overall vulnerability rank.

Functional Group Evaluation

We assessed overall climate vulnerability, potential for species distribution change, and directional effect of climate change by functional group, in order to evaluate the similarity of vulnerability ranks across functional groups. Additionally, sensitivity attribute scores among and within functional groups were examined using principal components analysis.

Species Vulnerability Narratives

Species narratives were developed for all 71 species to present information on vulnerabilities associated with exposure factors or biological sensitivities, and were intended to augment the general results of relative vulnerabilities across species. The narratives contain the distribution of tallies across vulnerability bins, the component exposure/attribute rankings, the overall climate vulnerability rank, and scores for potential for distribution change. In addition, a summary of the life history of each species and a description of relevant climate effects on that species is included.

Results

Overall Climate Vulnerability

The 71 species assessed were fairly equally divided between three climate vulnerability ranks: very high (31%, $n = 22$, red), high (34%, $n = 24$, orange) and moderate (35%, $n = 25$, yellow) (Fig. 4). No species were ranked in the low overall climate vulnerability category. Climate exposure scores for nearly all species (70 out of 71) were very high, with a single species, Atlantic sturgeon, having a climate exposure score of high. Biological sensitivity scores were distributed relatively equally among the three lower ranks (low, 35%; moderate, 34%, high, 31%), with only Atlantic sturgeon categorized as having very high sensitivity. Bootstrap analyses to assess the likelihood that species vulnerability rankings could change based on differences among species in individual expert scores showed a high certainty in the likelihoods of a majority of the species, with 70% of species having >90% certainty, while 24% of species had certainty scores between 60-90%. Only 6% of species had certainty scores <60%. One species, white grunt, had a >0.25 probability of moving one rank higher, from moderate to high, while two species, American eel and snook, had a >0.25 probability of moving one rank higher from high to very high. Four species (hogfish, striped bass, blueline tilefish, golden tilefish) had a >0.25 probability of moving one rank lower from very high to high, while four species (spotted seatrout, black drum, yellowtail snapper, almaco jack) had a >0.25 probability of moving one rank lower from high to moderate.

Potential for Change in Species Distribution

The majority of species assessed ($n = 40$, 56%) exhibited a high or very high potential for a species distribution change (Fig. 5). Twenty-four species were determined to have a moderate potential for a changing distribution, and seven were deemed to have a low potential for changing distribution. The species with the highest vulnerability to climate change (and therefore to a change in productivity or abundance) are also likely to have the lowest potential to change distributions. This general negative relationship is supported in the U.S. South Atlantic LME when examining the potential for distribution change versus overall climate vulnerability (Fig. 6). Of the seven species with a low potential for distribution change in this study, five have a very high overall vulnerability ranking and two have a high ranking. Fourteen of the 24 species with a moderate potential for distribution change had a very high overall vulnerability ranking, while seven species had a high ranking and three had a moderate ranking. Of the 40 species with high or very high potential for distribution change, the majority (n = 23) had only a moderate overall climate vulnerability, while 14 species were ranked high for climate vulnerability and three species were ranked very high.

Directional Effect of Climate Change

Negative impacts of climate change were predicted for only 18% (*n* = 13) of species assessed in this study (Fig. 7). These species include five diadromous species (striped bass, American eel, American shad, blueback herring, Atlantic sturgeon) and five invertebrate species (brown shrimp, eastern oyster, horseshoe crab, rock shrimp, Caribbean spiny lobster), as well as three species that have histories of over-exploitation (Nassau grouper, snowy grouper, spiny dogfish). Positive effects of climate change are expected for 21 species (30% of species assessed), including commercially and recreationally important reef fish species (red snapper, vermilion snapper), common coastal inshore species sought by anglers (red drum, spotted seatrout), and important forage fish species (anchovies, pinfish). The directional effect of climate change on the majority of species (37 species, 52%) was anticipated to be neutral (neither positive or negative effects).

Evaluation of Sensitivity Attributes and Exposure Factors

There was no clear dominant attribute among the 12 sensitivity attributes for all 71 species (Fig. 8). The highest scores belonged to attributes relating to reproduction and spawning (Early Life History Survival and Settlement, Spawning Cycle, Reproductive Complexity) and population viability (Population Growth Rate, Stock Size Status). These results were supported by the leave-one-out sensitivity analysis, which showed that Population Growth Rate and Stock Size Status were most important in determining vulnerability to climate change, with rankings changing for 12 and 9 species, respectively, when those attributes were eliminated from the analyses (Fig. 9). The relative contribution of each sensitivity attribute for each species is visualized in Fig. 10. The most vulnerable species were the anadromous fishes (Atlantic sturgeon, blueback herring, American shad). Attributes most influential in sensitivity ranking for these species were those dealing with early life history survival and dispersal, reproduction, and exploitation (Stock Size Status). Eastern oyster had very high scores in Adult Mobility, Sensitivity to Ocean Acidification, Sensitivity to Temperature, and Other Stressors. Several species with a history of overfishing (Nassau grouper, goliath grouper) as well as most deepwater reef fish had high sensitivity scores, and Population Growth Rate, Stock Size/Status, and Spawning Cycle were major influences. The least vulnerable species were pelagic species (dolphinfish, little tunny, wahoo). Ocean Acidification and Sea Surface Salinity were determined to be the most important exposure factors, with all 71 species scored as very high exposure for Ocean Acidification, and 70 species scored as very high for Sea Surface Salinity. Sea Surface Temperature was the next most impactful exposure factor, with 50 species scoring as very high exposure. Sensitivity analyses showed removal of each of these factors from the scoring resulted in the changing of the vulnerability scores of 46, 45, and 36 species, respectively.

Functional Group Vulnerability Results

Functional groups with very high climate vulnerability were Deepwater Reef Fish (100%), Diadromous Fishes (80%), Benthic Invertebrates (66%), and Reef Fishes (26%) (Fig. 11). Additionally, one of the six Elasmobranch species exhibited very high climate vulnerability, while four were scored as high. Pelagic Fishes all scored as moderate for climate vulnerability, while Coastal Fishes and Coastal Pelagic Fishes were split between moderate and high vulnerability. No functional groups contained any species with low overall climate vulnerability. In terms of potential for distribution change, all Pelagic Fishes have high or very high potential for distribution change, while Coastal Pelagics, Forage Fishes, and Elasmobranchs all had high potential. The majority of Coastal Fishes species (70%) had high potential, while the rest had moderate potential. Diadromous Fishes and Benthic Invertebrates were distributed between low potential and high potential for distribution change. Reef Fishes were equally split between moderate and high potential, while all Deepwater Reef Fishes species were estimated to have a moderate potential for distribution change. Functional groups with species expected to undergo negative effects from climate change as indicated by directional effects scoring include Benthic Invertebrates, Diadromous Fishes, Deepwater Reef Fishes, Reef Fishes and Elasmobranchs, although the majority of Deepwater Reef Fishes, Reef Fishes and Elasmobranchs were expected to undergo either positive or no effect from climate change. Functional groups with no species expected to undergo negative effects include Forage Fishes, Pelagic Fishes, Coastal Pelagic Fishes, and Coastal Fishes.

Principal components analysis shows most species were located proximal to other species within their functional groups (Fig. 12), suggesting that species within a given functional group have similar sensitivities. The functional group Reef Fishes was the exception, showing wide variability across the PC1 axis. The attributes most strongly influencing the PCA results were Stock Size Status, Population Growth Rate and Complexity in Reproductive Strategy, explaining 41% of the variance, followed by Sensitivity to Ocean Acidification, Population Growth Rate, and Adult Mobility, with these attributes explaining another 21% of the variance.

Species Vulnerability Narratives

Species narratives (Appendix E) were developed to detail species-specific climate vulnerabilities associated with various exposure factors or biological sensitivities. The narratives provide a graphic summary of the distribution of scores across vulnerability bins, the component exposure/attribute rankings, overall climate vulnerability rank, and scores for potential for distribution change. Life history summaries and a description of relevant climate effects on the species are also provided.

Discussion

The results of this CVA, which examined the susceptibility of 71 species of fish and invertebrates within the South Atlantic LME to reduced productivity or abundance because of changing climate, found that almost two-thirds (*n* = 46 of 71 species; 65%) exhibited high or very high vulnerability (Fig. 4). In addition, more than half of species assessed had high or very high potential for changes in distribution, a phenomenon already occurring farther north along the U.S. Atlantic coast, and is anticipated in the SEUS [14, 51]. Although none of the species assessed are expected to be entirely immune to climate effects, approximately half are predicted to experience neutral impacts overall with smaller proportions experiencing positive or negative effects. These results are similar to the findings of the Northeast U.S. Continental Shelf CVA, which found 60% of species assessed had high or very high overall climate vulnerability, while 50% of species had a high or very high potential to shift their distribution.

Ocean Acidification, Sea Surface Salinity, and Sea Surface Temperature were the environmental factors expected to undergo the greatest magnitude of change by 2055 in the SEUS. These three exposure factors had mean scores ≥ 3.5 for all but one species, Atlantic sturgeon. This result triggered the logic rule [16], resulting in very high climate exposure designation for these species. Atlantic sturgeon was influenced more by Air Temperature, a proxy in this analysis for water temperature for riverine and estuarine species, and thus exposure for Sea Surface Temperature was not scored as very high by experts. The findings of this CVA are similar to the results of the CVA carried out for the Northeast U.S. Continental Shelf [17], which found Sea Surface Temperature, Ocean Acidification, and Air Temperature were the most impactful exposure factors.

The projected changes in global oceanic pH, predicted to decrease by 0.14-0.35 units by the year 2100 [52, 53], are higher than any changes inferred from the fossil record for the previous 200 million years [54, 55]. Increasing ocean acidification has been shown to have direct impacts on marine fish, such as negatively affecting reproduction in marine teleosts [56]. Impairment of sensory abilities that enable larval fish to find suitable settlement habitat may also be attributable to increasing ocean acidification [57], although there is conflicting evidence and this is an area of active research (58, 59). Indirect effects include modifying the suitability of habitat important to fish or shellfish [60, 61], while indirect impacts include increasing conditions favorable for development of algal blooms, thereby potentially affecting survival and fitness [62]. Direct impacts on marine invertebrates are similar, with one study finding increasing acidification led to decreasing larval size, abnormal development and near-total larval mortality of one species of brittle star [63]. Increasing ocean acidification is expected to negatively impact larval survival and reproduction of mollusks, which will in turn lead to decreased population size, as well as changes in geographic distribution and community structure of these ecosystems [64]. Increasing acidification significantly lowered calcification rates in two species of shellfish [65], potentially affecting not only the coastal aquaculture economies that depend on these species, but also the human communities that depend on their role as ecosystem engineers in coastal ecosystems. Important reef-building corals such as the genus *Porites* have been shown to undergo as much as a 20% decline in skeletal density due to decreases in pH of seawater [66], thus threatening the integrity of the reef ecosystems they anchor and contributing to the degradation of the ecosystem services and coastal protections from extreme weather that reefs provide. Research into the effects of ocean acidification on marine fishes and shellfishes should continue to be prioritized in order to provide the best available scientific advice to management bodies on the effects of climate-driven environmental changes on LMRs, including the development of stock assessment models that include inputs for these changing variables.

Mean global sea surface temperature has increased 0.5°C since 1961 and is expected to increase by 1–3°C by the year 2100 [67]. Even small increases in sea surface temperature could have negative effects on marine fishes, including impacts on physiology [68, 69] and distribution [70]. Biodiversity is expected to decrease in tropical regions, partly as a result of thermally-driven local extinctions [71, 72], and partly due to range shifts of species to more poleward, thermally suitable waters. Increasing ocean temperature can also increase metabolic rates for marine organisms, causing a demand for more oxygen; however, increases in ocean temperature will decrease the availability of dissolved oxygen, thus affecting development, fitness and survival of marine biota [72-74]. While many studies have examined the effects of temperature on larval development and survival [75, 76] and reproduction of marine species [77], there are still substantial knowledge gaps. There have been some initial attempts at including environmental variables such as sea surface temperature in optimizing survey design [78] and modeling stock assessment results [79, 80], but research on the effects of temperature on productivity, abundance, and distribution of marine biota should continue in order to provide the best scientific advice to management bodies.

Salinity has been predicted to increase significantly in the subtropical Atlantic as a result of anthropogenic climate change [81]. The conventional explanation for this result is climate change will enhance the global water cycle, resulting in wet regions becoming wetter and dry regions, such as subtropical ocean areas, becoming drier [82]. These regions are also expected to get warmer, enhancing evaporation and leading to potentially higher salinity. One study found salinity was influenced by temperature, and when both variables were considered in the models, the entire Atlantic Ocean has a positive salinity trend [83]. For this CVA, climate models determined salinity exposure to be very high for 70 of 71 species. Very high salinity exposure, in combination with very high sea surface temperature and ocean acidification exposures, invoked the logic rule and resulted in an overall climate exposure component of very high for these species. This result was the driving reason behind why all species in the assessment ranged from moderate to very high overall climate vulnerability (i.e., no low vulnerability species). This result was distinctly different from the NEUS CVA, where salinity exposure was not high and 25% of species were classified as low overall climate vulnerability [17]. Sea surface temperatures are likely to continue to increase [84], and the synergistic effects of temperature increases on salinity dictate prudence when continuing to conduct basic experimental research on the effects on salinity on LMRs (e.g., [27]) with the goal of parameterizing these environmental variables for inclusion into stock assessments and other fishery management decision-making processes.

Other important climate exposure factors were sea level rise and Gulf Stream-induced upwelling. Sea level rise is increasing due to thermal expansion of seawater, as well as the accelerated melting of continental ice sheets in the polar regions. Increases of as much as 0.59 m above 1999 levels are predicted [53], while an analysis of altimeter data shows the rate of sea level rise doubling by 2100 [85]. Another study predicted increases of as much as 1.0 m by century's end based on a linear projection of past sea level rise [86], although critics note this study only considered the melting of alpine glaciers in their predictions, but not continental ice sheets, which could generate a sea level rise of up to 5 m [87]. More recent predictions indicate this pattern of increasing sea level rise will continue through at least the remainder of this century [36] with a worst-case scenario of 2.5 m of sea level rise by 2100 [39]. Sea level rise is expected to be acute in the SEUS, particularly in the states of Georgia and North Carolina (see Appendix B). Whether the actual rise is 1 or 5 m, it appears many coastal communities and important marine habitats will be at risk. The potential exists for displacement or alteration of valuable seagrass and mangrove habitats [88-90], important nursery areas for many species of fishes and shellfishes.

Climate models predict a general weakening of global circulation patterns by the year 2100 [46, 53]. Current data indicates a weakening of the AMOC [45, 91, 92]. Slowing oceanic circulation will likely decrease the amount of coastal water exchange mechanisms (e.g., eddies, upwelling), thus negatively impacting nutrient and larval transport. In addition, these upwelled water masses can be nutrient rich, enhance primary production and zooplankton assemblages, serve as nursery areas by providing a rich food supply for larval fishes spawned in or entrained into eddies, and can translocate larval fishes across the shelf [93, 94]. In addition to nutrient transport, the AMOC acts as a heat transport mechanism, transporting heat from the tropics to more poleward regions. Slowing circulation patterns could have significant implications for tropical areas that are already warming.

Examination of expert scores for biological sensitivity attributes indicate no individual attribute was as dominant as the exposure factors, but attributes related to reproduction, and larval survival and settlement had the highest scores (Fig. 8), followed closely by Other Stressors, Habitat Specificity, Dispersal of Early Life Stages, and Sensitivity to Ocean Acidification. The score for Sensitivity to Ocean Acidification was also notable, mirroring the results from the exposure factor scoring. These results reflect the concern marine organisms face a variety of threats from a changing climate, including reduced larval survival and impaired development, as well as climate-induced changes to phenology that might affect optimal linkages between spawning and food availability. Both of these scenarios could lead to reduced abundance and productivity of marine fish stocks in the SEUS. Other Stressors include anthropogenic impacts such as pollution, algal blooms, and habitat alteration (e.g., dredging, development, damming rivers). These stressors could exacerbate the well-being of species already stressed by a changing environment, and are likely to have the greatest impact on species with an estuarine, riverine, or nearshore component to their life cycle, notably anadromous or invertebrate species, which are some of the most vulnerable in our assessment. The influence of Population Growth Rate and Stock Size Status reflect the added vulnerability of overexploitation to recovery in the face of climate change and figures prominently in the designation of highly and very highly vulnerable to several species of exploited deepwater reef fishes (e.g., speckled hind, warsaw grouper, tilefish, blueline tilefish). The life strategies of these species (long-lived, slow-growing, late to mature) make them less likely to be able to recover from climate-driven population disruptions.

Previous studies have emphasized the importance of considering adaptive capacity in assessing the vulnerability of a species to climate change [95]. Adaptive capacity is the potential for a species to respond to environmental change by either 1) moving when environmental conditions deteriorate, 2) undergoing physiological or phenotypic changes that dampen the negative impacts of the environmental change, or 3) undergoing genetic adaptation in order to adapt to the changing environment. Adaptive capacity and sensitivity are often considered to be closely related, and some of the sensitivity attributes used in this study can be considered indicative of adaptive capacity. Adult mobility is an important component of adaptive capacity [96], allowing species to relocate to more favorable environments. Plasticity in phenotypic responses to changing environmental conditions are built into the sensitivity attributes in the form of sensitivities to temperature and ocean acidification, as well as in the attributes concerning habitat or prey specificity. A species able to adapt in these areas is more likely to be successful in adapting to a changing climate. While still understudied, the ability of marine organisms to adapt genetically to climate change is the subject of increasing research in recent years [97].

Although there is considerable documentation of distributional shifts of marine species in the mid- and northeast Atlantic regions of the United States [25, 51, 98], there is limited documentation of shifts in the SEUS, likely due to the fact SEUS continental shelf waters have not, to date, experienced the magnitude of temperature increases documented farther north along the U.S. Atlantic coast. There are recent anecdotal reports of important species such as dolphinfish being less abundant or available in the southeast, and fishermen that participated in workshops to examine this problem hypothesized temperature or other physical factors were a driver behind the recent paucity of dolphinfish in otherwise suitable habitats (abundant sargassum lines filled with bait fish) [99]. Dolphinfish and wahoo were scored as low in their biological Sensitivity to Temperature and as having a high potential for changing their distribution. While it is probably easier for free-swimming, eurythermal pelagic species such as these to shift their distribution in search of a more optimal temperature profile, if the ocean warms to the extent predicted by global climate models in the next half-century many more species may shift their geographic ranges northward in search of more optimal thermal profiles. Unfortunately, the species most vulnerable to an increasingly harsh climate are likely to be those species with the lowest potential to change their distribution – sessile invertebrates such as the eastern oyster, or anadromous species such as American shad or Atlantic sturgeon that are obligate users of vulnerable inshore habitats.

While the results for this assessment are presented at the species level, the functional grouping results provide useful information about the general responses of specific groups of fishes to climate change. Benthic Invertebrates, Deepwater Reef Fishes and Diadromous Fishes are the most vulnerable to climate change (Fig. 11). Caution should be used when assessing climate vulnerabilities at the functional group level, as species-specific sensitivities could be missed. For instance, while several species in the Reef Fishes functional group are in the high vulnerability category (Fig. 11), principal components analysis of biological sensitivity attributes show that Reef Fishes have a wide spread along the first principal component axis (Fig. 12) and assigning a coarse rank of vulnerable to all species within a functional group without considering sensitivities of individual species could lead to erroneous conclusions.

The goal of this study was to broadly and rapidly assess the climate vulnerability of a large number of important marine fishes and invertebrate species in the South Atlantic LME based on individual biological traits. While the completion of this effort took substantial resources and the involvement of a large number of people, it is true other methods currently used to assess climate vulnerability, such as mechanistic climate-population models [15, 100], are also resource-intensive methods, and it would likely take a considerable amount of time and resources to complete individual models for the 71 species we assessed in this study.

We anticipate the results from this study will be useful to managers in several ways. Information from the species vulnerability narratives contain a wealth of information and could be used as briefing material to present to fishery management councils in advance of particular assessments. The species narratives from the West Coast salmon CVA [19] were used in recent status reviews for Endangered Species Act requirements and recovery plans. In addition to informing regulatory processes such as fishery management plans, endangered species listings, National Environmental Policy Act impact statement decisions, and Biological Opinions, results can be used by fishery management councils to inform policy decisions. For example, results from the northeast CVA [17] were used by the Mid-Atlantic Fishery Management Council in risk scenario planning for evaluation of risks to managed species (https://www.mafmc.org/s/EAFM-Doc-Revised-2019-02-08.pdf). Results from the Bering Sea CVA [18] have been considered in discussions of prioritizing species for stock assessments. The results will contribute to continued development of Ecosystem-Based Fisheries Management, as well as add value to the current practice of single-species stock modeling by informing scientists which environmental variables might be most appropriate to consider in future species-specific modeling efforts. Species-specific results can be used to assess the vulnerability of fishing communities to a changing climate [101, 102] or in habitat vulnerability assessments [103].

We consider this effort to be just the first iteration of periodic climate vulnerability assessments for marine species. Future CVAs should benefit from improvements to the suite of global climate models. Higher resolution models combined with regional downscaling may allow the inclusion of environmental variables such as bottom temperature, which would greatly benefit the scoring of species such as deepwater reef fishes. Emission scenarios other than RCP 8.5 could be considered for predictive purposes. Information about species-specific phenotypic responses to environmental change or genetic adaption could be included as it becomes available to improve our assessment of adaptive capacity. The species list should be reviewed for inclusion of important species not assessed here. Species profiles can certainly be improved as new studies become available, allowing for more informed scoring by the expert panel. The expert panel of scorers can be revised to include a broader array of scientists beyond the mostly fishery scientists whom we included here. This process is time- and resource-intensive and should be done along similar time frames as current single-species stock assessments, integrated ecosystem assessments, or even the IPCC climate assessments. The value of this type of assessment is in its linkages to other assessments used to inform managers and policymakers of the potential vulnerability of ecological and social systems to climate change. This work supports the continued use of Ecosystem-Based Management and provides resources for managers concerned with climate adaptation of fisheries.

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Figures

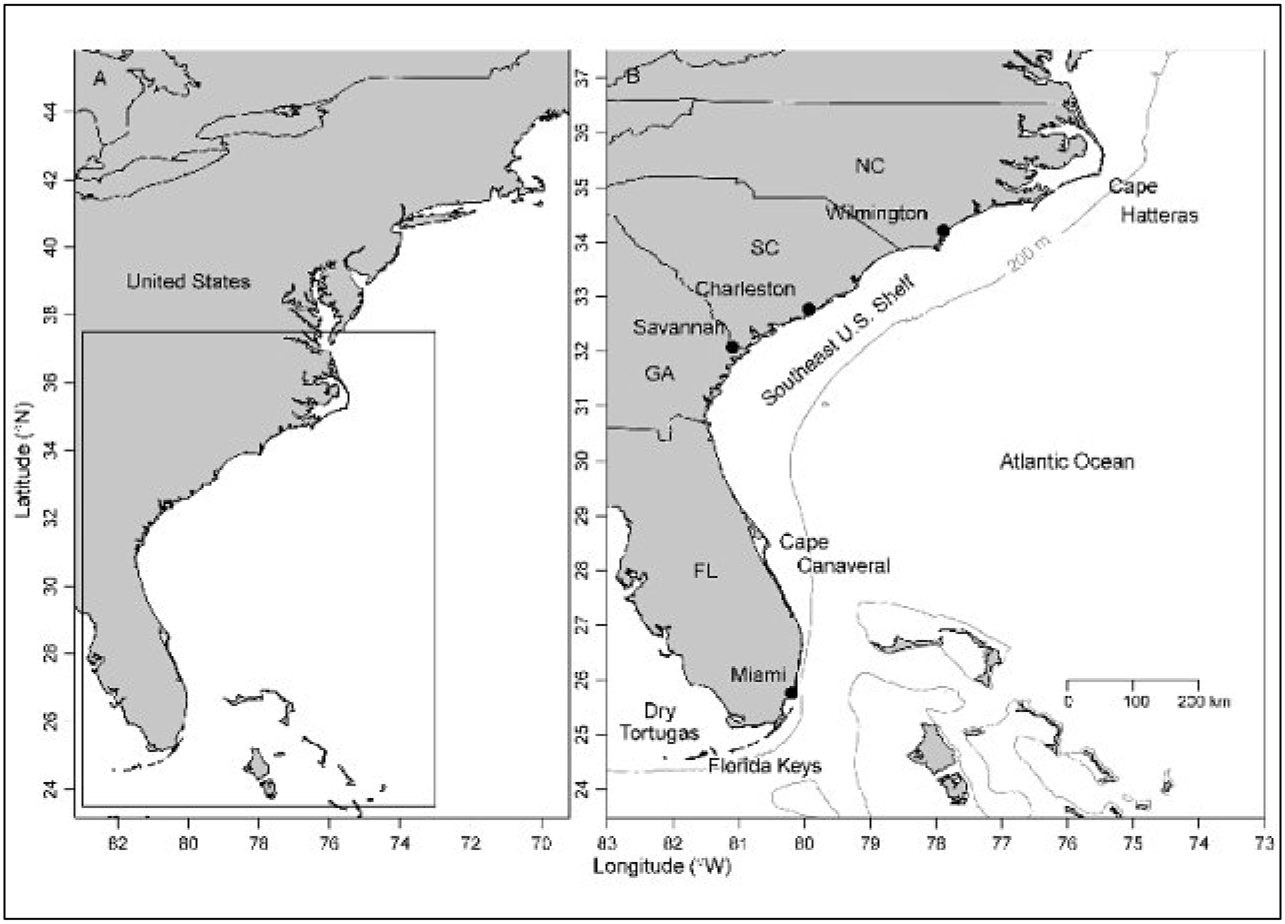


Figure 1. Study area for the climate vulnerability assessment. (A) East coast of the U.S., and (B), the U.S. South Atlantic Large Marine Ecosystem.

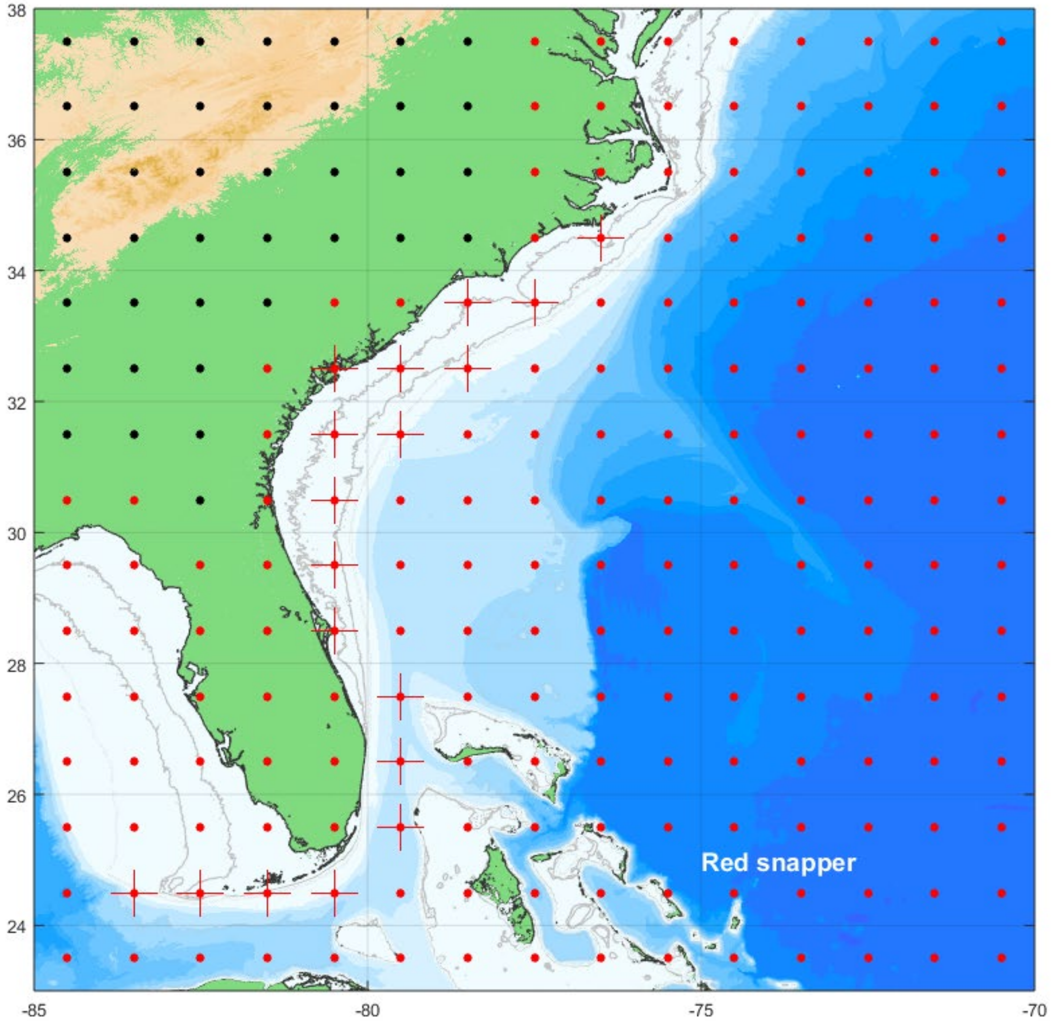


Figure 2. Species distribution of red snapper (*Lutjanus campechanus*) used in Climate Vulnerability Assessment. Red circles indicate all data nodes available in the ESRL data portal. Red crosses indicate data nodes selected to include in assessment and the assumed distribution.

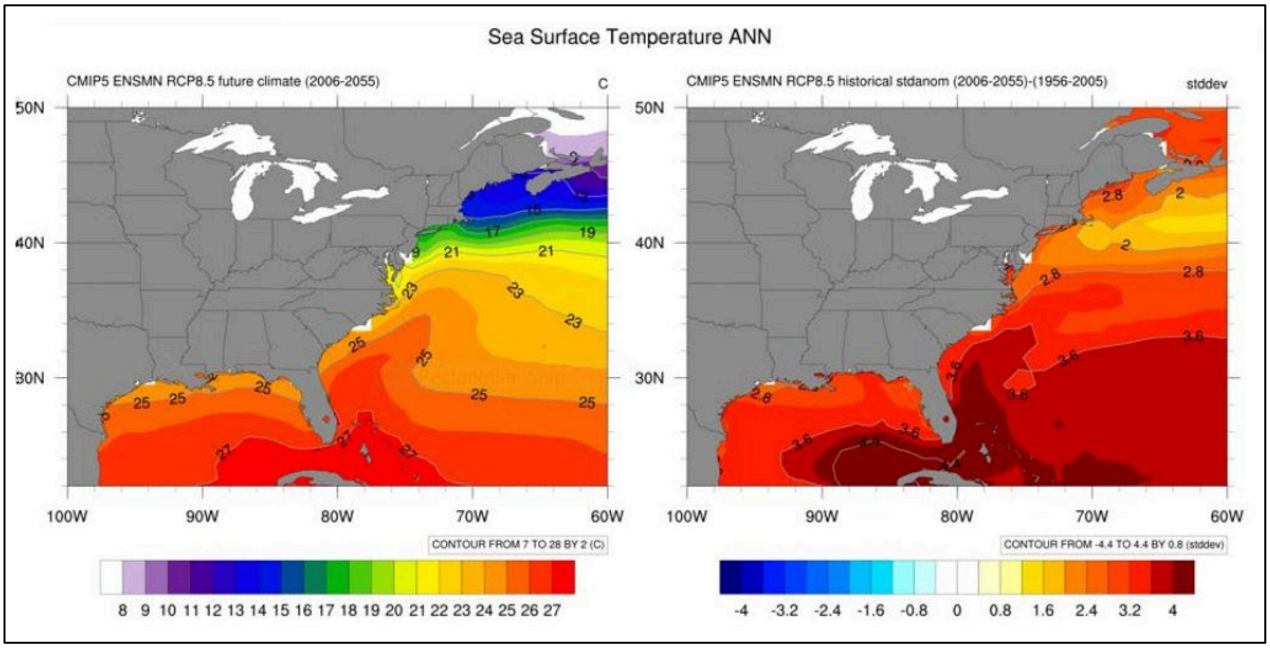


Figure 3. Results of Climate Modeling for Sea Surface Temperature. Outputs are from the Earth Systems Research Laboratory Data Portal. Left panel shows the temperature for the projected period, 2006-2055, while the right panel shows the standard anomaly between projected period and the past period (1956-2005).

Very High	🟨	🟧	🟥 Atlantic Sturgeon	🟥
High	🟩	🟨	🟧	🟥 Nassau grouper Eastern oyster Speckled hind Red grouper Blueback Herring Goliath grouper Warsaw grouper Snowy grouper Horseshoe crab Gag grouper American shad Dusky Shark White Shrimp Scamp Pink Shrimp Brown Shrimp Spiny Lobster *Hogfish* *Striped Bass* *Blueline Tilefish* *Tilefish**
Moderate	🟩	🟨	🟨	🟧 **American eel**** **Snook**** Red drum Sandbar shark Bonnethead shark Mutton snapper Sand tiger shark Red snapper Golden crab Redband parrotfish *Blue crab* *Gray snapper* Weakfish Sheepshead Southern Flounder Rock Shrimp Cobia Atlantic Sharpnose Shark Red Porgy Emerald Parrotfish *Spotted Seatrout* *Black Drum* *Yellowtail Snapper* *Almaco Jack*
Low	🟩	🟩	🟩	🟨 **White grunt** Gray triggerfish Bluefish Striped mullet Belted sandfish Cubbyu Slippery dick Black sea bass Atlantic croaker Spiny dogfish Spanish mackerel King mackerel Blue runner Spot Lane Snapper Atlantic Menhaden Tomtate Dolphin Greater Amberjack Pinfish Wahoo Anchovies Vermilion Snapper Little Tunny Lionfish
	Low	Moderate	High	Very High

Exposure

Figure 4. Overall climate vulnerability scores for South Atlantic Climate Vulnerability Assessment. Colors indicate degree of vulnerability: Low (green), Moderate (Yellow), High (orange), Very High (red). Bolding indicates ≥0.25 probability score is one vulnerability rank higher. Italics indicate ≥0.25 probability that score is one vulnerability rank lower. * indicates bootstrap analysis found the greatest probability of outcomes one rank lower (high) than the categorical rank (very high). ** indicates bootstrap analysis found the greatest probability of outcomes one rank higher (very high) than the categorical rank (high).

Figure 5. Potential for species distribution change. Species are grouped by their potential to change their distribution due to climate change: Green (low), yellow (moderate), orange (high), red (very high). Potential was estimated using a subset of biological sensitivity attributes: Habitat Specificity, Sensitivity to Temperature, Adult Mobility, Dispersal of Early Life Stages.

Overall, Climate, Vulnerability	Very, High	Atlantic Sturgeon, Eastern Oyster, American Shad, Spiny Lobster, Horseshoe Crab	Nassau Grouper, Gag, Speckled Hind, Pink Shrimp, Red Grouper, Brown Shrimp, Blueback Herring, Scamp, Goliath Grouper, Hogfish, Warsaw Grouper, Blueline Tilefish, Snowy Grouper, Golden Tilefish	Dusky Shark, White Shrimp, Striped Bass	
	High	Golden Crab, Rock Shrimp	Blue Crab, Redband Parrotfish, Sheepshead, Emerald Parrotfish, Spotted Seatrout, Yellowtail Snapper	American Eel, Weakfish, Red Drum, Southern Flounder, Sandbar Shark, Cobia, Bonnethead, Atlantic Sharpnose Shark, Mutton Snapper, Red Porgy, Sand Tiger Shark, Black Drum, Red Snapper, Almaco Jack, Gray Snapper, Bluefish,	
	Moderate		Belted Sandfish, Cubbyu, Slippery Dick	Snook, Lane Snapper, White Grunt, Atlantic Menhaden, Gray Triggerfish, Tomtate, Striped Mullet, Greater Amberjack, Black Seabass, Pinfish, Atlantic Croaker, Wahoo, Spiny Dogfish, Anchovies, Spanish Mackerel, Vermilion Snapper, King Mackerel, Little Tunny, Blue Runner, Lionfish, Spot	Dolphin
	Low				
		Low	Moderate	High	Very, High
		Potential, for, Species, Distribution, Change			

Figure 6. Potential for species distribution change in relation to overall climate vulnerability.

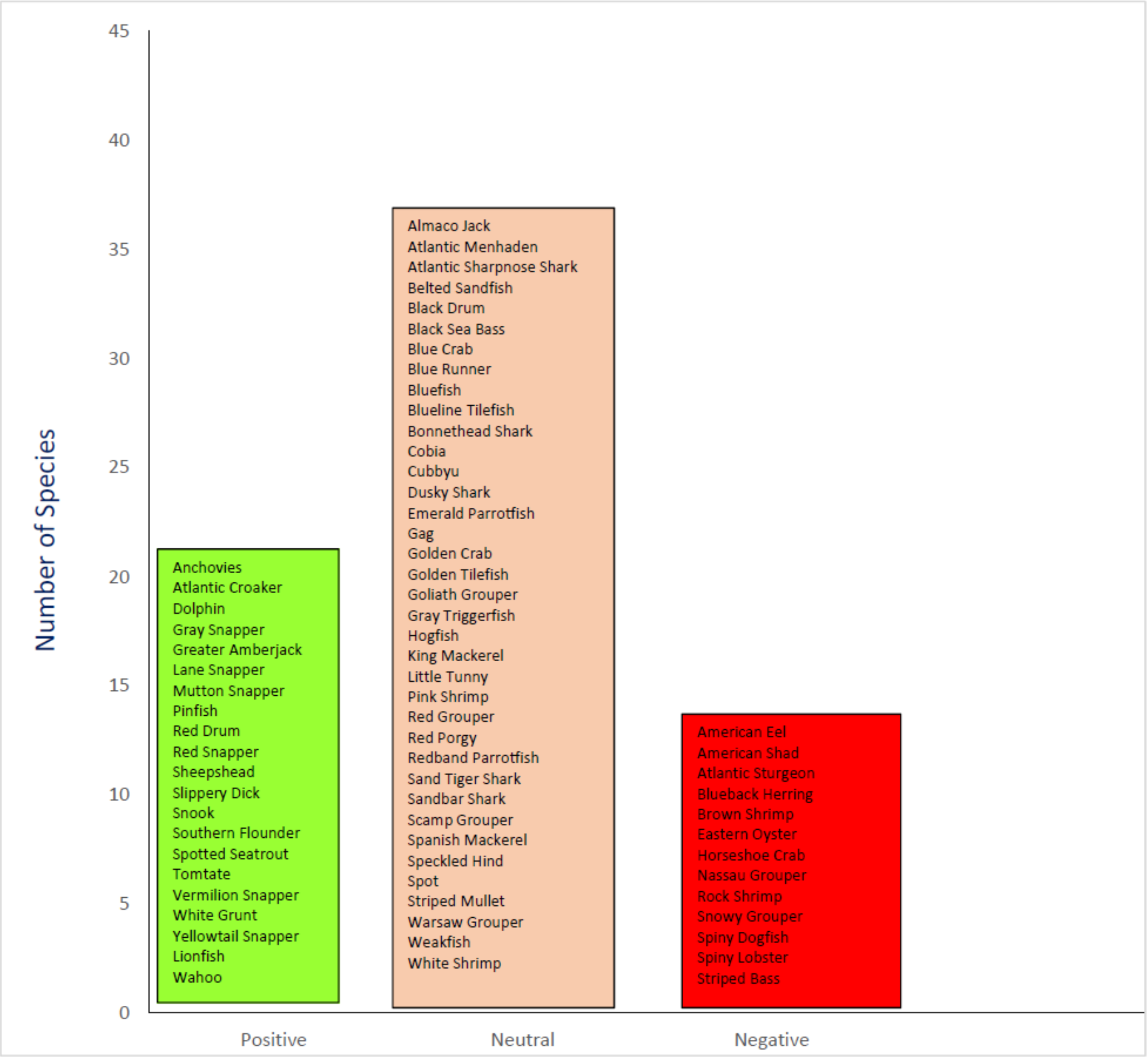
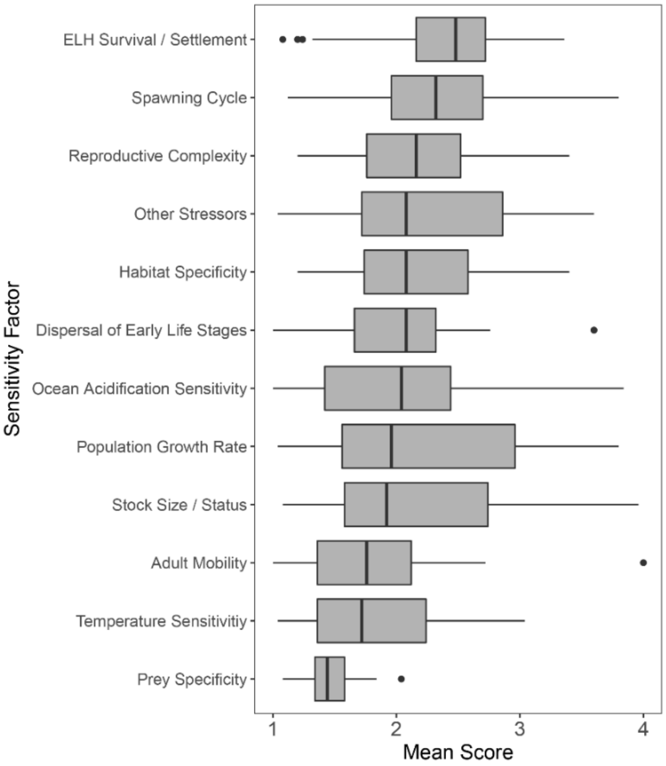


Figure 7. Directional effects of climate change. Colors indicate the expected overall effect of climate change: negative (red), positive (green), neutral (tan).

A.



B.

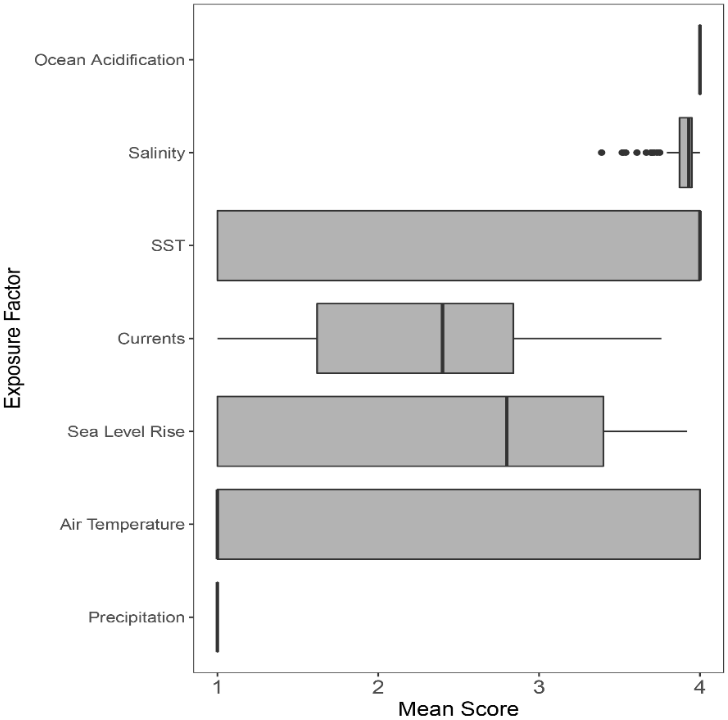


Figure 8. Distribution of mean scores of sensitivity attributes (top) and climate exposure factors (bottom). Central bars represent the median, hinges represent the 25th and 75th percentiles, and whiskers extend from hinges to the largest value no further than 1.5 * the inter-quartile range. Circular points represent outlying mean scores.

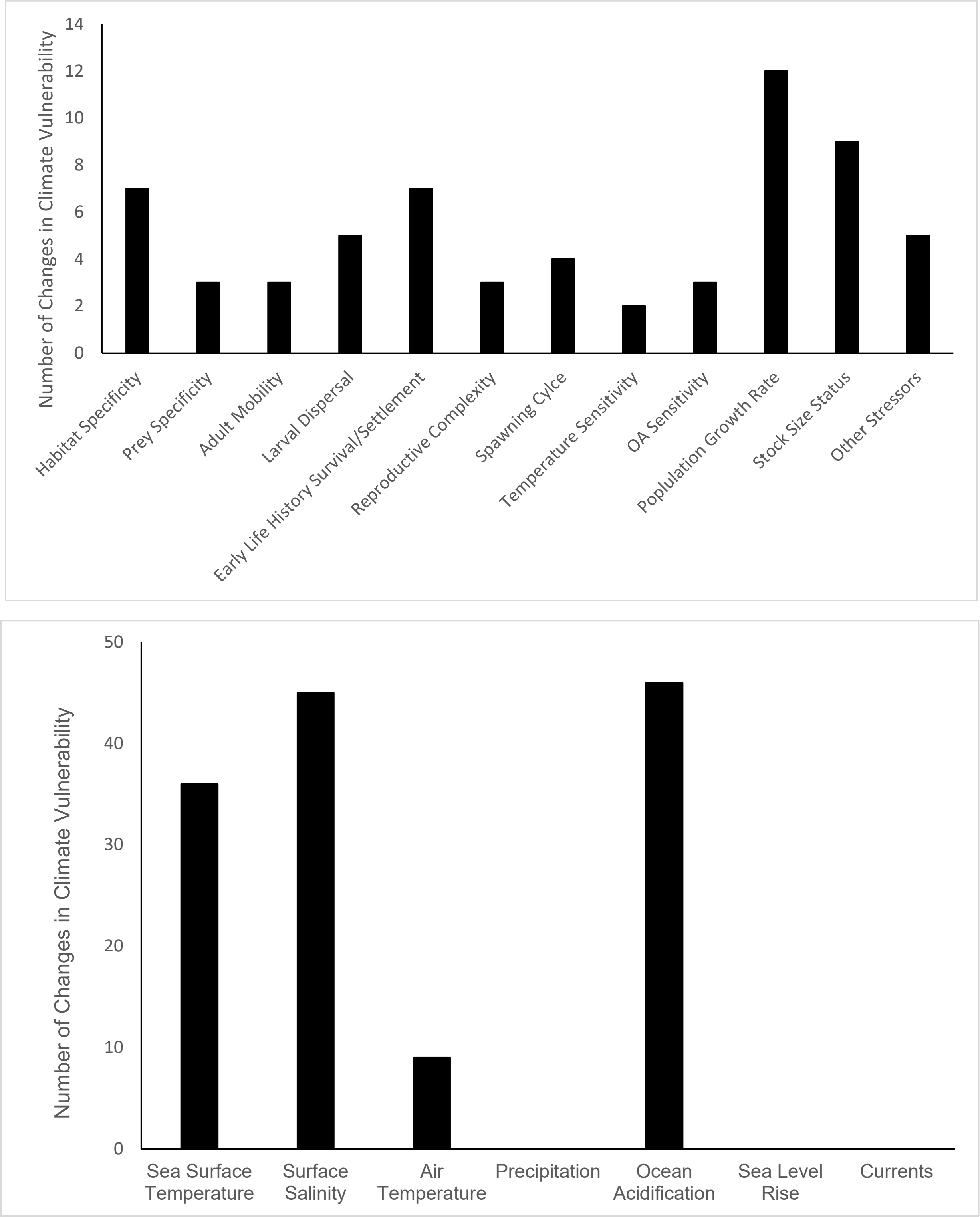


Figure 9. Sensitivity Analyses. Results of sensitivity analyses examining the effects of individual sensitivity attributes (A) or climate exposure factors (B) on the overall climate vulnerability rank across 71 species.

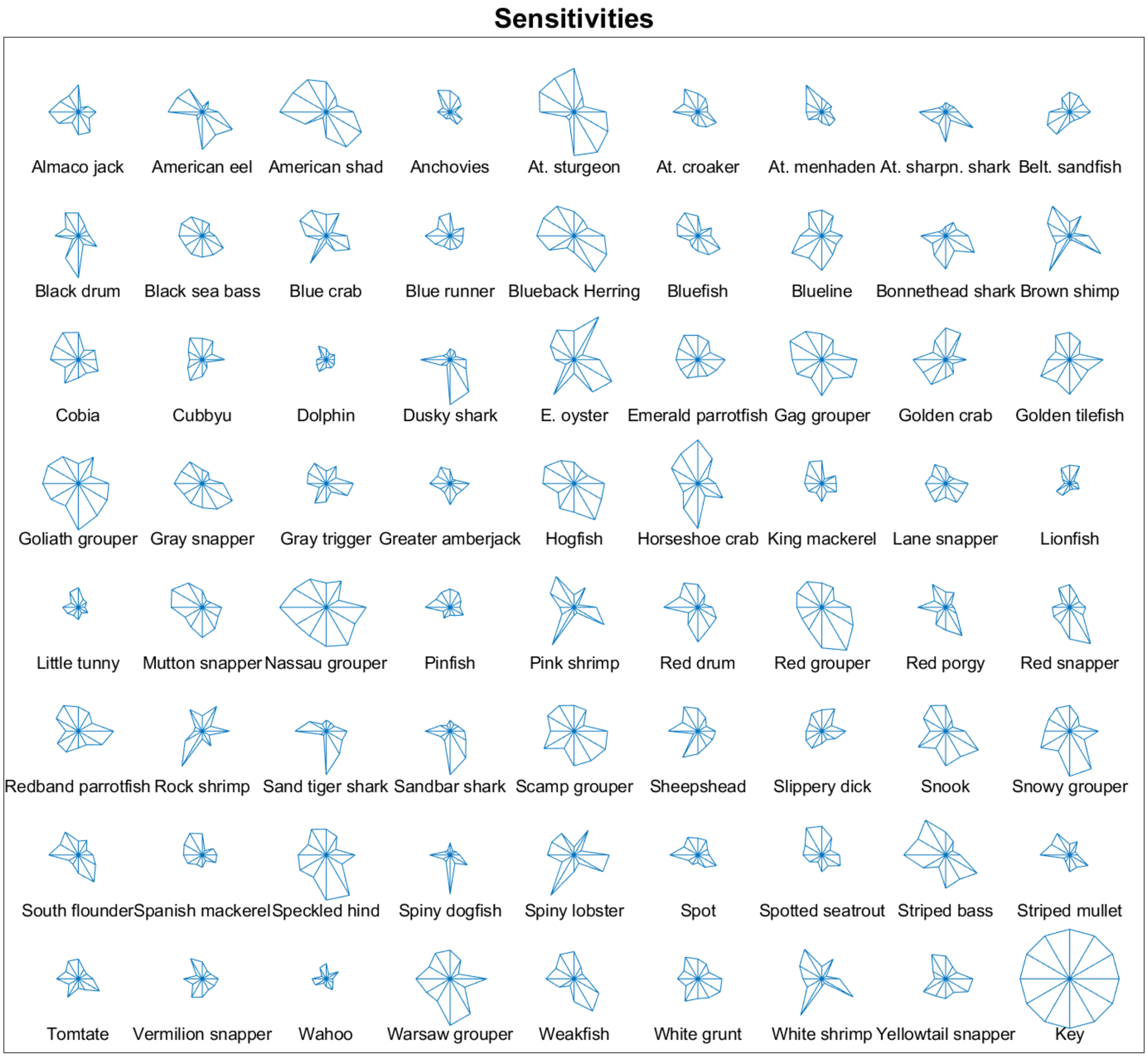


Figure 10. Relative contribution of each sensitivity attribute to overall sensitivity scores for all 71 species. Average sensitivity attribute scores for each species are shown as spokes. The 'Key' subgraph in the bottom row represents a model in which all 12 attributes have a score of 4.0 (the maximum). The habitat specificity attribute is shown as the spoke pointing directly to the right. Moving counterclockwise, the spokes then represent Prey Specificity, Adult Mobility, Early Life Stage Dispersal (pointing directly up), Early Life History Survival and Recruitment Requirements, Complexity in Reproductive Strategy, Spawning Cycle (pointing directly left), Sensitivity to Temperature, Sensitivity to Ocean Acidification, Population Growth Rate (pointing directly down), Stock Size/Status, and Other Stressors. The length of each spoke indicates the degree of contribution of that attribute to the overall sensitivity.

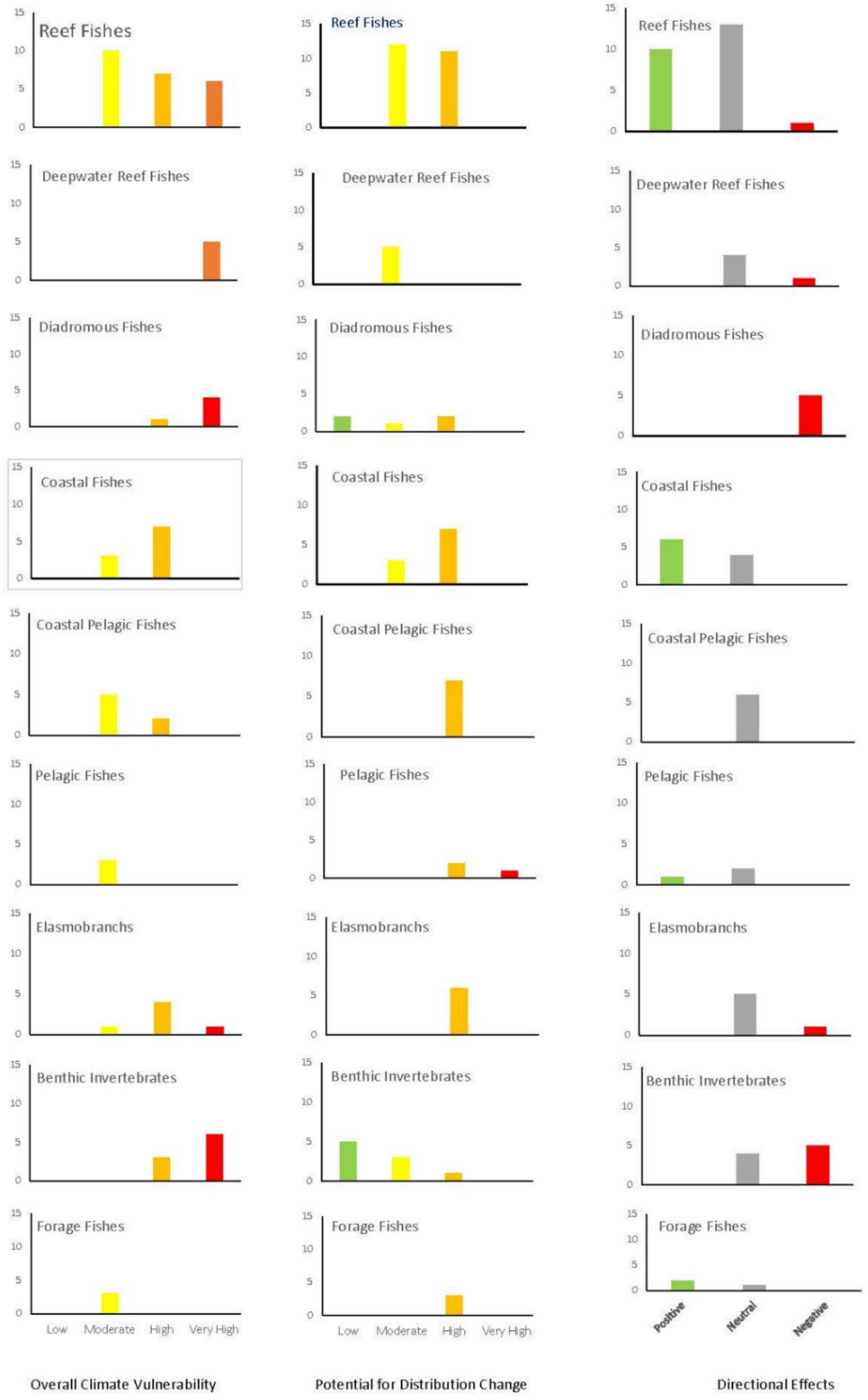


Figure 11. Functional groups. Number of species in each functional group by (A) overall climate vulnerability. (B) potential for distribution change and (C) directional effect of climate change.

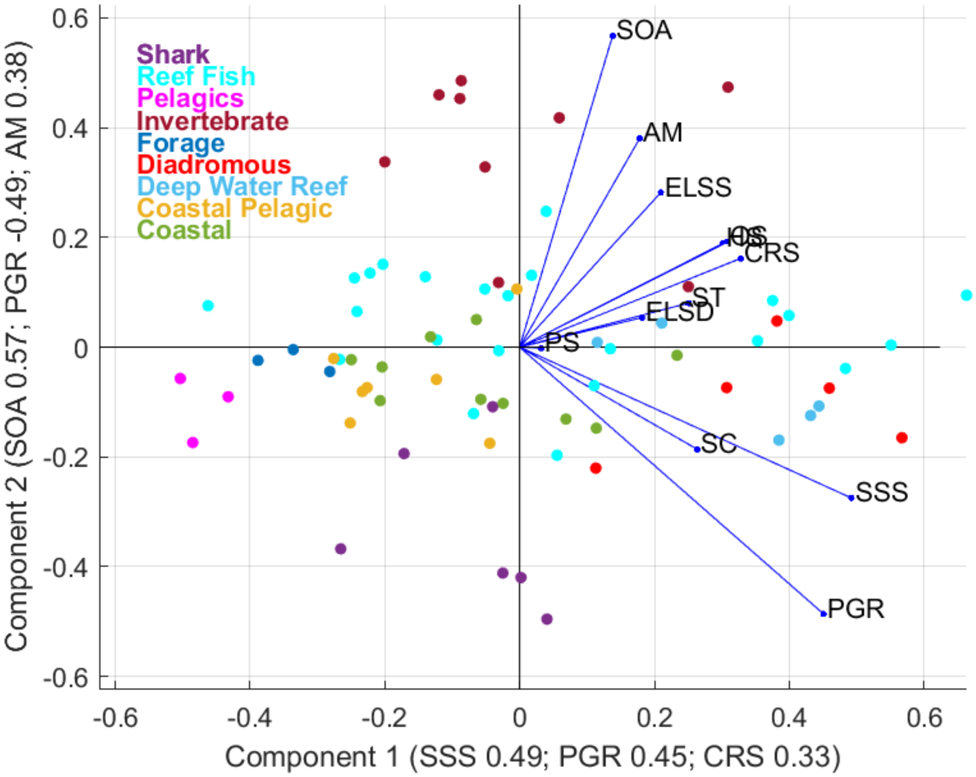


Figure 12. Principal Components Analysis of Species Sensitivity by Functional Group. PC1 explained 41.4% of the variance and was strongly influenced by Stock Size/Status (SSS), Population Growth Rate (PGR), and Complexity in Reproductive Strategy (CRS). All biological sensitivity attributes were positively loaded on PC1. PC2 explained 21.1% of the variance and was most influenced by Sensitivity to Ocean Acidification (SOA), Population Growth Rate, and Adult Mobility (AM). Most species are located in close proximity to other species in their functional groups. This suggests species within the same functional group have similar sensitivity levels to the biological attributes. However, there is a lot of variability for the Reef Fish functional group and this group has a wide spread along PC1. Assessing climate vulnerabilities at the functional group level might be appropriate for most species; however, individual sensitivities for species in the Reef Fish group may be missed when aggregating into functional groups. The amount of overlap among the groups is variable with Pelagics, Sharks, and Invertebrates showing the least amount of overlap with other functional groups and high overlap among the Coastal Pelagic and Coastal functional groups. Most of the spread within functional groups is along PC1, however, the spread for Invertebrates is larger along PC2 instead of PC1.

Tables

Table 1. Species assessed in the South Atlantic Fish and Shellfish Climate Vulnerability Assessment. Assigned functional group, common name, and scientific name of the 71 fish and invertebrate species included in the South Atlantic Fish and Shellfish Climate Vulnerability Assessment.

Functional Group	Common Name	Scientific Name
Coastal Fish	Atlantic croaker	Micropogonias undulatus
Coastal Fish	Black drum	Pogonias cromis
Coastal Fish	Red drum	Sciaenops ocellatus
Coastal Fish	Sheepshead	Archosargus probatocephalus
Coastal Fish	Common snook	Centropomus undecimalis
Coastal Fish	Southern flounder	Paralichthys lethostigma
Coastal Fish	Spot	Leiostomus xanthurus
Coastal Fish	Spotted seatrout	Cynoscion nebulosus
Coastal Fish	Striped mullet	Mugil cephalus
Coastal Fish	Weakfish	Cynoscion regalis
Coastal Pelagic Fish	Almaco jack	Seriola rivoliana
Coastal Pelagic Fish	Blue runner	Caranx crysos
Coastal Pelagic Fish	Bluefish	Pomatomus saltatrix
Coastal Pelagic Fish	Cobia	Rachycentron canadum
Coastal Pelagic Fish	Greater amberjack	Seriola dumerili
Coastal Pelagic Fish	King mackerel	Scomberomorus cavalla
Coastal Pelagic Fish	Spanish mackerel	Scomberomorus maculatus
Diadromous Fish	American eel	Anguilla rostrata
Diadromous Fish	American shad	Alosa sapidissima
Diadromous Fish	Atlantic sturgeon	Acipenser oxyrinchus
Diadromous Fish	Blueback herring	Alosa aestivalis
Diadromous Fish	Striped bass	Morone saxatilis
Deepwater Reef Fish	Blueline tilefish	Caulolatilus microps
Deepwater Reef Fish	Snowy grouper	Epinephelus niveatus
Deepwater Reef Fish	Speckled hind	Epinephelus drummondhayi
Deepwater Reef Fish	Tilefish	Lopholatilus chamaeleonticeps
Deepwater Reef Fish	Warsaw grouper	Epinephelus nigritus
Elasmobranchs	Atlantic sharpnose shark	Rhizoprionodon terraenovae
Elasmobranchs	Bonnethead shark	Sphyrna tiburo
Elasmobranchs	Dusky shark	Carcharhinus obscurus
Elasmobranchs	Sand tiger shark	Carcharias taurus
Elasmobranchs	Sandbar shark	Carcharhinus plumbeus
Elasmobranchs	Spiny dogfish	Squalus acanthias
Forage Fishes	Anchovies	Anchoa hepsetus & A. mitchilli
Forage Fishes	Atlantic menhaden	Brevoortia tyrannus
Forage Fishes	Pinfish	Lagodon rhomboides
Invertebrates	Blue crab	Callinectes sapidus

Invertebrates	Brown shrimp	Farfantapenaeus aztecus
Invertebrates	Caribbean spiny lobster	Panulirus argus
Invertebrates	Eastern oyster	Crassostrea virginica
Invertebrates	Golden crab	Chaceon fenneri
Invertebrates	Atlantic horseshoe crab	Limulus polyphemus
Invertebrates	Pink shrimp	Farfantapenaeus duoarum
Invertebrates	Rock shrimp	Sicyonia brevirostris
Invertebrates	White shrimp	Litopenaeus setiferus
Pelagic Fish	Dolphinfish	Coryphaena hippurus
Pelagic Fish	Little tunny	Euthynneus alletteratus
Pelagic Fish	Wahoo	Acanthocybium solandri
Reef Fish	Belted sand fish	Serranus subligarius
Reef Fish	Black sea bass	Centropristis striata
Reef Fish	Cubbyu	Pareques umbrosus
Reef Fish	Emerald parrotfish	Nicholsina usta
Reef Fish	Gag	Mycteroperca microlepis
Reef Fish	Goliath grouper	Epinephelus itajara
Reef Fish	Gray snapper	Lutjanus griseus
Reef Fish	Gray triggerfish	Balistes capriscus
Reef Fish	Hogfish	Lachnolaimus maximus
Reef Fish	Lane snapper	Lutjanus synagris
Reef Fish	Lionfish	Pterois sp.
Reef Fish	Mutton snapper	Lutjanus analis
Reef Fish	Nassau grouper	Epinephelus striatus
Reef Fish	Red grouper	Epinephelus morio
Reef Fish	Red porgy	Pagrus pagrus
Reef Fish	Red snapper	Lutjanus campechanus
Reef Fish	Redband parrotfish	Sparisoma aurofrenatum
Reef Fish	Scamp	Mycteroperca phenax
Reef Fish	Slippery dick	Haelichoeres bivittatum
Reef Fish	Tomtate	Haemulon aurolineatum
Reef Fish	Vermilion snapper	Rhomboplites aurorubens
Reef Fish	White grunt	Haemulon plumieri
Reef Fish	Yellowtail snapper	Ocyurus chrysurus

Table 2. Climate Exposure Factors and Sensitivity Attributes. List of climate exposure factors and sensitivity attributes used in the climate vulnerability assessment. See NMFS Climate Vulnerability Assessment Methodology (Morrison et al. 2015) for more details.

Exposure Factor	**Goal**	**Low Score**	**Very High Score**
Mean Ocean Surface Temperature	To determine if there are changes to mean ocean surface temperature between 1956-2005 and 2006-2055 time periods.	Low magnitude of change	High magnitude of change
Mean Ocean Surface Salinity	To determine if there are changes to mean ocean surface salinity between 1956-2005 and 2006-2055 time periods.	Low magnitude of change	High magnitude of change
Mean Air Temperature	To determine if there are changes to mean air temperature between 1956-2005 and 2006-2055 time periods.	Low magnitude of change	High magnitude of change
Mean Precipitation	To determine if there are changes to mean precipitation between 1956-2005 and 2006-2055 time periods. Precipitation is a proxy for streamflow.	Low magnitude of change	High magnitude of change
Mean Ocean pH	To determine if there are changes to mean ocean pH between 1956-2005 and 2006-2055 time periods. pH represents ocean acidification.	Low magnitude of change	High magnitude of change
Sea Level Rise	To evaluate the magnitude of sea level rise relative to the ability of nearshore habitats to change	Low magnitude of change	High magnitude of change
Gulf Stream-Induced Upwelling	To evaluate changes in large scale circulation.	Low magnitude of change	High magnitude of change
Sensitivity Attributes			
Habitat Specificity	To determine, on a relative scale, if the stock is a habitat generalist or a habitat specialist while including information on the type and abundance of key habitats.	Habitat generalist	Habitat specialist
Prey Specificity	To determine, on a relative scale, if the stock is a prey generalist or a prey specialist.	Prey generalist	Prey specialist
Sensitivity to Temperature	To use the species geographic distribution as a proxy for temperature sensitivity. Species distributions more accurately predict thermal requirements than do stock distributions.	Wide temperature range	Narrow temperature range
Sensitivity to Ocean Acidification	To estimate a stock’s sensitivity to ocean acidification based on its relationship with “shelled species.” (followed Kroeker et al. 2012).	Stock not reliant on sensitive taxa	Stock is a sensitive taxa

Adult Mobility	To estimate the ability of the stock to move to a new location if their current location changes and is no longer favorable for growth and/or survival.	High mobility	Low mobility
Dispersal of Early Life Stages	To estimate the ability of the stock to colonize new habitats when/if their current habitat becomes less suitable.	High dispersal	Low dispersal
Early Life History Survival and Settlement Requirements	To determine the relative importance of early life history requirements for a stock.	Generalist with few requirements	Specialist with specific requirements
Complexity in Reproductive Strategy	To determine how complex the stock's reproductive strategy is and how dependent reproductive success is on specific environmental conditions.	Low complexity, broadcast spawning	High complexity, aggregation spawning
Spawning Cycle	To determine if the duration of the stock's spawning cycle could limit the ability of the stock to successfully reproduce if necessary conditions are disrupted by climate change.	Year-round spawning	One event per year
Stock Size/Status	To estimate stock status to clarify how much stress from fishing the stock is experiencing and to determine if the stock's resilience or adaptive capacity are compromised due to low abundance.	High abundance	Low abundance
Population Growth Rate	To estimate the relative productivity of the stock.	High population growth	Low population growth
Other Stressors	To account for conditions that could increase the stress on a stock and thus decrease its ability to respond to changes.	Low level of other stressors	High level of other stressors

Table 3. Definitions used by experts to score data quality for each biological sensitivity attribute and climate exposure factor. Each expert scored data quality independently resulting in 5 data quality scores for each sensitivity attribute and 4 data quality scores for each climate exposure factor.

Data Quality Score	**Description**
3	Adequate Data. The score is based on data which have been observed, modeled or empirically measured for the species in question and comes from a reputable source (e.g., peer-reviewed literature).
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 species, come from outside the study area or the reliability of the source may be limited.
1	Expert Judgement. The attribute score reflects the expert judgement of the reviewer and is based on their general knowledge of the species, or related species, and their relative role on the ecosystem.
0	No Data. No information to base an attribute score on. Very little is known about the species or related species and there is no basis for forming an expert opinion.

Table 4. Decision rule used to calculate species' overall biological sensitivity and climate exposure. A certain number of individual scores above a certain specified threshold trigger this decision rule, used to determine the overall biological sensitivity and overall climate exposure.

Overall Sensitivity or Exposure Score	**Numeric Score**	**Decision Rule**
Very high	4	3 or more factors with mean score ≥3.5
High	3	2 or more factors with mean score ≥ 3.0
Moderate	2	2 or more factors with mean score ≥ 2.5
Low	1	All other scores

Appendices

Appendix A. Sensitivity Attribute Definitions and Bins

Habitat Specificity

Goal: To determine, on a relative scale, if the stock is a habitat generalist or a habitat specialist while incorporating information on the type and abundance of key habitats.

Relationship to climate change: Generalists stocks should be more resilient to changing resource availability (habitat and food) than specialists (Wilson et al. 2008, Clavel et al. 2011, Graham et al. 2011, Pecl, 2014). This is because specialists are dependent on not only their own response to climate change, but also the impact on their habitat (EPA 2009). Note: the type and distribution of these habitats should be considered for this attribute.

Background: Changes in climate are expected to alter marine and coastal habitats that fish stocks depend upon. Species that are habitat generalists (can utilize several different habitat types) are expected to be more likely to succeed in a changing environment (Wilson et al. 2008, Clavel et al. 2011). The more a species specializes on a specific habitat, the more likely the species will be impacted by an environmental change. However, not all habitats are expected to be impacted equally. Species that depend on habitats that are abundant and wide ranging are less likely to be impacted by changes than species that depend on habitats that are limited in scope. We expect habitats that are created by disturbances (e.g., coral rubble or edge habitats) to increase with climate change. In addition, biological habitats (i.e., live coral reefs, deep water corals, mangroves, salt marshes, sea grass beds) are more likely to be impacted by the changes than physical habitats (sand, mud, rocky bottom). When considered together, these three criteria (habitat specialist or generalist; whether or not the stock depends on biological habitats; and habitat availability) are indicative of how a stock will be impacted by climate-induced changes on habitat.

How to use expert opinion: This attribute will be scored using a combination of the three criteria described above: habitat specialist or generalist; whether or not the stock depends on biological habitats (i.e., live coral reefs, deep water corals, mangroves, salt marshes, sea grass beds); and habitat availability (limited vs. abundant). It is understood that these criteria are not dichotomous but are a continuum. Stocks that are dependent on "disturbed" habitats should do fine or increase with climate change, so put these species in the "low" bin. If you think that a stock fits in multiple scoring bins, weight your 5 tallies between the appropriate bins. Using your expert opinion, account for any lifespan or ontogenetic shifts in diet; however, limit your response to the juvenile and adult life stages as larvae are considered under the attribute "early life history survival and settlement requirements."

Habitat Specificity Bins:

1. Low: The stock is a habitat generalist and/or utilizes very common abiotic habitats. Occurrences of the stock have been documented in diverse habitats. Also, included in this bin are stocks that are restricted to one abiotic habitat which is widespread and common (e.g., vast stretches of sandy bottom, or pelagic waters over a large range).

2. Moderate: The stock strongly prefers a particular habitat. The stock prefers a particular habitat, but can survive in other habitats (with possible impacts to their fitness).
3. High: The stock is a specialist on an abundant biological habitat. The stock is a specialist that is restricted to a specific, but common biological habitat.
4. Very High: The stock is a specialist on a restricted biological habitat. The stock is a specialist that is restricted to a specific and uncommon biological habitat.

Prey Specificity

Goal: To determine, on a relative scale, if the stock is a prey generalist or a prey specialist.

Relationship to climate change: Generalists stocks should be more resilient to changing resource availability (habitat and food) than specialists (Wilson et al. 2008, Clavel et al. 2011, Graham et al. 2011, Pecl et al. 2014). Understanding how reliant a stock is on specific prey species could predict its ability to persist as the climate changes. Specialists (who have specific prey requirements) are likely to be more vulnerable to climate change because their persistence is dependent on not only their own response to climate change, but also the response of their prey. During mass extinction events of the past, diet specialists were more prone to extinction than diet generalists (Clavel et al. 2011).

Background: Climate change impacts extend beyond the stock in question to include species within its food web (e.g., prey, predators and competitors).

How to use expert opinion: The scoring bins below estimate the stocks' relative distribution along a continuum that runs between prey specialists and prey generalists. Using your expert opinion, account for any lifespan or ontogenetic shifts in diet; however, limit your response to the juvenile and adult life stages as larvae are considered under the attribute "early life history survival and settlement requirements." For this attribute, prey type refers to groups of similar species; copepods, krill, forage fish, etc., for example, are each categorized as a prey type.

Prey Specificity Bins:

1. Low: The stock eats a large variety of prey. The stock can eat a variety of prey types depending on what is available. Include detritivores, herbivores, and omnivores in this bin.
2. Moderate: The stock eats a limited number of prey types. The stock can feed on a wide variety of prey species, but are restricted to a limited number (~3) of prey types (copepods, krill, forage fish, etc).
3. High: The stock is partial to a single prey type. The stock's diet is composed of one main prey type. The stock is able to switch to a different prey type if the preferred food is unavailable, but this may negatively impact fitness.
4. Very High: The stock is a specialist. The stock is dependent on one prey type and is unable to switch to alternatives if the preferred prey is unavailable.

Adult Mobility

Goal: To estimate the ability of the stock to move to a new location if their current location changes and is no longer favorable for growth and/or survival.

Relationship to climate change: Site-dependent species that are unable to move to better habitat when a location becomes unfavorable are less able to adapt to environmental change than highly mobile species (Foden et al. 2013).

Background: As climate change occurs, habitats that were once suitable may change and no longer be able to sustain a given stock of fish. Similarly, what was once unsuitable habitat may become suitable. A stock can survive changes in habitat as long as they have the ability to disperse from unsuitable habitat and find new, suitable habitat; and dispersal ability can be used as a proxy for the capacity to change distribution (Pecl et al. 2014). This can occur through larval dispersal and settlement (covered under the "Dispersal of Early Life Stages" attribute) or through adult mobility. Species can be limited in their mobility by physical or behavioral (e.g., won't swim across open ocean) barriers.

How to use expert opinion: This attribute represents a continuum from sessile to highly migratory organisms. Use your expert opinion to place the stock in question in the appropriate bin according to its physical and behavioral ability to move. Homing behavior for spawning should not be considered here as it is accounted for in the "Complexity in Reproductive Strategy" attribute. For this attribute, we define site-dependent stocks as those whose adults are site-attached (i.e., spend their entire adult phase in one limited location).

Adult Mobility Bins:

1. Low: Non-site dependent. The stock is highly mobile and non-site dependent.
2. Moderate: Site dependent but highly mobile. The stock has site-dependent adults capable of moving from one site to another if necessary.
3. High: Site dependent with limited mobility. The stock has site-dependent adults that are restricted in their movement by environmental or behavioral barriers.
4. Very High: Non-mobile. The stock has sessile adults.

Dispersal of Early Life Stages

Goal: To estimate the ability of the stock to colonize new habitats when/if their current habitat becomes less suitable.

Relationship to climate change: In general, the greater the dispersal of larvae, the better its ability to respond to climate change. Wide distribution of eggs and larvae can lead to greater ability to colonize new habitats in areas that are suitable for survival. Conversely, if a stock has limited larval distribution and the habitat in the localized area becomes unsuitable, then the stock is more likely to be negatively affected.

Background: For marine species, extended larval dispersal is an important strategy for colonizing new areas. Duration of the larval stage may impact dispersal distance and stock persistence. Jablonski and Lutz (1983) found that marine invertebrates with relatively long planktonic larval stages were more persistent in the fossil record than those species with non-planktonic larvae and had lower extinction rates. Early life stage dispersal is affected by a number of factors including spawning, advection, diffusion, larval behavior, planktonic duration, planktonic survival, and settlement habitat (Pineda *et al.* 2007; Hare and Richardson 2013). In general, studies have found that spawning time and place and planktonic duration are key factors, but the other factors can be important in specific situations.

How to use expert opinion: The main point of this attribute is to estimate dispersal ability. If no information is known about actual dispersal distances, capacity for larval dispersal can be estimated by a stock's larval duration (hatching to settlement in benthic species and hatching to yolk-sac re-absorption in pelagic species) (Pecl et al. 2014). However, if information about actual dispersal distances are known, use that information. If a stock has a relatively short larval duration, but is known to disperse large distances, or if the larvae are able to influence dispersal through selective tidal stream transport, adjust your tallies accordingly. Keep in mind that long-distance dispersal of only a small fraction of the larvae could still be adequate for colonization of new areas in a changing climate. We note that since elasmobranchs have evolved life history strategies that produce a smaller number of well-developed offspring, the impact of this attribute will be reduced: 1) for elasmobranchs with live birth, dispersal will occur while in utero and should be scored as low to moderate, 2) for elasmobranchs with egg cases, egg dispersal will be more limited, but juveniles will have the ability to disperse if needed so these stocks should be scored as moderate to high.

Dispersal of Early Life Stages Bins:

Larval durations utilized in Bins are adapted from Pecl *et al*. (2014); distances are provided on a log-scale to show general/large changes in magnitude.

1. Low: Highly dispersed eggs and larvae. Duration of planktonic eggs and larvae greater than 8 weeks and/or larvae are dispersed >100 km from spawning locations.
2. Moderate: Moderately dispersed eggs and larvae. Duration of planktonic eggs and larvae less than 8 but greater than 2 weeks and/or larvae are dispersed 10-100 km from spawning locations.
3. High: Low larval dispersal. Duration of planktonic eggs and larvae less than 2 weeks and/or larvae typically found over the same location as parents.
4. Very High: Minimal larval **dispersal.** Benthic eggs and larvae or little to no planktonic early life stages.

Early Life History Survival and Settlement Requirements

Goal: To determine the relative importance of early life history requirements for a stock.

Relationship to climate change: In general, the early life stages (eggs and larvae) of marine fish are characterized by high mortality rates, via predation, starvation, advection, or unsuitable conditions. Small changes in the environment can lead to large changes in early life survival, which can affect recruitment and year-class strength. Large scale climate change could have a greater impact on species that have more specific early life history and settlement requirements.

Background: Close to 100 years ago, fisheries scientists recognized the importance of recruitment variability in fish populations (Hjort 1914). Despite considerable research devoted to fisheries recruitment, there is still considerable uncertainty about how environmental variability impacts recruitment (Punt et al. 2013). Scientists now understand that multiple processes are important during the egg and larval stages (Houde 2008). Conditions that can lead to decreased or negligible recruitment include:

- Larvae that are dependent on specific biological conditions in the water column during their larval stage. For example, if the larvae are dependent on the presence of food at a specific point in development, different emergence of the larvae and the food (due to dependence on different cues) could result in a mismatch in availability. Alternatively, if the larvae have evolved to survive in low predator (and low food) conditions, a change in predation pressure could impact survival (Bakun 2010).

- Larvae or eggs that are dependent on specific physical conditions to survive (e.g., specific temperature requirements for eggs, temporary gyres that provide food and retention for larvae, calm conditions that allow for concentration of larval prey, specific transport pathways to nursery habitats, etc.) (Houde 2008).
- Larvae that are dependent on a cue for settlement or metamorphosis that could be impacted by a changing climate (Pecl et al. 2014).

For the purpose of this assessment, early life history requirements include the environmental conditions necessary for larval survival, and encompass the eggs, pelagic larvae stages, and settlement. The more specific the early life history requirements, the more precise the environmental conditions may need to be, and thus the more vulnerable the stock may be in a changing environment. Note: some fish species, namely elasmobranchs, have evolved life history traits which minimize or eliminate early life stages either by birthing well-developed young or by laying egg cases that allows embryos to fully develop before hatching. Therefore, elasmobranchs should be ranked as "Low."

How to use expert opinion: Marine species are largely dependent on both physical and biological conditions during their larval stage. However, the reliance on specific conditions varies between stocks. For the bins below, recruitment can be characterized as low variability when there is relatively constant recruitment events every 1-2 years, and high variability when the stock experiences highly episodic recruitment events (Pecl et al. 2014). If no citable reference is available on a stock's early life history survival and settlement, the score may be based on expert opinion.

Early Life History Survival and Settlement Bins:

1. Low: Larval requirements are minimal. Stock has general requirements for the larval stage that are relatively resilient to environmental change. Elasmobranchs should be ranked as "Low."
2. Moderate: Larval requirements are minimal or unknown. Stock requirements are not well understood and recruitment is relatively constant, suggesting limited environmental influence.
3. High: Larvae have some specific requirements. Stock requirements are not well understood, but recruitment is highly variable and appears to have a strong dependence on environmental conditions.
4. Very High: Larvae have multiple specific requirements. Stock has specific known biological and physical requirements for larval survival.

Complexity in Reproductive Strategy

Goal: To determine how complex the stock's reproductive strategy is and how dependent reproductive success is on specific environmental conditions.

Relationship to climate change: Species that have complex reproductive strategies (that require a series of events or special conditions) are more likely have these conditions disrupted by changes in the environment.

Background: There is great diversity in reproductive strategies in marine fishes. The more complex the reproductive strategy, the more precise the conditions may need to be, and thus the more vulnerable the stock may be to environmental change. For our purposes, complexity in reproductive strategy is defined as reproductive behaviors, characteristics or cues that create specific requirements that must be met in order for reproduction to be successful. Species with reproductive events that are dependent on temperature (vs. day-length) cues will be more sensitive to climate change (Pecl *et al*. 2014).

How to use expert opinion: A list of common reproductive characteristics that may affect the reproductive capacity of a stock in a changing climate is provided below. To score, determine if any of these examples apply to the stock. Note: this is not intended to be an exhaustive list. If other characteristics exist that may affect a stock's reproduction capacity in a changing climate, incorporate that information and adjust your score appropriately.

Example reproductive characteristics that create "complexity":

- The stock has known temperature effects on reproduction. Examples include temperature-dependent sex changes, and temperature cues that impact spawning, gonad development, etc.
- The stock uses large spawning aggregations. Large spawning aggregations can contribute to a high sensitivity because a large number of individuals must get to the spawning area simultaneously (i.e., migration or cues to migrate may be impeded by a change in the environment), the spawning area has to retain the environmental conditions that made it successful in the past, and the reproductive success for that year is dependent on the conditions present at one time period.
- The stock experiences decreased recruitment per spawner, or a weakening in the strength of density dependence, at low stock sizes, potentially because of depensation/Allee effects. If unknown, does the stock share life history characteristics that would predict depensation effects (e.g., significant changes in the relative abundance of the stock's predators/prey at low stock densities, decreased fertilization success at low stock sizes)?
- The reproductive success of the stock requires the use of vulnerable habitats (freshwater, estuaries, mangroves, salt marshes, corals) for spawning or rearing of young. Vulnerable habitats are likely to experience larger climate change impacts (such as changes in salinity, dissolved oxygen, pollution, sedimentation, or water depth), and **stocks that require these habitats for successful reproduction will likely be impacted.**

Complexity in Reproductive Strategy Scoring Bins: If a particular characteristic is suspected to have a large impact on the stock, adjust the score appropriately.

1. Low: Simple reproductive strategy. The stock contains no more than one characteristic that suggest complexity in reproductive strategy.
2. Moderate: Slight complexity. The stock has two characteristics that suggest complexity in reproductive strategy.
3. High: Complex reproductive strategy. The stock has three characteristics that suggest complexity in reproductive strategy.
4. Very High: Very complex reproductive strategy. The stock has four or more characteristics that suggest complexity in reproductive strategy.

Spawning Cycle

Goal: To determine if the duration of the spawning cycle for the stock could limit the ability of the stock to successfully reproduce if necessary conditions are disrupted by climate change.

Relationship to climate change: It is assumed that stocks that spawn throughout the year will be more likely to be successful in a changing environment: “Protracted spawning is believed to enhance offspring survival by allowing the stock to “hedge its bet” against adverse environmental conditions” (Marteinsdottir and Thorarinsson 1998). Conversely, stocks that spawn all at once in major events are more likely to experience recruitment failure with potential changes in environmental conditions.

Background: Spawning characteristics describe the spawning activity of a stock (in aggregate, not individually) over a particular time frame. If a stock spawns several times per year across a variety of seasons, then they will likely be less susceptible to climate change because their reproductive events are not dependent on just one set of very specific conditions (e.g., phenological events). Increased spawning events, also help to protect against vulnerabilities associated with single spawning aggregations (see the “Complexity in Reproductive Strategy” attribute). Similarly, stocks that reproduce seasonally are also less likely to adapt to climate change as they are dependent on environmental conditions historically present during a given season that may not persist through time. For example, spring-like conditions and related activities have occurred progressively earlier since the 1960s (Walther *et al*. 2002) and changes in spawning season and location have already been observed and predicted to continue (Shoji *et al*. 2011; Rijnsdorp *et al*. 2009). Note: We are describing the spawning activity of the entire stock, not the individual. In other words, we are interested in the time from when spawning commences until when it ends, not how long a single individual spawns.

How to use expert opinion: It is impossible to distill every potential spawning cycle into 4 scoring bins. The below bins are rough breaks in a continuum of possibilities. If a species does not fit the below bins, use your expert judgment to best score the species based on the above discussion. For stocks (such as elasmobranchs) that are born as fully developed juveniles capable of long distance movements, there is less concern over a short hatching/mating period, and these stocks should be ranked low to moderate.

Spawning Characteristics Bins:

1. Low: Consistent throughout the year. Stocks that spawn continuously throughout the year without a defined “spawning season” are less likely to suffer spawning failure. Example: a stock that spawns daily or monthly.
2. Moderate: Several spawning events throughout the year. Stocks that spawn several times per year and spawn across more than one season have a moderate likelihood of spawning success to be impacted by climate change. Example: a stock that spawns in both the spring and summer.
3. High: Several spawning events per year within a confined time frame. Stocks that may spawn several times per year but all spawning events in that year take place in one season have a higher likelihood of being affected by climate change. Example: the spawning season occurs once a year and lasts over a period of less than 3 months.
4. Very High: One spawning event per year. Stocks that require very specific environmental/social cues to initiate spawning and that only spawn once per year have the highest likelihood of being affected by climate change. Example: the spawning season occurs once a year over a brief period of time.

Sensitivity to Temperature

Goal: To use information regarding temperature of occurrence or the distribution of the species as a proxy for its sensitivity to temperature.

Relationship to climate change: Species that experience a wide range of temperature regimes are more likely to persist in a warming ocean.

Background: A species temperature requirements can be a good predictor of how it will respond to climate change. For species that lack specifics on temperature requirements, the latitudinal coverage of the species can be a proxy for temperature tolerance (Pecl *et al*. 2014). Since species can cover a wide tropical latitude but still have a limited temperature tolerance, distribution of a species within or across provinces can be used instead. Spalding *et al*. (2007) (Figure 2) divides coastal waters of the world into 62 provinces and 232 ecoregions. Even though Spalding's provinces are not specifically based on temperature (they also consider upwelling, currents, salinity, nutrients, etc.), they can be used to delineate areas with similar thermal conditions.

In addition, a species' distribution in the water column and seasonal movements can indicate its sensitivity to temperature. Species that make large diurnal migrations across the thermocline have lower sensitivities to changing temperatures than species that have limited depth distributions. Additionally, species that make large seasonal migrations and track seasonally changing water temperatures may have more sensitivity to temperature than indicated by range alone.

How to use expert opinion: Use known temperature requirements to score this attribute when available. When temperature information is not known, use the species distribution, along with Figure 1 to determine if a species is found across >1 province. Also use knowledge of seasonal and diurnal movements to adjust the tallies. Keep in mind that you can adjust your tallies depending on the distribution of the species relative to the area of interest (i.e., if the area of interest is at the edge of the distribution of the species, consider if the species is expected to move out of or expand into the area of interest). Spalding *et al*. (2007) only characterize coastal environments; therefore, use your expert opinion for open ocean species. If information about temperature requirements or depth distributions is available, use this to modify your response. For example, if a species is found across 2 provinces, but it has a limited depth distribution, the expert could distribute the 5 tallies between bins 2 and 3. If a species' sensitivity changes with ontogeny, consider the most limited stage when determining the most appropriate bin(s).

Given that a stock range will always be less than a species range, if scoring temperature dependence for a stock, consider not only the stock range, but also the species range as the species range may predict the stock's ability to adapt. Consideration of the species distribution relative to the study area is also important. Stocks at the cold edge of the species range would be expected to fare well, while stocks at the warm edge of its species range may not (Planque and Fredou 1999, Drinkwater 2005).

Temperature Sensitivity Bins:

1. Low: Large temperature range. Species occurs in a wide range of temperatures (>15ºC), or is found across 3 or more provinces.
2. Moderate: Moderate temperature range. Species occurs in a moderately wide range of temperatures (10-15ºC), or is found across 2 provinces.
3. High: Somewhat limited temperature range. Species occurs in a moderately narrow range of temperatures (5-10ºC), or is found within one province but has a variable depth distribution.

4. Very High: Very limited temperature range. Species occurs in a narrow range of temperatures (<5ºC), or is found within one province and has a limited depth distribution (i.e., depth range is <100 m).

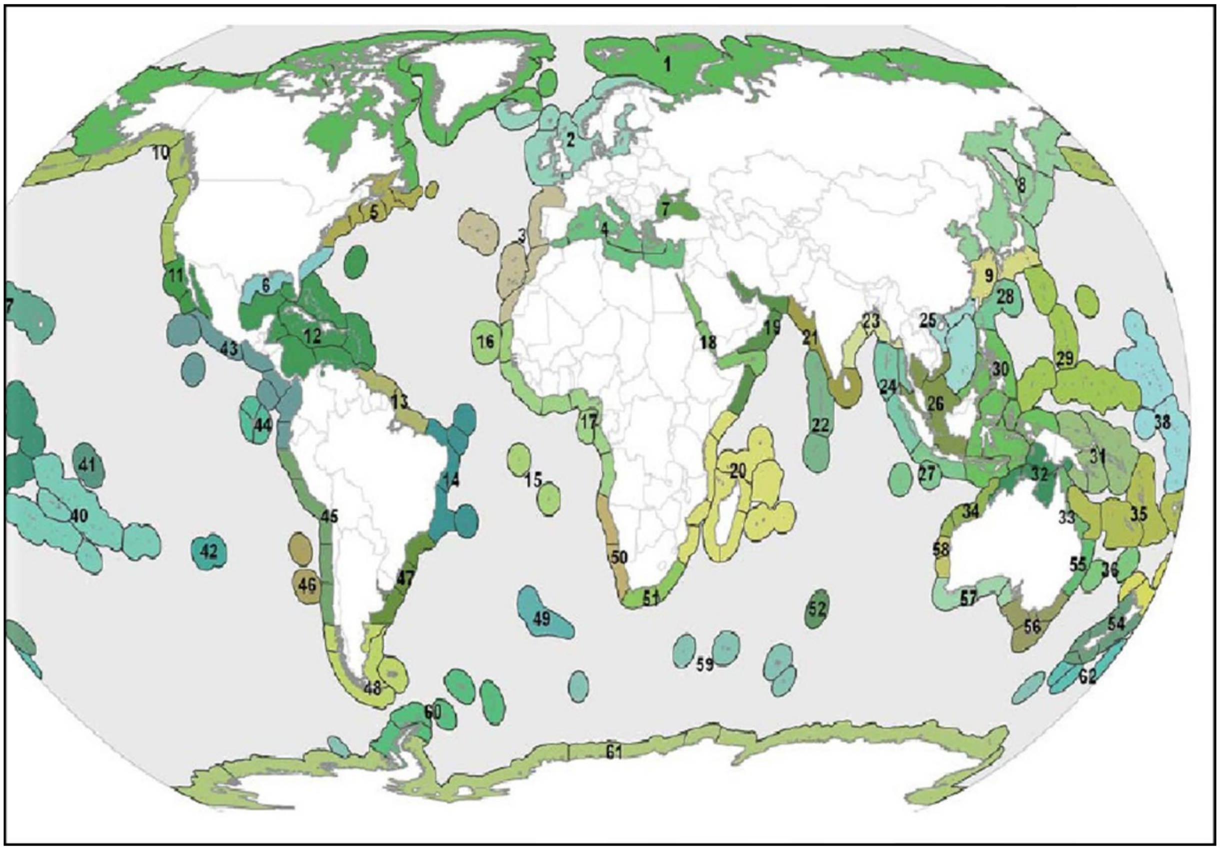


Figure originally published in Spalding et al. 2007. Provinces are provided in color with ecoregions outlined.

Sensitivity to Ocean Acidification

Goal: To estimate a stock's sensitivity to ocean acidification (OA) based on its relationship with "sensitive taxa."

Relationship to climate change: Impacts of OA on marine organisms can be highly variable, with considerable variability between taxa and species (Kroeker *et al*. 2013). Therefore, we are estimating impact of OA by examining the dependence of the stock on sensitive taxa. For example, current research shows a consistent negative impact of OA on mollusks and corals, so species in either of these classes or dependent on species in these classes should be considered more sensitive to changes in ocean pH. We expect the volume of research into ocean acidification to increase in the near future, so this attribute will be updated as new information becomes available.

Background: Ocean acidification is often called "the other carbon dioxide problem," and is the term given to the chemical changes in the ocean as a result of carbon dioxide emissions (Wicks and Roberts 2012). While initial research suggested that the majority of species that have calcium carbonate or chitin shells or those that lay down calcium carbonate skeletons (corals) will be negatively impacted by ocean acidification (Arnold *et al*. 2009; Hoegh-Guldberg *et al*. 2007; Honisch *et al*. 2012; Kawaguchi *et al*. 2011; Orr *et al*. 2005), recent studies have highlighted a high variability in response between different shelled organisms and suggest that not all shelled species will be impacted to the same degree and not all impacts will be negative. (i.e., Ries *et al*. 2009; Kroeker *et al*. 2013). For example, Kroeker *et al*. (2013) in a meta-analysis of 228 studies found significant and consistent negative impacts of OA on the larval stages of mollusks and corals (see Figure 4 from Kroeker *et al*. below). However, recent research suggests soft corals may not be as sensitive as stony corals (Gabay et al. 2014) In contrast, high variability in the responses of crustaceans suggests impacts may be species specific within this group, with brachyuran crustaceans showing a higher resistance (Kroeker *et al*. 2013).

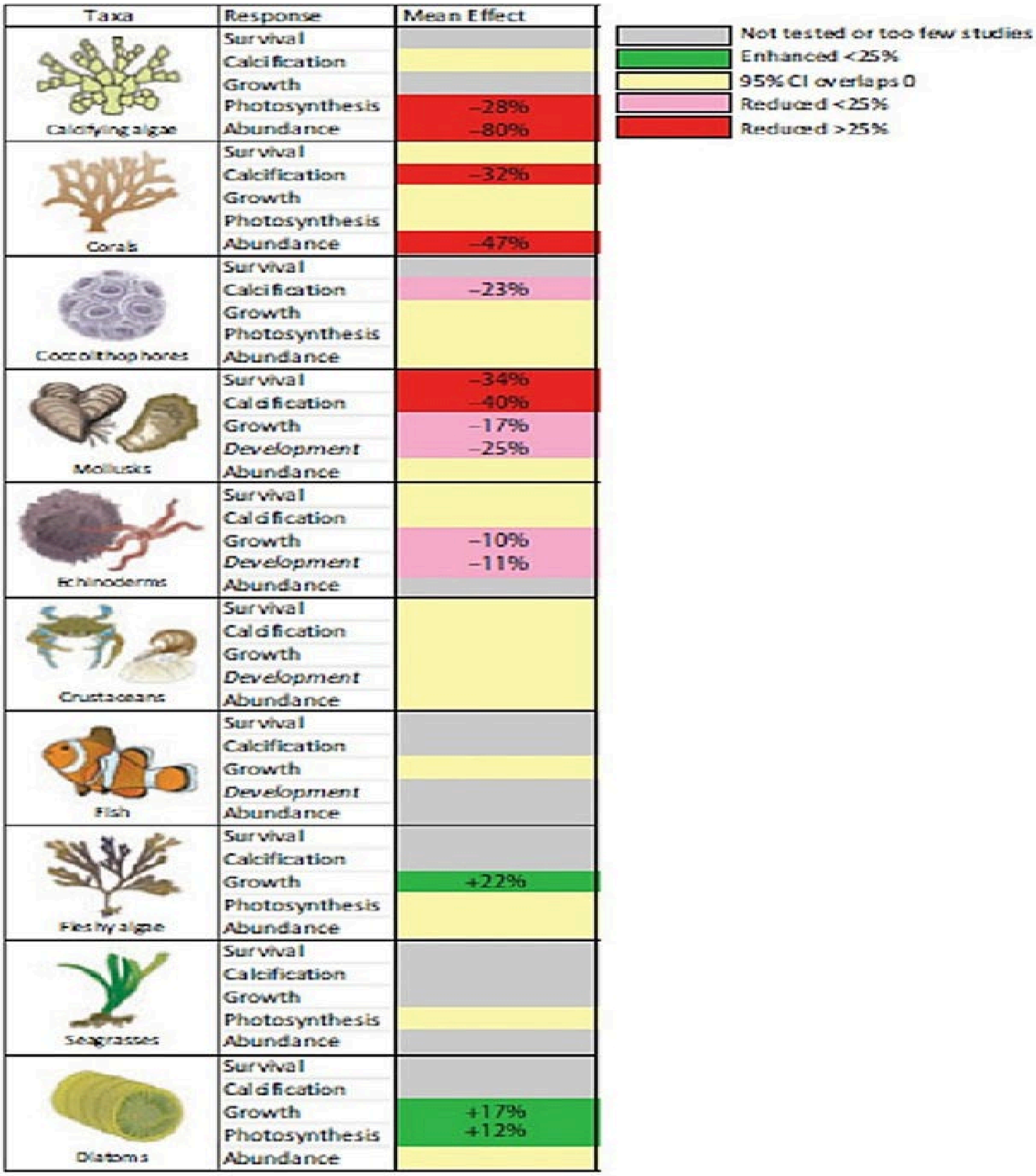
The direct effect of ocean acidification on finfish is not well understood. Recent research suggests impacts on finfish stocks will be most prevalent at the egg and early larval stages (Baumann *et al*. 2011; Franke and Clemmenssen 2011; Frommel *et al*. 2011), but juvenile and adult olfaction and behavior may also be affected (Munday *et al*. 2009; 2014). Despite these studies, not enough is known to be able to predict which finfish stocks will be more sensitive. This attribute will be updated when more information is available on which finfish stocks are more likely to be directly impacted by ocean acidification.

How to use expert opinion: Use the results presented in Figure 1 (originally published as Fig. 4 in Kroeker *et al*. 2013) or other relevant information to bin species. When scoring, base your score on the most sensitive life stage, if appropriate. In cases where research has shown that the effects of OA may be positive or mitigated by biological processes (e.g., reduced OA by plant absorption of CO_2), use your expert judgment to inform the score. We have binned sensitive taxa which are directly impacted by changes in OA as “very high” and those dependent on sensitive taxa as “high” due to the indirect impact. However, use your expert opinion to place your tallies between these groups depending on your perception of the species’ adaptability.

Sensitivity to Ocean Acidification Bins:

Sensitive taxa are taxa that consistently show negative effects from OA, such as hard corals, mollusks, calcified algae, and echinoderms (Kroeker *et al*. 2013).

1. Low: Stock either does not use sensitive taxa, or is expected to respond positively to ocean acidification. The stock does not utilize sensitive taxa for food or habitat. Species expected to respond positively to ocean acidification should be scored as low.
2. Moderate: Stock is somewhat reliant on sensitive taxa. The stock utilizes sensitive taxa as either food or habitat, but can switch to non-sensitive taxa when necessary. This can include omnivores and species that prefer coral habitats but can utilize any rigid structure.
3. High: Stock is reliant on sensitive taxa. The stock is dependent on sensitive taxa for either food or habitat (i.e., cannot switch to a non-sensitive alternative).
4. Very High: Stock is a sensitive taxa. The stock is a sensitive taxa (such as corals or mollusks) that have been shown to have a consistent negative impact of OA on survival.



Taxa	Response	Mean Effect
Calcifying algae	Survival	▨
	Calcification	🟨
	Growth	▨
	Photosynthesis	🟥 −28%
	Abundance	🟥 −80%
Corals	Survival	🟨
	Calcification	🟥 −32%
	Growth	🟨
	Photosynthesis	🟨
	Abundance	🟥 −47%
Coccolithophores	Survival	▨
	Calcification	🟪 −23%
	Growth	🟨
	Photosynthesis	🟨
	Abundance	🟨
Mollusks	Survival	🟥 −34%
	Calcification	🟥 −40%
	Growth	🟪 −17%
	Development	🟪 −25%
	Abundance	🟨
Echinoderms	Survival	🟨
	Calcification	🟨
	Growth	🟪 −10%
	Development	🟪 −11%
	Abundance	▨
Crustaceans	Survival	🟨
	Calcification	🟨
	Growth	🟨
	Development	🟨
	Abundance	🟨
Fish	Survival	▨
	Calcification	▨
	Growth	🟨
	Development	▨
	Abundance	▨
Fleshy algae	Survival	▨
	Calcification	▨
	Growth	🟩 +22%
	Photosynthesis	🟨
	Abundance	🟨
Seagrasses	Survival	▨
	Calcification	▨
	Growth	▨
	Photosynthesis	🟨
	Abundance	▨
Diatoms	Survival	▨
	Calcification	▨
	Growth	🟩 +17%
	Photosynthesis	🟩 +12%
	Abundance	🟨

▨ Not tested or too few studies
🟩 Enhanced <25%
🟨 95% CI overlaps 0
🟪 Reduced <25%
🟥 Reduced >25%

Figure originally published in Kroeker *et al*. 2013: Summary of effects of acidification among key taxonomic groups. Effects are represented as either mean percent (+) increase or percent (-) decrease in a given response. Percent change estimates were back transformed from the mean *LnRR*, and represent geometric means, that are conservative of the arithmetic means.

Population Growth Rate

Goal: To estimate the relative productivity of the stock.

Relationship to climate change: More productive stocks are, in general, more resilient to long term changes in the environment, such as climate change (Lande 1993; Pecl et al. 2014).

Background:

Productivity is a measure of the capacity of the stock to reproduce and recover if the population is reduced. In general, it is thought that highly productive stocks are more resilient to change because they are quicker to respond to impacts, such as fishing, or catastrophic events (Lande 1993; Pecl et al. 2014). In fisheries, productivity can be measured as the maximum intrinsic rate of increase (r_{max}). We are interested in the maximum intrinsic rate of increase as it describes how fast a population is able to recover from a disturbance. Given density dependence, the classic model of population growth can be given by: $\frac{\partial N}{\partial t} = r_{max} N \left(1 - \frac{N}{K}\right)$, where K is carrying capacity and for which population growth rate is maximized at 0.5K.

If a direct measurement of the maximum intrinsic rate of increase (r_{max}) is unavailable, other biological reference points that are correlated with population growth rate can be used: von Bertalanffy growth rate (k), age at maturity, maximum age, natural mortality and maximum length (Patrick *et al*. 2009; Hutchings et al. 2012). Scoring bins for these proxies were developed from an analysis of 141 marine fish species that were considered to be representative of U.S. fisheries (Patrick *et al*. 2009).

How to use expert opinion: Multiple proxies may be used to inform the final score, but the accuracy and precision of the different proxies should be considered. For example, a stock with a "good" estimate of age at maturity is in the range for a "High" score, and a "fair" estimate of maximum age is in the range for the "High" scoring bin. In that case, the scorer should use their expert opinion to weight their response according to their confidence in the estimates. If no estimates are available, estimate a relative score for the stock across a continuum of r-selected (low) vs. k-selected (high) species.

Population Growth Rate Bins:

Parameter	Low	Moderate	High	Very High
Maximum growth rate (r_{max})	> 0.50	0.16 - 0.50	0.05 - 0.15	< 0.05
von Bertalanffy K	> 0.25	0.16 - 0.25	0.11 - 0.15	<= 0.10
Age at maturity	< 2 yrs	2 - 3 yrs	4 - 5 yrs	> 5 yrs
Maximum age	< 10 yrs	11 - 15 yrs	15 - 25 yrs	> 25 yrs
Natural mortality (M)	> 0.50	0.31 - 0.50	0.21 - 0.30	< 0.2
Maximum length	< 55 cm	55 – 85 cm	85 – 150 cm	> 150cm

Stock Size/Status

Goal: To estimate stock status to clarify how much stress from fishing the stock is experiencing and to determine if the stock's resilience or adaptive capacity are compromised due to low abundance.

Relationship to climate change: It is assumed that a stock that has a large biomass is more resilient to changes in climate. Conversely, stocks with very low biomass are likely to be in a compromised ecological position and therefore may have a diminished capability to respond to climate change (Rose 2004). The genetic diversity, as well as the abundance, of a stock can impact its susceptibility. The assumption is that species with a limited genetic diversity could be more negatively impacted by climate change as their offspring would be less variable and thus less likely to have the combination of genes needed to adapt to changes in the environment.

Note: stocks that are at historical high biomass levels may be an indication of a net positive effect to an environmental change.

Background: Fish stocks that are already being affected by other stressors are likely to have faster and more acute reactions to climate change. Fishing is the largest stressor currently impacting fish stocks (Jackson *et al*. 2001), and the magnitude of the stress can be estimated through the status of the stock. Stock size/status can be measured as a ratio of the current stock size (B) over the biomass at maximum sustainable yield (B_{MSY}) and is a commonly used biological reference point for U.S. federally managed stocks. For other areas, B_{max} may be available and can also be used. Use the following link for information on current estimates of B/B_{MSY} in U.S. species: http://www.nmfs.noaa.gov/sfa/statusoffisheries/SOSmain.htm.

Low genetic variation can decrease a species' ability to adapt to climate change. Large variation in reproductive success between individuals, large fluctuations in population size, and frequent local extinctions can all decrease genetic diversity (Grosberg and Cunningham 2001). Presence of these characteristics could suggest a decreased ability to adapt to changes in the environment.

Beyond stock status and genetic diversity, there are additional concerns for stocks that are particularly rare. The IUCN classifies stocks with a population <10,000 mature individuals as vulnerable (IUCN 2014). Therefore, for the purposes of this attribute, stocks with population sizes less than 10,000 individuals are considered to have significantly reduced ability to adapt to climate change and should be scored as "Very High."

How to use expert opinion: If a direct measure of biomass is not available, biomass proxies (such as survey indices or spawning stock biomass) may be used. For data-poor stocks with an unknown status, or stocks that are analyzed as part of a species group, use your expert opinion to estimate the stock size and rate the data quality accordingly. We note that B_{MSY} can change (NEFSC 2012), which will affect B/B_{MSY} ratio and thus vulnerability scores. In situations where B_{MSY} has been recently updated, use your expert opinion to adjust your scores appropriately. Also, if a stock has known low genetic diversity, adjust your ranks accordingly.

Stock Size/Status Bins:

1. Low: $B/B_{MSY} \geq 1.2$ (or proxy)
2. Moderate: $B/B_{MSY} \geq 0.8$ but < 1.2 (or proxy)
3. High: $B/B_{MSY} \geq 0.5$ but < 0.8 (or proxy)
4. Very High: $B/B_{MSY} < 0.5$ (or any stock below <10,000 mature individuals)

Other Stressors

Goal: To account for conditions that could increase the stress on a stock and thus decrease its ability to respond to changes.

Relationship to climate change: In most cases but not all, climate change is predicted to exacerbate the effects of other stressors. Fish stocks that are already being affected by other stressors are likely to have faster and more acute reactions to climate change.

Background: Scientists theorize that species experiencing additional stressors are more likely to have faster and more acute reactions to climate change (Stein et al. 2013, Sumaila et al. 2011). A stress is an activity that induces an adverse effect and therefore degrades the condition and viability of a natural system (Groves *et al*. 2000; EPA 2008). This attribute attempts to take into account interactions between climate change and other stressors already impacting fish stocks. Some examples of other stressors include: habitat degradation, invasive species, disease, pollution, and hypoxia. Although climate change is not currently the biggest threat to many natural systems, its effects are projected to be an increasingly important source of stress in the future (Mooney *et al*. 2009). Consideration of observed and projected impacts of climate change in the context of other environmental stressors is essential for effective planning and management (Tingley et al. 2014).

How to use expert opinion: For the purpose of this assessment, we are looking for detrimental impacts from other stressors. We have provided examples of other stressors that may be impacting stocks, but the list is not exhaustive. If the stock being scored is suffering from a known or suspected stressor that is not listed below, adjust the score appropriately. The magnitude of the stressors should also be considered. If a single stressor is suspected of a large impact on the stock, adjust the score appropriately. It is expected that in some cases, impacts of climate change could create positive impacts (e.g., reduction in predators). If you suspect positive impacts, adjust tallies toward the lower bins as appropriate. We are not including fishing pressure as a stressor here as it is covered under the "stock size/status" attribute.

Example of stressors the stock may be experiencing:

- The habitat on which the stock depends is degraded. Examples include anthropogenic effects or changes to freshwater input, stratification, storm intensity, and hypoxia.
- The stock is currently exposed to detrimental levels of pollution (chemical and/or nutrient).
- The stock has experienced a known increase in parasites, disease, or harmful algal bloom exposure.
- The stock has experienced a detrimental impact due to a change in the food web. Examples include increases in the abundance of predators or competitors, or the introduction of an invasive species that negatively impacts the stock. Do not include changes to prey here as they are covered under the "prey specificity" attribute.

Other Stressors Bins: If a single stressor is suspected of a large impact on the stock, adjust the score appropriately.

1. Low: Stock is experiencing no known stress other than fishing. Stock is experiencing no more than one known stressor.
2. Moderate: Stock is experiencing limited stress other than fishing. Stock is experiencing no more than two known stressors.

3. High: Stock is experiencing moderate stress other than fishing. Stock is experiencing no more than three known stressors.
4. Very High: Stock is experiencing high stress other than fishing. Stock is experiencing four or more known stressors.

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Appendix B. Sea Level Rise Exposure in the United States South Atlantic

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 6,000-7,000 years (Donahue 2011, Blum and Roberts 2009), 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 in Georgia and the Carolinas, due to high wave exposure, a low-relief coastal slope, and abundance of barrier islands, with North Carolina displaying one of the highest vulnerabilities to sea level rise on the Atlantic coast (Ellin et al. 2013; 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 (up to 50 mm/yr) than 3.4 mm/yr (Sweet et al. 2017a). Coupled with changing extreme rainfall events, sea level rise is threatening a rapidly growing population, critical industries, and a significant tourism economy in the US Southeast (Carter et al. 2018).

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 (Craft et al. 2009, Morris et al. 2002, Short and Neckles 1999, Duarte 2001, Nichols et al. 1999, 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 US South Atlantic is largely characterized by low relief coastlines that typically experience relatively small 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 tidal 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.

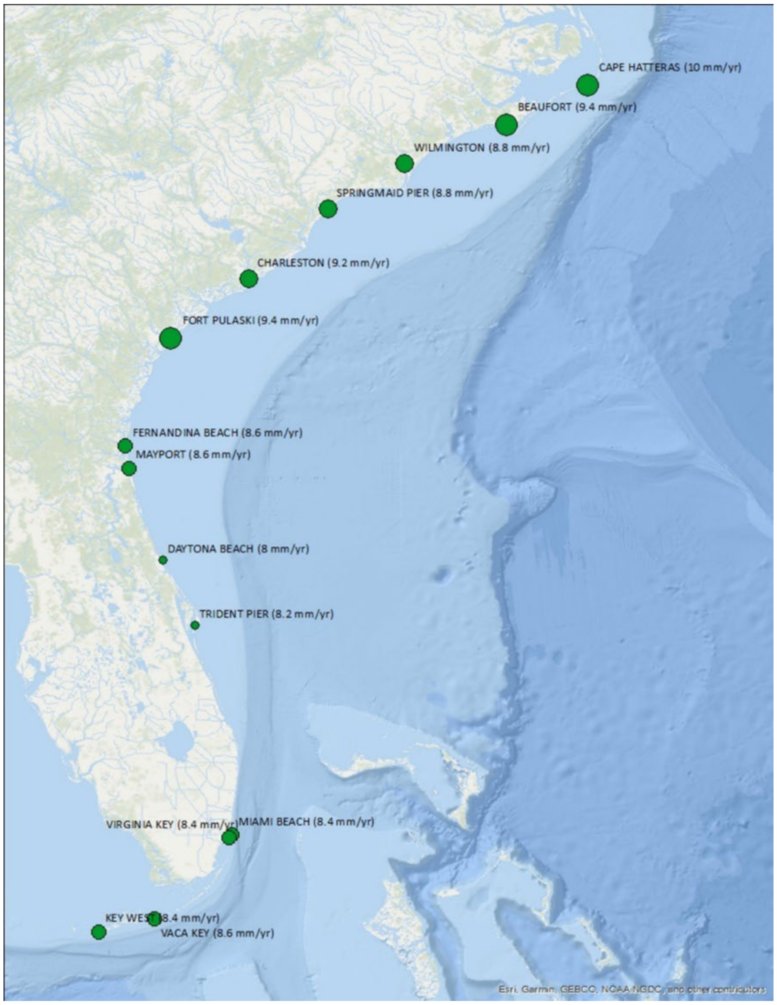

Figure 1. Mean rates of relative sea level rise across the United States South Atlantic from 2000-2050. Relative sea levels are rising across the U.S. South Atlantic with highest rates in the Carolinas, where vast low-lying coastal areas are particularly susceptible to sea level rise that may be affected by land subsidence and changes in oceanographic circulation (Carter et al. 2018).

Table 1 - Relative sea level rise trends for select tide gauge stations in the Southeast U.S. Atlantic Coast (listed north to south). The second column corresponds to the projected relative sea level rise by the year 2050 (based on the Intermediate-Medium scenario; baseline year 2000). The third column represents the projected average rate of sea level rise per year presented in Sweet et al. (2017b).

Tide Gauge Station	Total Projected Relative Sea Level Rise by 2050 (mm)	Mean Relative Sea Level Rise Rate (mm/year) 2000-2050
Cape Hatteras	500	10.0
Beaufort	470	9.4
Wilmington	440	8.8
Springmaid Pier	440	8.8
Charleston I	460	9.2
St. Georges	360	7.2
Fort Pulaski	470	9.4
Fernandina Beach	430	8.6
Mayport	430	8.6
Daytona Beach	400	8.0
Trident Pier	410	8.2
Miami Beach	420	8.4
Virginia Key	420	8.4
Vaca Key	430	8.6
Key West	420	8.4
Cape Hatteras	500	10.0
Beaufort	470	9.4
Wilmington	440	8.8
Springmaid Pier	440	8.8
Charleston I	460	9.2
St. Georges	360	7.2
Fort Pulaski	470	9.4
Fernandina Beach	430	8.6
Mayport	430	8.6
Daytona Beach	400	8.0
Trident Pier	410	8.2
Miami Beach	420	8.4
Virginia Key	420	8.4
Vaca Key	430	8.6
Key West	420	8.4

Scoring Exposure to Sea Level Rise

Recent research suggests that sea level rise is increasing across the US South Atlantic and particularly in Georgia and the Carolinas (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.

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 within 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 within 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 within their range are 9 or more mm/year.

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Appendix C. Gulf Stream-Induced Upwelling Exposure Factor

The southeast Atlantic Ocean and coastal region of the United States encompasses a large area from Cape Hatteras, North Carolina to Key West, along the Straits of Florida. The width of the continental shelf (< 100 m deep) varies across the region, ranging from about 10 km in southern Florida to 50 km off Cape Canaveral, Florida to over 120 km off Georgia. This region is identified as a Large Marine Ecosystem (LME) and has a surface area of about 300,000 km^2. As a whole, the Southeast U.S. Continental Shelf LME is considered a moderately productive Class II ecosystem (150-300 gCm-2yr-1; Aquarone 2009), largely due to the interactions between the Gulf Stream and continental shelf waters, as well as substrate types. Substrates on the continental shelf and shelf-break consist primarily of sand and mud substrates, with patches of hard, rocky temperate reefs scattered throughout the region (Miller & Richards 1980; Schobernd & Sedberry 2009). Tropical coral reefs also occur off southeastern Florida and the Florida Keys, with associated diverse fish communities, and deep-water coral pinnacles range from Florida to North Carolina (Lumsden et al. 2007).

The Gulf Stream, a powerful ocean current, is the dominant oceanographic feature that strongly influences the oceanographic and temperature dynamics of the outer (40 m – shelf break) continental shelf waters. It originates off south Florida, bringing warm water northward along the southeast coast of the U.S., and its meanders and warm and cold core eddies significantly affect the physical oceanography of the continental shelf and slope. These features also tend to aggregate prey and predators, and are frequently targeted by commercial and recreational fishing activities. The warming influence of the Gulf Stream allows tropical and subtropical species to inhabit areas as far north as North Carolina (Miller & Richards 1980), especially in deeper water (Whitfield et al. 2014). The inner (0-20 m) and middle (20-40 m) shelves are dominated by 18 estuaries, including the Albemarle-Pamlico Sound (the second largest estuary in the nation) and Indian River Lagoon, river systems, and their runoff; local winds; and Gulf Stream eddies (Atkinson et al. 1985; Lee et al. 1991). Even so, the southeast U.S. Atlantic continental shelf is characterized by relatively low freshwater input as compared to other regions of the U.S. and lacks a nutrient rich water mass, such that inorganic nitrogen rarely accumulates in resident shelf waters (Yoder 1991). The mid-shelf current flow is strongly influenced by local wind events with frequencies of two days to two weeks. Vertically well-mixed conditions are present in fall and winter, in contrast with vertically stratified conditions in the spring and summer.

The primary source for delivery of nutrients to the southeast U.S. continental shelf waters is the Gulf Stream. The Gulf Stream is a nutrient stream, transporting macronutrients (nitrate, phosphate, silicate) necessary for marine phytoplankton growth along the eastern continental margin of the United States from the Straits of Florida to Cape Hatteras at globally significant rates (Whitt 2019). Gulf Stream induced upwelling events of nutrient-rich North Atlantic Central Water (NACW) occur approximately every ten days, related to the strength and position of the Gulf Stream and upwelling-favorable winds (Atkinson 1977, Lee & Atkinson 1983, Hyun & He 2010). Winter and spring conditions affecting wind and the density of shelf water usually inhibit the NACW from penetrating beyond the outer shelf. In contrast, summer wind conditions and warmer, less dense shelf waters are more favorable to allow penetration of NACW shoreward as a bottom intrusion of the outer and middle shelf, and the narrow inner shelf off Florida (Yoder et al. 1985; Yoder 1991). Upwelling typically occurs when the Gulf Stream is more intensive (higher flow), located closer to shore, and southwest winds are consistently strong, causing deep, cold, nutrient-rich waters to replace surface waters that have been pushed northward and eastward (Aretxabaleta et al. 2006; Hyun & He 2010). The nutrient rich, cold NACW bottom intrusions give rise to plankton blooms and are the most important processes affecting summer plankton productivity where they occur (Yoder 1991). Plankton blooms, in turn, can affect life history processes at higher trophic levels such as fish larval development (Yoder 1983) and spawning (Checkley et al. 1988). Upwelling can also occur as Gulf Stream waters are deflected when encountering topographic features, such as the Charleston Bump (a bathymetric rise to 375 m on the continental slope from the relatively flat, >700 m depths of the Blake Plateau), resulting in permanent meanders, eddies, and persistent upwelling (Blanton et al. 1981; Atkinson & Targett 1983; Govoni & Hare 2001). In addition to the Charleston Bump, eddies are known to propagate in this fashion in the southeast region off Miami, and downstream of Cape Canaveral. Upwelling and onshore transport in the cold core of frontal eddies pumps new nutrients from deep waters 500-700 m beneath the Gulf Stream directly onto the outer shelf and into the euphotic zone in cold, subsurface intrusions (Atkinson & Targett 1983; Lee et al. 1991). Pitts (1999) found high abundances of fish and crustacean larvae in cold upwelled water off central Florida and suggested that upwelling may play an important role in advecting larvae to the inner shelf and adjacent estuaries where settlement can occur. Govoni & Hare (2001) and Govoni et al. (2013) suggested that the upwelling, nutrient rich waters associated with eddies formed at the Charleston Bump enhance primary production and zooplankton assemblages, serve as nursery areas by providing a rich food supply for larval fishes spawned in or entrained into eddies, and can translocate larval fishes across the shelf.

The Gulf Stream is part of the upper north-flowing limb of the Atlantic Meridional Overturning Circulation (AMOC), a large scale circulation system that influences the oceanography of the southeastern U.S. Atlantic. The AMOC has played a role in rapid climate change in the geologic past, and is known to not only influence the North Atlantic and surrounding landmasses, but also the Earth's climate (Srokosz & Bryden 2015; Buckley & Marshall 2016; Caesar et al. 2018; Zhang et al. 2019). In the Atlantic Ocean, the AMOC carries warm, near-surface waters (via the Gulf Stream) into far-northern latitudes and returns cold deep waters southward into the South Atlantic (Ezer et al. 2013; Praetorius 2018; Whitt 2019). The AMOC is a major transporter of heat from the tropics into the North Atlantic, and changes in the AMOC are predicted to impact the volume transport of the Gulf Stream and have profound implications for climate change (Bryden et al. 2005; Ezer et al. 2013; Smeed et al. 2014; Caesar et al. 2018).

There is limited information on large-scale patterns of environmental change that can be attributed to climate change in the southeastern U.S. Atlantic region, due in part to incomplete region-wide ocean observing systems and limited knowledge on the influence of natural

long-term variability (Hoegh-Guldberg et al. 2014). The Gulf Stream appears to be weakening along with the broader, related AMOC (Srokosz & Bryden 2015; Rahmstorf et al. 2015; Caesar et al. 2018; Smeed et al. 2018; Jackson et al. 2019), and future climate change scenarios predict further weakening (Liu et al. 2017), which may have implications for regional primary and secondary productivity patterns if it results in declines in the magnitude, duration or frequency of Gulf Stream-related upwelling events.

Scoring Exposure to Gulf Stream-Induced Upwelling:

Ideally, exposure is scored as the overlap between a species' distribution and the magnitude of the expected climate change. Unfortunately, due to high uncertainty associated with how climate change will impact ocean circulation, we do not have maps showing the magnitude of the expected change to the AMOC and Gulf Stream. However, the description provided above suggests that the following assumptions are reasonable under future climate change scenarios: 1) the AMOC and Gulf Stream are predicted to lose strength (decreased flow), 2) resulting in fewer eddies and meanders, and 3) decreased upwelling associated with eddies, meanders, and topographic deflections (e.g., Charleston Bump). Therefore, we might expect those species with life history characteristics that tend to reside primarily on the inner shelf to experience a lower magnitude of change, and species with life history characteristics that result in time spent on the middle or outer shelf (where proximity to the Gulf Stream and upwelling are more pronounced) to experience a higher magnitude of change. Use your expert knowledge of a species' distribution to determine where overlap with the Gulf Stream occurs. Species that have a high overlap with the Gulf Stream and upwelling should have a higher exposure score than species that have a low overlap with the Gulf Stream and upwelling.

Descriptions of low (1) and high (4) exposure are provided as bookends of a continuum. Use your tallies across all four bins to represent your expert opinion of how much the species will be exposed to changes in Gulf Stream-induced upwelling. For example, if a stock spends some of its life cycle in an area with nearshore currents and partially outside this area, it should be scored between a 1 and 4. If a species has a particular critical life stage, experts can weight their scores based on the areas where critical life stages occur.

> 1) Low: Score stocks as low if their distributions overlap almost exclusively with inner shelf conditions.
>
> 4) High: Score stocks as high if their distributions overlap almost exclusively with conditions on the middle or outer continental shelves, where changes in Gulf Stream transport, eddy propagation, and upwelling are expected to be experienced.

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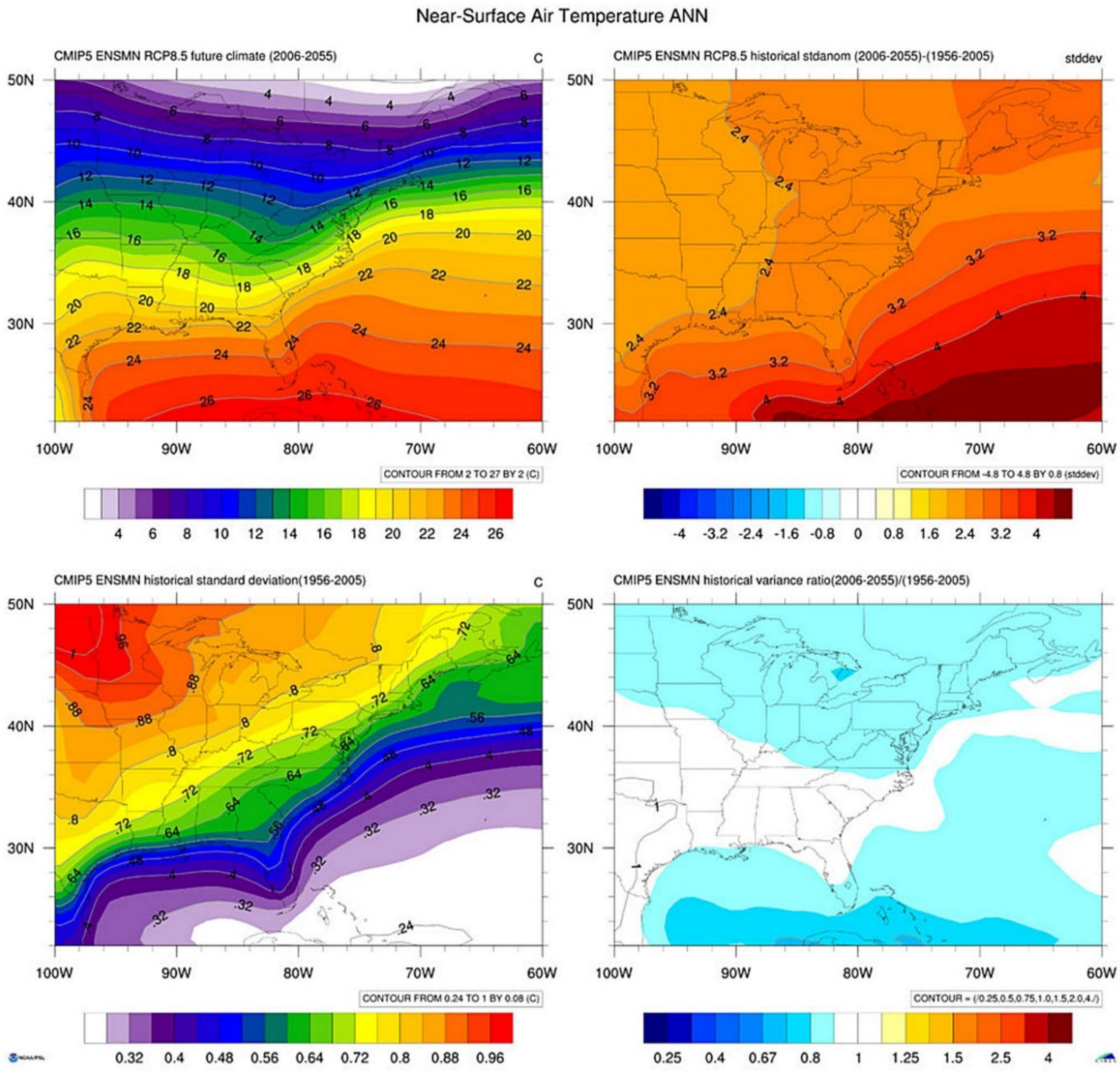
Appendix D. Climate model outputs for the five quantitative exposure factors used in the CVA: Air Temperature, Sea Surface Salinity, Sea Surface pH (proxy for Ocean Acidification), Sea Surface Temperature, and Precipitation.

Outputs in the pages that follow are from the Earth Systems Research Laboratory Data Portal. Modeling was done using the RCP 8.5 scenario. Variable plots presented are:

> Upper left panel – Mean climate from the model for the historical experiment for the period 1956-2005.
>
> Upper right panel – Difference in the mean climate in the future time period (2006-2055) compared to the historical reference period (1956-2005). The anomaly is standardized by the de-trended interannual standard deviation for the historical reference period (1956-2005).
>
> Lower left panel – Interannual (detrended) standard deviation for the historical reference period (1956-2005).
>
> Lower right panel – Ratio of the de-trended variance in the future (2006-2055) divided by the past (1956-2005).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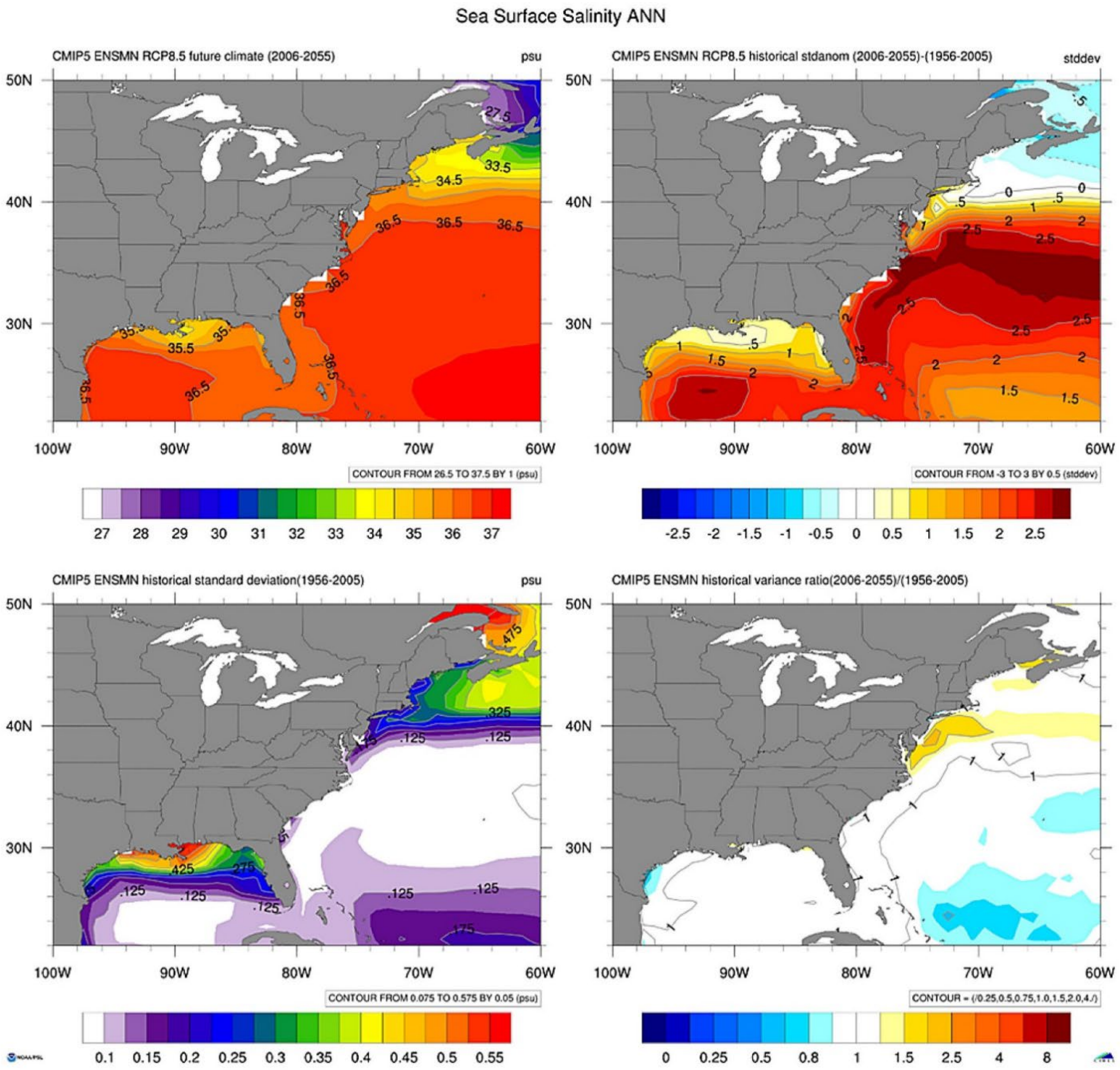
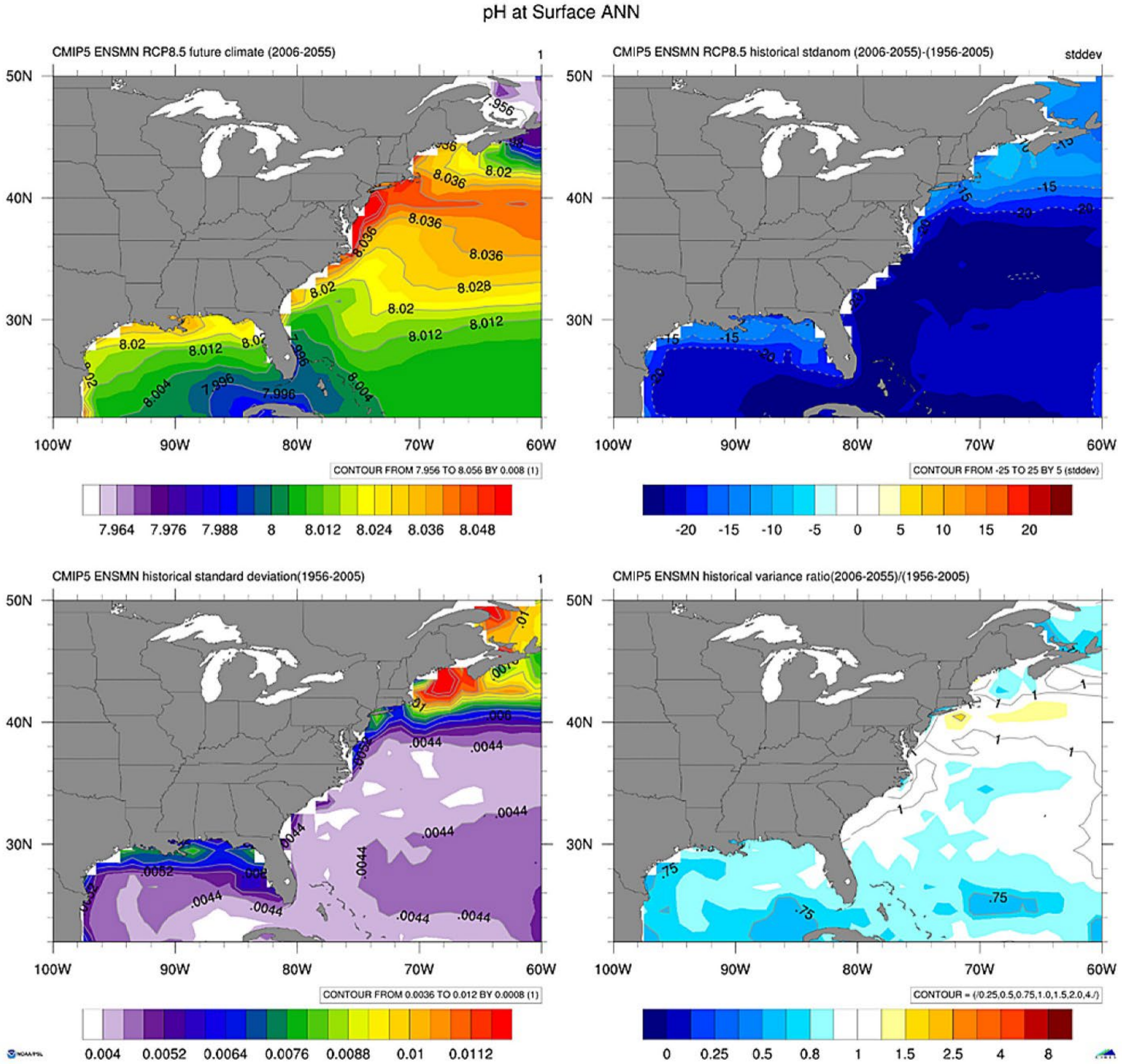
CMIP5 ENSMN RCP8.5 future climate (2006-2055)
C
CONTOUR FROM 2 TO 27 BY 2 (C)
4 6 8 10 12 14 16 18 20 22 24 26
CMIP5 ENSMN RCP8.5 historical stdanom (2006-2055)-(1956-2005)
stddev
CONTOUR FROM -4.8 TO 4.8 BY 0.8 (stddev)
-4 -3.2 -2.4 -1.6 -0.8 0 0.8 1.6 2.4 3.2 4
CMIP5 ENSMN historical standard deviation(1956-2005)
C
CONTOUR FROM 0.24 TO 1 BY 0.08 (C)
0.32 0.4 0.48 0.56 0.64 0.72 0.8 0.88 0.96
CMIP5 ENSMN historical variance ratio(2006-2055)/(1956-2005)
CONTOUR = (/0.25,0.5,0.75,1.0,1.5,2.0,4./)
0.25 0.4 0.67 0.8 1 1.25 1.5 2.5 4
50N
40N
30N
100W
90W
80W
70W
60W


Sea Surface Salinity ANN
CMIP5 ENSMN RCP8.5 future climate (2006-2055)
psu
CONTOUR FROM 26.5 TO 37.5 BY 1 (psu)
27 28 29 30 31 32 33 34 35 36 37
CMIP5 ENSMN RCP8.5 historical stdanom (2006-2055)-(1956-2005)
stddev
CONTOUR FROM -3 TO 3 BY 0.5 (stddev)
-2.5 -2 -1.5 -1 -0.5 0 0.5 1 1.5 2 2.5
CMIP5 ENSMN historical standard deviation(1956-2005)
psu
CONTOUR FROM 0.075 TO 0.575 BY 0.05 (psu)
0.1 0.15 0.2 0.25 0.3 0.35 0.4 0.45 0.5 0.55
CMIP5 ENSMN historical variance ratio(2006-2055)/(1956-2005)
CONTOUR = (/0.25,0.5,0.75,1.0,1.5,2.0,4./)
0 0.25 0.5 0.8 1 1.5 2.5 4 8
50N
40N
30N
100W
90W
80W
70W
60W
NOAA/PSL


pH at Surface ANN
CMIP5 ENSMN RCP8.5 future climate (2006-2055)
1
CONTOUR FROM 7.956 TO 8.056 BY 0.008 (1)
7.964 7.976 7.988 8 8.012 8.024 8.036 8.048
CMIP5 ENSMN RCP8.5 historical stdanom (2006-2055)-(1956-2005)
stddev
CONTOUR FROM -25 TO 25 BY 5 (stddev)
-20 -15 -10 -5 0 5 10 15 20
CMIP5 ENSMN historical standard deviation(1956-2005)
1
CONTOUR FROM 0.0036 TO 0.012 BY 0.0008 (1)
0.004 0.0052 0.0064 0.0076 0.0088 0.01 0.0112
CMIP5 ENSMN historical variance ratio(2006-2055)/(1956-2005)
CONTOUR = (/0.25,0.5,0.75,1.0,1.5,2.0,4./)
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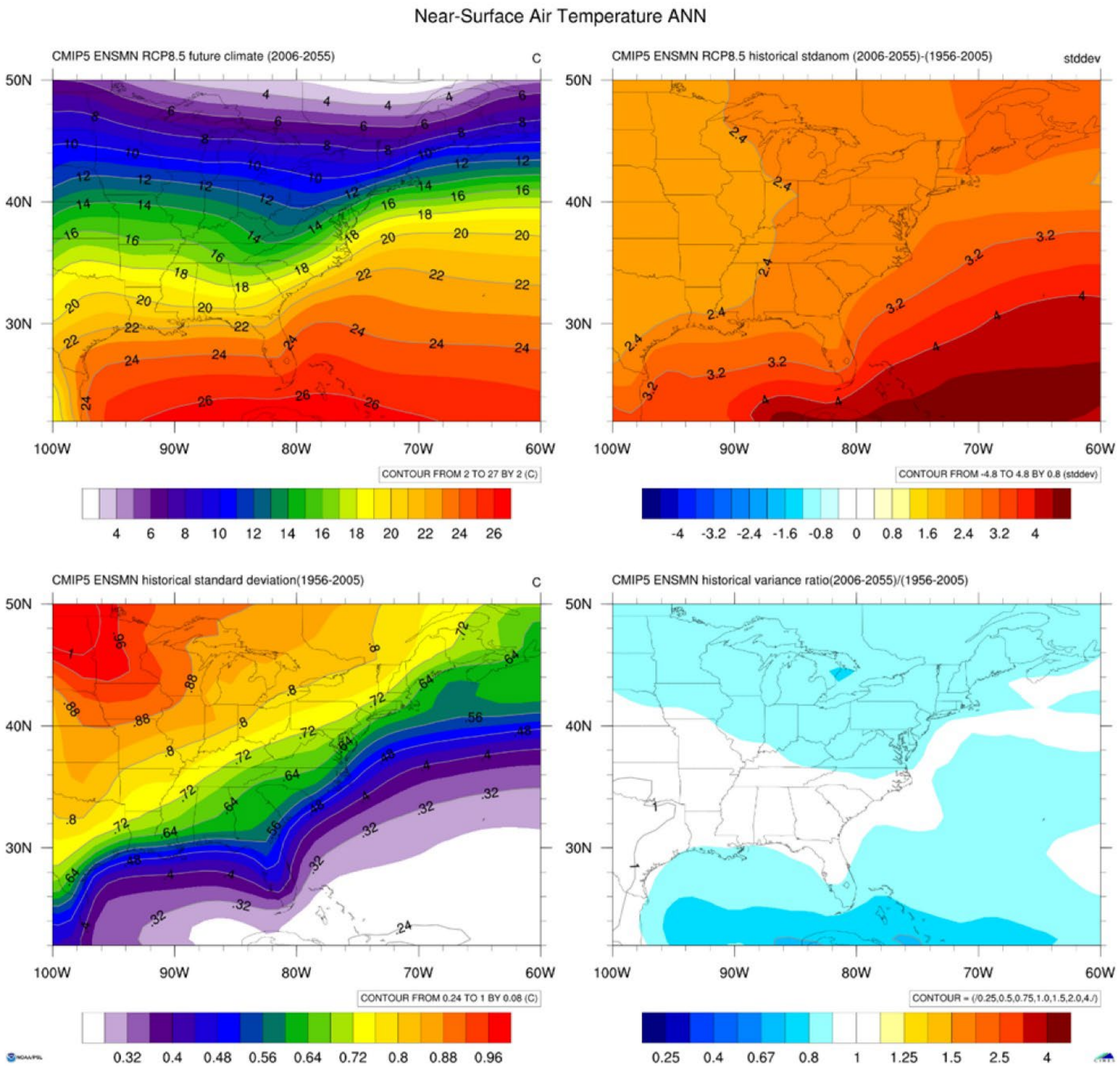
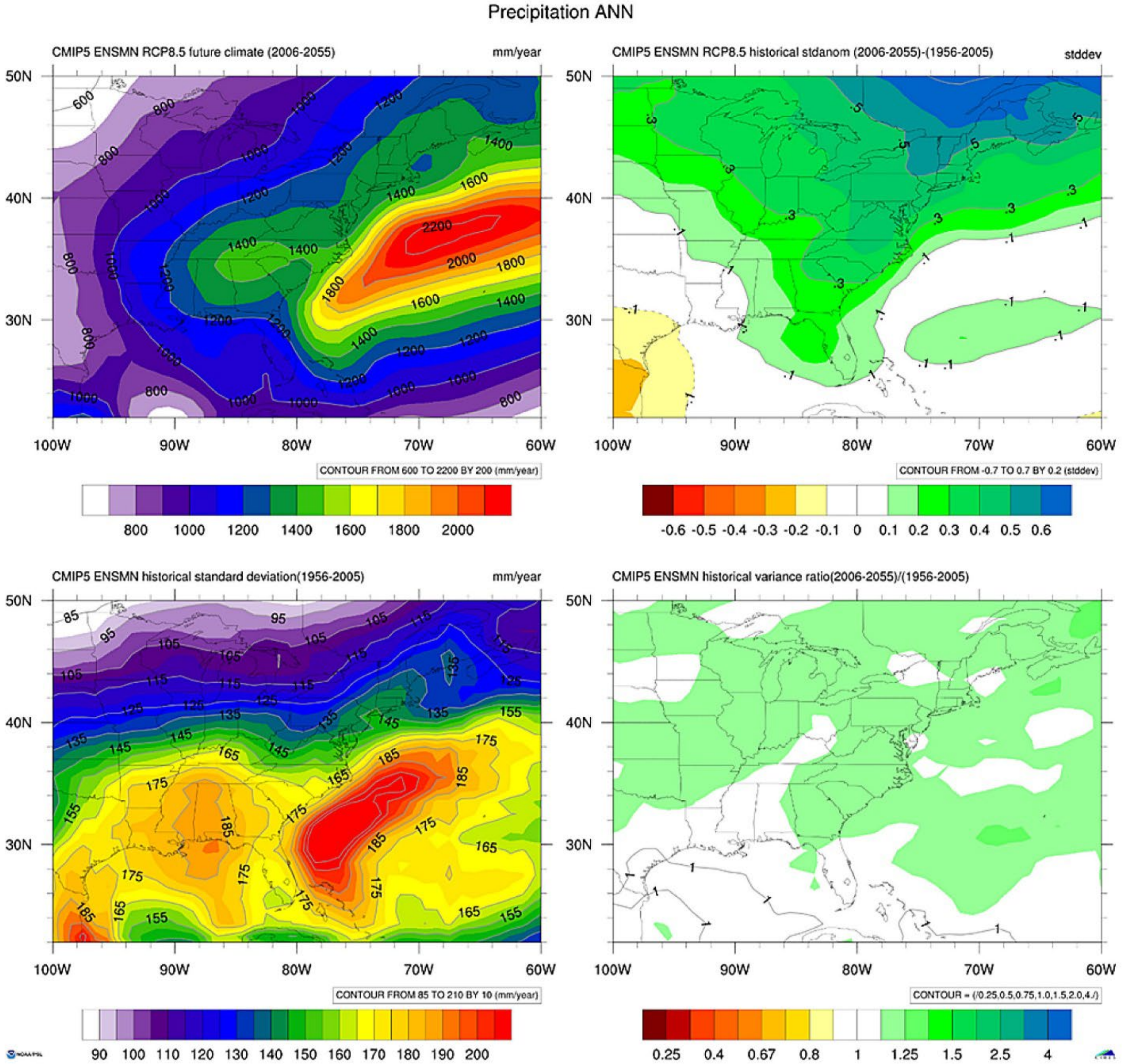
50N
40N
30N
100W
90W
80W
70W
60W


Near-Surface Air Temperature ANN
CMIP5 ENSMN RCP8.5 future climate (2006-2055)
C
CONTOUR FROM 2 TO 27 BY 2 (C)
4 6 8 10 12 14 16 18 20 22 24 26
CMIP5 ENSMN RCP8.5 historical stdanom (2006-2055)-(1956-2005)
stddev
CONTOUR FROM -4.8 TO 4.8 BY 0.8 (stddev)
-4 -3.2 -2.4 -1.6 -0.8 0 0.8 1.6 2.4 3.2 4
CMIP5 ENSMN historical standard deviation(1956-2005)
C
CONTOUR FROM 0.24 TO 1 BY 0.08 (C)
0.32 0.4 0.48 0.56 0.64 0.72 0.8 0.88 0.96
CMIP5 ENSMN historical variance ratio(2006-2055)/(1956-2005)
CONTOUR = (/0.25,0.5,0.75,1.0,1.5,2.0,4./)
0.25 0.4 0.67 0.8 1 1.25 1.5 2.5 4
50N
40N
30N
100W
90W
80W
70W
60W



Precipitation ANN

CMIP5 ENSMN RCP8.5 future climate (2006-2055) mm/year

CMIP5 ENSMN RCP8.5 historical stdanom (2006-2055)-(1956-2005) stddev

CMIP5 ENSMN historical standard deviation(1956-2005) mm/year

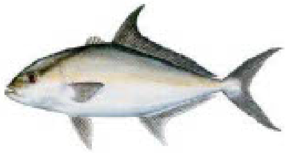
CMIP5 ENSMN historical variance ratio(2006-2055)/(1956-2005)

Appendix E. Species Information Sheets and Species Narratives.

Supporting Information. Species Narratives.

Table of Contents

Almaco Jack – *Seriola rivoliana*

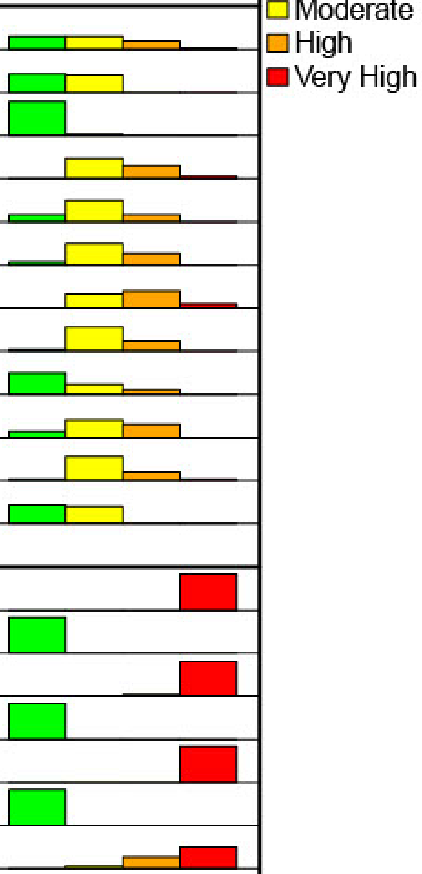


Overall Vulnerability Rank = High 🟧

Biological Sensitivity = Moderate 🟨
Climate Exposure = Very High 🟥

Data Quality = 58% of scores ≥ 2

	Seriola rivoliana	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2	3	
	Prey Specificity	1.5	3	
	Adult Mobility	1	2.6	
	Dispersal of Early Life Stages	2.5	1	
	Early Life History Survival and Settlement Requirements	2	0.8	
	Complexity in Reproductive Strategy	2.2	1.8	
	Spawning Cycle	2.7	2.4	
	Sensitivity to Temperature	2.2	2.8	
	Sensitivity to Ocean Acidification	1.5	2.2	
	Population Growth Rate	2.2	2.4	
	Stock Size/Status	2.3	0.8	
	Other Stressors	1.5	1.6	
	Sensitivity Score	Moderate		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	3.9	3	
	Precipitation	1	0	
	Ocean Acidification	4	2	
	Sea Level Rise	1	0	
	Currents	3.5	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		High		



Almaco Jack (*Seriola rivoliani)*)

Overall Climate Vulnerability Rank: High. (44% bootstrap results in Moderate, 56% bootstrap results in High). The results of the bootstrap analysis indicated that Almaco Jack were borderline between a high and moderate overall vulnerability ranking.

Climate Exposure: Very High. Four exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) Salinity (3.9) and Currents (3.5). Exposure to all three factors occurs during the life stages.

Biological Sensitivity: Moderate. Two sensitivity attributes scored above 2.5: Spawning Cycle (2.7) and Dispersal of Early Life Stages (2.5), two attributes for which little is known for Almaco Jack. This uncertainty likely led to the species being scored higher for these attributes.

Distributional Vulnerability Rank: High**.** Two attributes indicated increased potential for distribution shift: adult mobility, and habitat specificity. Almaco Jack are habitat generalists that are highly mobile, and they have a fairly broad temperature tolerance as well.

Directional Effect in the Southeast U.S. Shelf: The effect of climate change on Almaco Jack on the Southeast U.S. Shelf is estimated to be neutral. The species is a highly mobile pelagic, open-ocean dweller which is widely geographically distributed. Almaco Jack does not rely on estuarine areas for critical early life stages, thus may avoid the impacts of anthropogenic stressors. Effects of Ocean Acidification are likely to be minimal.

Data Quality: 58% of the data quality scores were 2 or greater. Data gaps for life history knowledge of Almaco Jack include early life history survival and settlement, dispersal of early life stages, complexity in reproductive strategy, and stock size/status.

Climate Effects on Abundance and Distribution: Changing climate could have moderate to large effects on the abundance and distribution of Almaco Jack. The species enjoys fairly broad thermal tolerances and should not be greatly affected by moderate sea surface temperature increases. They are highly mobile fish and, coupled with this tolerance, would likely expand their range into warming northern waters. There may be effects of ocean acidification on certain diet components, although almaco jack may opportunistically switch to other items. The species does not use estuarine areas in their life cycle, but they do depend on offshore sargassum habitat for both food and refuge as juveniles, and disruption of currents might affect early life stage fitness and survival.

Life History Synopsis**:** Almaco Jack enjoy a circumtropical distribution, occurring from Cape Cod south to Buenos Aires, Argentina, throughout the Gulf of Mexico, Caribbean, and in the Bahamas. The species has been found at depths from 3-252 m. Adult Almaco Jack are mostly demersal in oceanic waters, in close proximity to the seafloor, are attracted to structure (reefs/ledges/wrecks) and are rarely found inshore (Smith-Vaniz et al. 2015). Juvenile Almaco Jack are opportunistic feeders in both the sargassum and open water, eating chaetognaths, copepods, crustaceans and fish, primarily *Decapterus* scad (Casazza and Ross 2008). Adults eat primarily fishes, but also some crabs and shrimp (Manooch and Haimovici 1983, Smith-Vaniz et al. 2015). Adults are highly mobile, with no behavioral or physical constraints on their ability to move. Little is known of their reproductive biology. Almaco Jack are known to form spawning groups in Gladden Spit, Belize (Heyman 2001, Smith-Vaniz et al., 2015). Spawning occurs throughout spring, summer and fall, depending on water temperature (UWI 2020) Little is known from the literature of the early life stages of Almaco Jack. It is likely that larvae grow fairly rapidly, as other carangids do, living in the open ocean, in close proximity to sargassum habitat while juveniles. Almaco Jack occurs across a fairly wide range of temperatures within their geographic distribution, but their preferred temperature range is reported as 22.1-28.6°C, mean 27.3°C (Fishbase). Almaco Jack may be slightly affected by increasing ocean acidification due to the inclusion of some invertebrates in the diet of the juveniles; however they likely grow rapidly through that phase and switch to a diet consisting primarily of fishes. The species has a slow population growth rate, based on an age-at-maturity of 4.5 years, a relatively long longevity of 22 years, a large maximum size of >1 m total length, and fairly low growth coefficient K = 0.13. These characteristics could make population recovery slow in the face of climate disruption. Almaco Jack have not been assessed in the Atlantic; the IUCN lists the species as a Species of Least Concern. Almaco Jack does not use estuarine or nearshore areas for its life stages, and thus will not likely suffer from other potential stressors such as habitat degradation, eutrophication, lionfish predation, etc.

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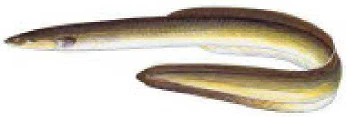
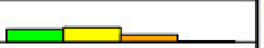
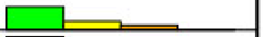
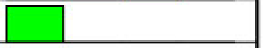
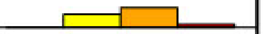
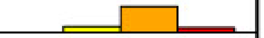
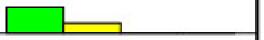
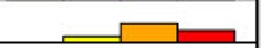
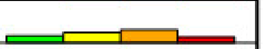
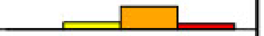
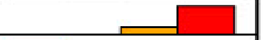
American Eel – *Anguilla rostrata*



Overall Vulnerability Rank = High 🟧

Biological Sensitivity = Moderate 🟨
Climate Exposure = Very High 🟥

Data Quality = 75% of scores ≥ 2

	Anguilla rostrata	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.9	2.6	
	Prey Specificity	1.2	2.8	
	Adult Mobility	1.5	3	
	Dispersal of Early Life Stages	1	2.8	
	Early Life History Survival and Settlement Requirements	2.5	2	
	Complexity in Reproductive Strategy	2.7	1.8	
	Spawning Cycle	3	2.2	
	Sensitivity to Temperature	1.1	2.6	
	Sensitivity to Ocean Acidification	1.3	2	
	Population Growth Rate	3.2	2	
	Stock Size/Status	2.5	1.6	
	Other Stressors	3	1.4	
	Sensitivity Score	Moderate		
Exposure Factors	Sea Surface Temperature	1	0	
	Air Temperature	4	3	
	Salinity	3.8	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	3.4	3	
	Currents	2.8	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

American Eel (*Anguilla rostrata*)

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

Climate Exposure: Very High. Three exposure factors contributed to this score: Air Temperature (4.0), Ocean Acidification (4.0) and Salinity (3.8). American Eel will be exposed to Ocean Acidification and Salinity during the open ocean phase of their life history and will be vulnerable to temperature fluctuations during the riverine portion of their life cycle. They may be moderately vulnerable to Ocean Acidification as juveniles consume some crustaceans in their diet.

Biological Sensitivity: Moderate. Six sensitivity attributes contributed to the moderate ranking with scores greater than 2.5: Early Life History Survival and Settlement (2.5), Complexity in Reproduction (2.7), Spawning Cycle (3.0), Population Growth Rate (3.2), Stock Size/Status (2.5) and Other Stressors (3.0). Little is known of their early life history phase, and adults are thought to die after a single spawning event conducted after long migrations from the ocean to their natal riverine systems.

Distributional Vulnerability Rank: High. Three attributes indicated increased potential for distribution shift: adult mobility, early life stage dispersal, and habitat specificity. American Eel are highly mobile, undertaking long migrations from inshore nursery habitats to oceanic spawning grounds.

Directional Effect in the Southeast U.S. Shelf: The effect of climate change on American Eel is estimated to be negative. Shifts in oceanic currents such as the Gulf Stream have the potential to affect larval dispersal, survival, and recruitment, as American Eel spawn in the Sargasso Sea and leptocephalus larvae rely on oceanic transport to reach estuarine nurseries. Successful recruitment could also be impacted by the effect of increasing temperature and reduced precipitation on the amount of freshwater flow into coastal estuarine areas. The effect of ocean acidification is likely to be minimal.

Data Quality: 75% of the data quality scores were 2 or greater. There are gaps (uncertainties) in data for Stock Size/Status, Complexity in Reproductive Strategy, and Other Stressors.

Climate Effects on Abundance and Distribution: Climate-driven changes in ocean circulation were identified as the likely cause of synchronous declines in American and European Eel recruitment (Castonguay et al. 1994), while Bonhommeau et al. (2008) proposed that reduction in Anguillid recruitment worldwide was likely caused by decreases in oceanic primary production brought on by climate-driven processes. Sullivan et al. (2006), after finding that abundance of glass eels entering estuaries was correlated to winter precipitation, hypothesized that increased freshwater flow into the coastal ocean enhanced detection by returning glass eel. A warmer, drier climate could conversely lead to less successful recruitment due to reduced freshwater flow. While the American Eel has life history characteristics indicating the potential for distribution shift, the species is already widely distributed along the entire Eastern Seaboard of the United States, and the ability to expand their distribution once in freshwater is limited.

Life History Synopsis: American Eel is a species of large catadromous eel (family Anguillidae) that can attain large size (≅ 1.5 m). They are found from freshwater rivers to offshore waters of the continental slope (Sargasso Sea). Juvenile American Eel habitat ranges from the headwaters of rivers, through the estuaries, and includes nearshore marine waters all the way out to the Sargasso Sea, where leptocephali larvae likely are carried by Gulf Stream currents while they develop. They rely on active transport to exit the Gulf Stream and reach estuarine/nearshore/riverine areas. Adult habitat includes these nearshore/inshore areas as well as the marine environment. American Eels are vulnerable to anthropogenic alteration of nearshore habitat, and dams pose serious impediments to their upstream migrations. Larval American Eels feed on phytoplankton, zooplankton and detritus, while juveniles are opportunistic, consuming insects, crustaceans, and small fishes. Upon maturation, eels metamorphose to a silver stage eel and undertake a non-feeding migration from freshwater habitat to the marine spawning habitat in the Sargasso Sea (McCleave 2001, McCairns et al. 2005). American Eel are highly mobile with adults conducting long migrations (>1000km) from inshore habitat areas to the Sargasso Sea for spawning, and juveniles migrating back to inshore nursery habitat, where they remain for years until they mature. Climate-mediated changes to offshore current patterns and transport could have a deleterious effect on survival of American Eel. Spawning has not been observed in the wild, but based on size of leptocephalus larvae, timing is likely late winter to early spring. American Eels are thought to be semelparous, dying after a single spawning event (based on lack of documented occurrences of spent American Eels). Little is known of the earliest life stages. Transparent leptocephali larvae hatch after about 19 days and develop at sea, metamorphosing into elvers in nearshore waters and estuaries after drifting passively in currents for hundreds of kilometers. Elvers migrate into estuaries and rivers, staying there until attaining sexual maturity at between 3-30 years. Once mature, they migrate out of their rivers, estuaries and nearshore waters and begin the spawning migration back to the Sargasso Sea. American Eels occupy a fairly broad range of temperatures within their geographic distribution, from approximately 0.5 to 25° C (Fishbase.org). They are found at depths from 0-460 m. American Eels include some crustaceans in their diets as juveniles, but are generally opportunistic predators and the impacts of Ocean Acidification may be minimal. American Eel likely have a slow population growth rate, based on a high longevity (>43 yrs), a moderate to large maximum body size (50-150 cm, depending on latitude), a moderate growth coefficient, a high natural mortality rate, and large maximum body size. These characteristics combined indicate that American Eel would be vulnerable to population disturbances. American Eel stock status and stock assessment reference points could not be determined by a 2017 stock assessment (ASMFC 2017, but trends analyses indicated that the stock was still depleted, as abundance has continued to decline over time. American Eels are one, well-mixed, panmictic, breeding population which lacks appreciable phylogeographic population structure (Avise 2003). Potential stressors for American Eel populations are many, and include anthropogenic alteration of their inshore habitat (estuaries and rivers), including pollution as well as dams which inhibit their migrations upriver. Changes in precipitation patterns affecting streamflow could be deleterious. American Eel are subject to parasitization by *Anguillicoloides crassus*, a parasitic swim bladder nematode. Zimmerman and Welsh (2012) found that length-at-age was lower in previously infected American Eels in the Potomac River watershed than those uninfected, potentially reducing reproductive capabilities. Hein et al. (2014) found parasite prevalence was higher in South Carolina than in New York and Chesapeake Bay and possibly has been increasing over time. Additionally, the authors suggest that milder winters due to climate change could increase infection.

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Sullivan MC, Able KW, Hare JA, Walsh HJ. Anguilla rostrata glass eel ingress into two, US east coast estuaries: patterns, processes and implications for adult abundance. J Fish Biol. 2006; 69(4): 1081-1101. doi: 10.1111/j.1095-8649.2006.01182.x

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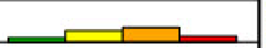
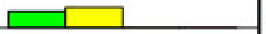
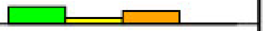
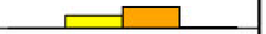
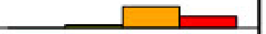
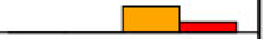
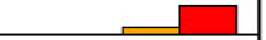
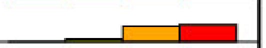
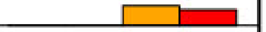
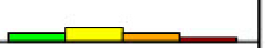
American Shad – *Alosa sapidissima*

Overall Vulnerability Rank = Very High 🟥

Biological Sensitivity = High 🟧
Climate Exposure = Very High 🟥

Data Quality = 100% of scores≥ 2

	Alosa sapidissima	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.6	2.6	
	Prey Specificity	1.6	2.2	
	Adult Mobility	1.9	3	
	Dispersal of Early Life Stages	2.7	3	
	Early Life History Survival and Settlement Requirements	3.2	2.2	
	Complexity in Reproductive Strategy	3.3	2.8	
	Spawning Cycle	3.8	3	
	Sensitivity to Temperature	2.3	3	
	Sensitivity to Ocean Acidification	1.1	2.6	
	Population Growth Rate	2.4	2.6	
	Stock Size/Status	3.4	2.2	
	Other Stressors	3.4	2.8	
	Sensitivity Score	High		
Exposure Factors	Sea Surface Temperature	1	0	
	Air Temperature	4	3	
	Salinity	3.7	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	3.1	2.8	
	Currents	2.2	2.8	
	Exposure Score	Very High		
Overall Vulnerability Rank		Very High		

- 🟩 Low
- 🟨 Moderate
- 🟧 High
- 🟥 Very High

American shad (*Alosa aestivalis*)

Overall Climate Vulnerability Rank: Very High. (98% bootstrap results in Very High, 2% bootstrap results in High.

Climate Exposure: Very High. Three exposure factors contributed to this score: Salinity (3.7), Ocean Acidification (4.0) and Air Temperature (4.0). American Shad are exposed to the effects of acidification and salinity during their marine life stages and to the effects of air temperature during their riverine spawning reproductive phase, moving inshore into estuarine/riverine areas to spawn.

Biological Sensitivity: High. Five sensitivity attributes scored above 3.0, contributing to a High ranking: Early Life History Survival and Settlement (3.2), Complexity in Reproductive Strategy (3.3), Spawning Cycle (3.8), Stock Size/Status (3.4) and Other Stressors (3.4). American Shad have a low to moderate population growth rate. Adults spend the majority of their lives in the marine environment before migrating into riverine areas at age 4-5 to spawn, sometimes well upriver. Most populations in the U.S. Southeast are at all time low levels and have not recovered in recent years. During their riverine phase they are subject to anthropogenic disturbances (pollution, runoff, dredging, etc).

Distributional Vulnerability Rank: Low. Three attributes indicated limited vulnerability to distribution shift: sensitivity to temperature, limited early life stage dispersal, and relatively high habitat specialization. American Shad exhibit high site fidelity, a characteristic which limits the likelihood of distribution shift.

Directional Effect in the Southeast U.S. Shelf: The effect of climate change on American Shad is estimated to be negative. Changes in streamflow (caused by changing precipitation patterns) and warming temperatures will likely cause decreases in productivity. Projected increases in salinity would likely negatively affect early life stages. Ocean acidification will impact some prey items. American Shad will likely be negatively impacted by anthropogenic disturbances to riverine/estuarine habitat.

Data Quality: 100% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution: Climate effects will impact the survival and productivity of American Shad along the East Coast. Changes in spring river flows could affect recruitment (Crecco et al. 1986). Temperature is known to affect both larval growth and survival (Leach and Houde 1998). Reproductive success is influenced by the temperature of the natal river (Leggett and Carscadden, 1978). Increasing salinity would be detrimental to survival as the egg stage does not tolerate salt water (Chittenden 1973).

Life History Synopsis**:** American Shad is an anadromous fish species, distributed in the southeastern United States in nearshore and estuarine/riverine waters from North Carolina through the St. Johns River in east central Florida. Adults occur in marine waters, spending the majority of their life at sea, returning to freshwater streams to spawn (Morrow, 1980), sometimes traveling as far as 630 km upstream (Hildebrand 1964). Non-spawning adults are found in schools near the surface of continental shelf waters in spring, summer and autumn, also found in brackish waters (Hildebrand, 1964). Larvae spend their initial 3 to 4 months in riverine-nursery areas during summer and migrate out to sea by autumn. Juveniles form schools at 20-30 mm TL and gradually move downstream (Jones et al., 1978). Pre-migratory juveniles are habitat generalists, whereas earlier life stages and spawning adults are more selective (Ross et al. 1993). Juvenile American Shad diet is primarily planktonic, and includes copepods (e.g., Calanus), euphausids, and mysids. Adults are known to feed mainly on plankton and copepods (Whitehead 1985), but have also been described as opportunistic (Chittenden 1976); they are known to slow or cease their feeding upon returning to freshwater to undertake upstream spawning migrations (Scott and Crossman 1998). Adults are highly mobile, migrating from offshore waters to several hundred km up natal streams to spawn, and young adults undertake reverse migrations from nursery areas to offshore waters. They are not physically limited in their ability to migrate. After living in the ocean most of their lives, adult American Shad migrate into rivers to spawn, usually at 4-5 years of age. These migrations are heavily influenced by increasing water temperatures. Climate-mediated changes in water temperature may affect the timing of migration, which may affect spawning and juvenile success and lead to a match-mismatch between predator and prey species (Boesch 2008). Conversely, migration of juvenile shad into the ocean in late summer/autumn is triggered by falling temperature, and migration to the ocean could be delayed due to warmer fall temperatures (Kane 2013). Planktonic larval duration is approximately three weeks. Eggs may float from 0-35 km in lower river/upper estuarine areas before hatching. American Shad occur across a wide temperature gradient (5-26℃) along the U.S. East Coast; in rivers of the U.S. southeast coast their temperature range is 16-21.5 ℃ (Leggett 1976). They can occupy a large portion of the water column, from the surface to 250 m (Able and Fahay 2010). American Shad may be moderately affected by increasing ocean acidification as their diet consists primarily of items with chitinous shells, which ocean acidification has been shown to affect (Mustafa et al. 2015). American Shad population growth rate is judged to be moderate to low based on a fairly high growth coefficient, a medium maximum size, a delayed age-at-maturity (4-5 years), a low to moderate maximum age, and an elevated natural mortality rate (based on high fecundity). Therefore, recovery of American Shad stocks in the southeastern U. S from population disturbances could be delayed. The last coastwide stock assessment for American Shad, completed in 2007, found that stocks are currently at all-time lows and do not appear to be recovering. There are no coastwide reference points for American Shad. A benchmark stock assessment was initiated in 2017 to analyze American Shad stock status, with expected completion in the fall 2020. Primary causes for stock decline include overfishing, pollution and habitat loss due to dam construction and other habitat alteration. A peer review panel recommended that current restoration actions should be reviewed and new ones should be identified and applied, and suggested considering a reduction of fishing mortality, enhancement of dam passage and mitigation of dam-related fish mortality, stocking and habitat restoration (ASMFC 2020).

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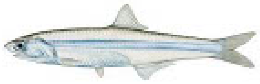
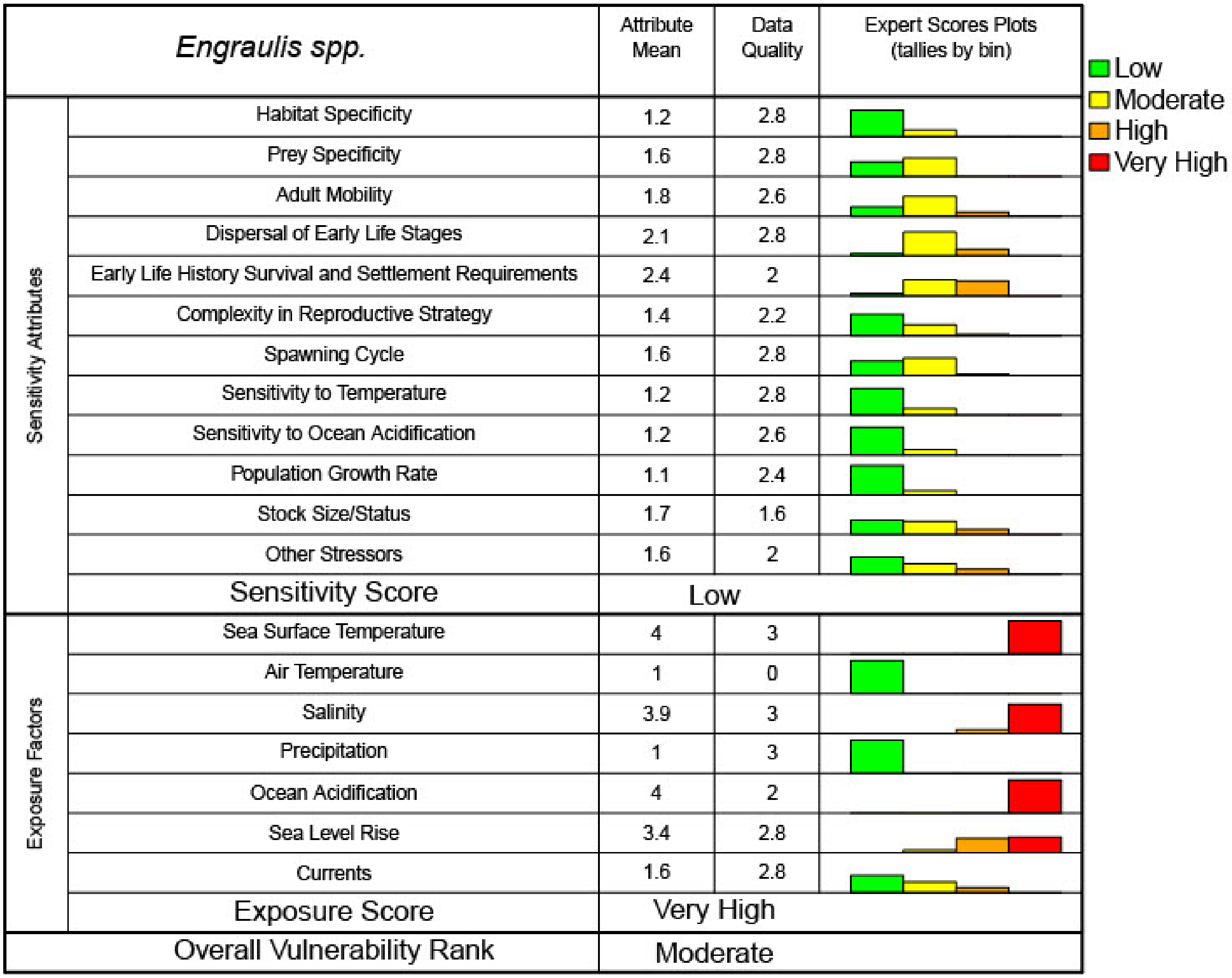
Anchovies – *Engraulis spp.*



Overall Vulnerability Rank = Moderate 🟨

Biological Sensitivity = Low 🟩
Climate Exposure = Very High 🟥

Data Quality = 92% of scores ≥ 2



	Engraulis spp.	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.2	2.8	
	Prey Specificity	1.6	2.8	
	Adult Mobility	1.8	2.6	
	Dispersal of Early Life Stages	2.1	2.8	
	Early Life History Survival and Settlement Requirements	2.4	2	
	Complexity in Reproductive Strategy	1.4	2.2	
	Spawning Cycle	1.6	2.8	
	Sensitivity to Temperature	1.2	2.8	
	Sensitivity to Ocean Acidification	1.2	2.6	
	Population Growth Rate	1.1	2.4	
	Stock Size/Status	1.7	1.6	
	Other Stressors	1.6	2	
	Sensitivity Score	Low		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	3.9	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	3.4	2.8	
	Currents	1.6	2.8	
	Exposure Score	Very High		
Overall Vulnerability Rank		Moderate		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Anchovies (*Anchoa hepsetus* and *Anchoa mitchilli*)

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

Climate Exposure: Very High. Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Salinity (3.9). Anchovies use coastal, nearshore and estuarine habitats throughout their life.

Biological Sensitivity: Low. No sensitivity attributes scored above 2.5: Anchovies are short lived, fast growing species with relatively fast population growth rates. The species are habitat and prey generalists, and are not currently threatened by overexploitation within their range.

Distributional Vulnerability Rank: High. Three attributes indicated potential for distribution shift: high adult mobility, widely dispersing early life stages, and low habitat specialization. Anchovies are mobile fish found in estuarine, nearshore and coastal waters, and they have widely dispersing early life stages.

Directional Effect on the Southeast U.S. Shelf: The effect of climate change on anchovies on the Southeast U.S. Shelf is projected to be positive . Anchovies enjoy a wide thermal and salinity tolerance. Bioenergetics models of Bay Anchovy from Chesapeake Bay predict that consumption of zooplankton will increase with warming waters (Lou and Brandt 1993), thereby increasing productivity. The effect of ocean acidification over the next 30 years is expected to be minimal.

Data Quality: 92% of the data quality scores were 2 or greater. Information was lacking for stock size/status, likely because the two species are not currently assessed by resource managers.

Climate Effects on Abundance and Distribution: Few studies of the effect of climate change on Anchoa spp.have been conducted. Bay Anchovy consumption of zooplankton was predicted to increase with increasing sea surface temperature in the Chesapeake Bay (Lou and Brandt, 1993) An ecosystem bioenergetics study from the Black Sea indicated that population productivity of Anchovies would increase as temperature rises (Güraslan et al., 2014) .

Life History Synopsis**:** The Anchovies (bay anchovy and striped anchovy) are small schooling species found in estuarine and nearshore coastal waters out to 70 m from 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). While the bay anchovy doesn't range past the Yucatan, the striped anchovy is found as far south as Uruguay. Both species have a fairly wide temperature range, with bay anchovy found in waters from 4-39°C, while striped anchovy have been taken in temperatures from 15-35°C. Both anchovy species are found in shallow coastal waters and brackish estuaries. Bay anchovies will use estuaries and lagoons with muddy bottoms to 25 m depth, and are found in salinities from 1-36 ppt, while striped anchovies, while found in shallow estuaries, mostly utilize shallow coastal waters out to

70 m (Robinette 1983). Both Anchovy species specialize on zooplankton (primarily copepods) when young but diets become more generalist when older, with bay anchovy feeding on gastropods, isopods, mysid shrimp and small fishes, while adult striped anchovy feed on gastropods, foraminifera, ostracods, and an occasional annelid (Munroe, 2015; Peebles et al. 2015). Neither species of Anchovy is limited in its mobility. Bay anchovy undertake seasonal offshore migrations in the northern part of their range. Both species are known to spawn during spring and summer months in northern areas and year round in the southern part of the range. Spawning usually commences after water temperatures reach 20°C. Spawning areas range from in or near estuaries to the continental shelf. Timing of spawning has been hypothesized to co-occur with timing of copepod abundance. Bay anchovy eggs hatch in 24 hr at room temperature, while striped anchovy eggs hatch at 48 hr at a water temperature of 19" to 21°C. Larval duration in bay anchovies from the Newport River Estuary, NC, is around 45 days, at which time individuals of approximately 22.5 mm complete metamorphosis. Rapid larval growth rates likely allow animals spawned early in the season (May to early June) to mature and spawn by late summer or early fall of the same year (Fives et al. 1986). Anchovies have little or no reliance on prey items likely to be affected by ocean acidification. Anchovies have a rapid population growth rate, based on their fast growth rate, high natural mortality (Acosta 2000), a short lifespan comprised of multiple year classes (Able et al. 2001), and early age at maturity (Peebles et al. 2007). The species should have the ability to recover quickly from population disturbances. Anchovies have not been assessed in the southeastern U. S., but there do not appear to be any substantial threats to this species. It is exploited in parts of its range, but this is not expected to impact its global population. Potential stressors for anchovies include habitat alteration/degradation of the estuarine habitat they utilize, decreases in freshwater input into estuaries (Kelble et al. 2010), and excessive predation on all life stages of the species by a number of predators (e.g., weakfish, striped bass, etc).

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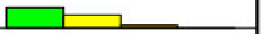
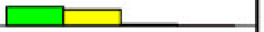
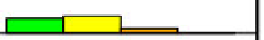
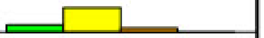
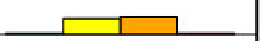
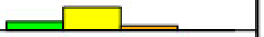
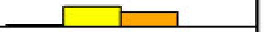
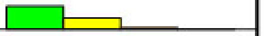
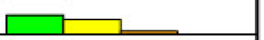
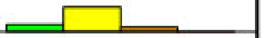
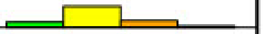
Atlantic Croaker – *Micropogonias undulatus*

Overall Vulnerability Rank = Moderate 🟨

Biological Sensitivity = Low 🟩
Climate Exposure = Very High 🟥

Data Quality = 83% of scores ≥ 2

Micropogonias undulatus		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.5	3	
	Prey Specificity	1.5	3	
	Adult Mobility	1.7	2.6	
	Dispersal of Early Life Stages	1.9	1.8	
	Early Life History Survival and Settlement Requirements	2.5	2.2	
	Complexity in Reproductive Strategy	1.9	2	
	Spawning Cycle	2.4	3	
	Sensitivity to Temperature	1.2	3	
	Sensitivity to Ocean Acidification	1.4	2.4	
	Population Growth Rate	1.6	2.6	
	Stock Size/Status	1.9	1.8	
	Other Stressors	2.1	2.6	
	Sensitivity Score	Low		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	3.9	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	3.6	3	
	Currents	1.7	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		Moderate		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Atlantic Croaker (*Micropogonias undulatus*)

Overall Climate Vulnerability Rank: Moderate. (94% bootstrap results in Moderate, 6% bootstrap results in High).

Climate Exposure: Very High. our exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0), Salinity (3.9) and Sea Level Rise (3.6). Atlantic Croaker use shelf/coastal/nearshore habitats as adults and have an obligate freshwater/estuarine existence during early life history stages, thus making the species potentially vulnerable to increasing sea level rise.

Biological Sensitivity: Low. No sensitivity attributes scored above 2.5: Early Life History Survival and Settlement Requirements (2.4) was borderline between low and moderate, likely due to their estuarine habit as young of the year/juveniles. Adults spawn offshore on the continental shelf and pelagic larvae are dependent on current transport into estuarine nursery areas.

Distributional Vulnerability Rank: High. Three attributes indicated higher potential for distribution shift: adult mobility, widespread early life stage dispersal, and relatively low habitat specialization.

Directional Effect in the Southeast U.S. Shelf: The effect of climate change on Atlantic Croaker on the Southeast U.S. Shelf is projected to be positive. Recruitment and abundance will likely increase as a result of warming temperatures, although this positive result may be offset somewhat by projected increases to salinity or changes to offshore currents, necessary for larval transport to estuarine nursery areas. The effect of ocean acidification over the next 30 years is expected to be minimal.

Data Quality: 83% of the data quality scores were 2 or greater. Small data gaps were found to exist for stock size/status and dispersal of early life stages.

Climate Effects on Abundance and Distribution: Studies have posited that climate may have a variety of effects on productivity and distribution of Atlantic Croaker. Warming climate is predicted to lead to increasing recruitment and higher abundance, which could lead to a shift in distribution northward (Hare et al. 2010). While Diamond et al. (2013) predicted that warming temperatures would positively affect Atlantic Croaker in the mid-Atlantic, they also predicted that increased variability in salinity, increased offshore transport due to changes in oceanic circulation patterns, and sea-level rise would have negative effects.

Life History Synopsis**:** Atlantic Croaker are a small-medium (up to 55 cm, common size 30 cm) demersal member of the drum family (Sciaenidae). Along the southeastern U. S. they range from North Carolina through central Florida, and from Tampa Bay north through the Gulf of Mexico around to the Yucatan Peninsula and Cuba (Castro-Aguirre et al. 1999). Post-larvae and juveniles are obligate estuarine-freshwater nursery users. Pelagic young of year (YOY) of 8–20 mm total length (TL) leave shelf waters and enter larger estuaries, eventually moving into nursery habitats associated with low-salinity tidal creeks (Able and Fahay 1998, Norcross 1991). Preferred habitat of adults is sandy-mud bottoms in inshore coastal waters, remaining in shallower water until they move to the continental shelf waters (out to 200 m) in fall to spawn and overwinter. The major prey of young-of-the-year Atlantic Croaker are polychaetes, copepods, and mysids (FFWCC 2010; Sink, 2011; Soto et al. 1999). Detritus is also a major component of the juvenile diet. Adult Croaker collected in Chesapeake Bay ate primarily polychaetes, anchovies, mysid shrimp, amphipods, fishes and crabs, as well as detritus (Nye, Lowensteiner and Miller 2011). Adults are mobile, but not highly so. They conduct inshore-offshore migrations between nursery grounds and spawning areas. They have been found to be limited in their mobility by hypoxic events (Craig and Crowder 2005). Atlantic Croaker spawn predominantly on the continental shelf, at depths ranging from 7 to 81 m, but also in tidal inlets and estuaries (Diaz and Onuf 1985; Able and Fahay 2010). Exact spawning locations may be related to warm bottom waters (Miller et al. 2002). Street et al. (2005) reported spawning occuring at water temperatures of 16-25°C in North Carolina, while Norcross and Austin (1988) concluded spawning was correlated with bottom temperatures higher than 16°C in the Mid Atlantic Bight. In Chesapeake Bay and North Carolina, spawning begins as early as August and usually peaks in October (Diaz and Onuf 1985), but may continue until February in North Carolina (Warlen 1982). Pelagic larvae are transported into estuaries via flood tides, upstream bottom currents, and other large-scale and localized oceanographic processes (Joyeux 1998). Larvae entering Chesapeake Bay were typically 20–26 days old and 5–7 mm SL (Nixon and Jones 1997). Larvae are initially pelagic, but move to brackish bottom waters on ebbing tides to complete their development into juveniles (Miller 2002). Atlantic Croaker enjoy a fairly wide range of temperatures within their geographic distribution, from approximately 14 to 27° C (Fishbase). Larvae are more tolerant of colder temperatures, but extreme cold events are a likely source of larval mortality. Atlantic Croaker are not likely to be affected by increased ocean acidification as they are not dependent on shell-forming taxa in their diet. Atlantic Croaker have a moderately fast population growth rate, based on a growth coefficient of 0.20-0.36, a maximum age of 11 years, a relatively small maximum body size (550 cm, average size 30 cm) and an intermediate natural mortality rate (mean of methods 0.28) (Foster 2001). Thus, populations of Atlantic Croaker should be capable of recovering from population disturbances without difficulty. 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. The panel agreed that recent removals are likely sustainable (i.e., unlikely to result in further depletion of Atlantic Croaker), and no immediate management actions were recommended. A genetic study found weak stock structure between Atlantic Croaker populations in the Gulf of Mexico and SEUS Atlantic waters, but no evidence of genetic differences in Atlantic Croaker along the Eastern Seaboard of the U. S. (Lankford et al. 1999). Juvenile Atlantic Croaker may be affected by anthropogenic activities such as hydrological modifications (ditching and channelization), pollution, hypoxia caused by eutrophication, alteration of natural shorelines, and harmful algal blooms.

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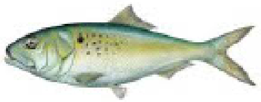
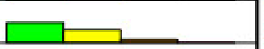
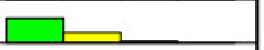
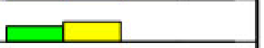
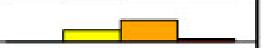
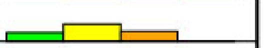
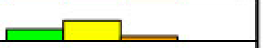
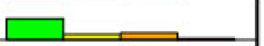
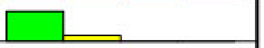
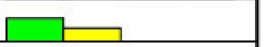
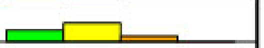
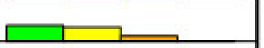
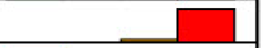
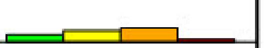
Atlantic Menhaden – *Brevoortia tyrannus*



Overall Vulnerability Rank = Moderate 🟨

Biological Sensitivity = Low 🟩
Climate Exposure = Very High 🟥

Data Quality = 100% of scores≥ 2

	Brevoortia tyrannus	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.4	3	
	Prey Specificity	1.5	2.8	
	Adult Mobility	1.4	3	
	Dispersal of Early Life Stages	1.6	3	
	Early Life History Survival and Settlement Requirements	2.8	2.8	
	Complexity in Reproductive Strategy	2	2.8	
	Spawning Cycle	1.8	3	
	Sensitivity to Temperature	1.7	2.6	
	Sensitivity to Ocean Acidification	1.2	2.4	
	Population Growth Rate	1.4	3	
	Stock Size/Status	1.8	2	
	Other Stressors	1.7	2.2	
	Sensitivity Score	Low		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	3.9	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	3.5	3	
	Currents	2.4	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		Moderate		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Atlantic Menhaden (*Brevoortia tyrannus*)

Overall Climate Vulnerability Rank: Moderate. 100% bootstrap results in Moderate.

Climate Exposure: Very High. Four exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0), Salinity (3.9), and Sea Level Rise (3.5). Atlantic Menhaden are estuarine-dependent oceanic spawners. The species is a well-managed exploited fishery species and is not considered overfished or undergoing overfishing.

Biological Sensitivity: Low. A single sensitivity attribute scored above 2.5: Early Life History Survival and Settlement Requirements (2.8). The species is a well-managed exploited fishery species and is not considered overfished or undergoing overfishing.

Distributional Vulnerability Rank: High. Atlantic Menhaden are habitat generalists that are highly mobile and have widely dispersive early life stages.

Directional Effect on the Southeast U.S. Shelf: The effect of climate change on Atlantic Menhaden on the Southeast U.S. Shelf is expected to be neutral. Increased recruitment linked to warming temperatures could increase productivity of stocks on the southeast shelf. This increased productivity could be offset by emigration out of the region if Atlantic Menhaden shift their distribution northward as those waters warm and become suitable habitat. The effect of ocean acidification over the next 30 years is likely to be moderate, as copepods are a large portion of the diet of Atlantic Menhaden.

Data Quality: 100% of the data quality scores were 2 or greater. Atlantic menhaden are a well-studied and highly managed species with minimal data gaps.

Climate Effects on Abundance and Distribution: Wood and Austin (2009) in a study from Chesapeake Bay suggested that Atlantic Menhaden productivity may change with changes in precipitation and temperature. Atlantic Menhaden distribution is already changing, with a northward range expansion into the Gulf of Maine reported during warming periods (Dow 1977). Walsh et al. (2015) documented that the time of spawning of Atlantic Menhaden in the Northeast U.S. Shelf has also changed with more spawning in spring in recent years. Atlantic Menhaden spawn offshore and rely on larval transport by currents; thus, changes in oceanic circulation patterns could affect survival of potential recruits (Rogers and Van Den Avyle 1989). Copepods are an important diet component for Atlantic Menhaden, and a recent study has shown that copepods are affected by increasingly acidic conditions. The deleterious effects of ocean acidification are reinforced by other stressors likely to be present, such as thermal stress (Wang et al. 2018).

Life History Synopsis**:** Atlantic Menhaden are estuarine-dependent and marine, migratory members of the Clupied family. They form large, near-surface schools which are harvested by a large industrial purse-seine fishery centered in Virginia's territorial sea (Smith 1991). Atlantic Menhaden range from central Florida to the Gulf of Maine, although the center of their distribution is from the Carolinas through the Mid-Atlantic; during summer Atlantic Menhaden segregate along the Eastern Seaboard by size and age with larger and older individuals occurring farther north (Ahrenholz 1991). Adults reside in nearshore coastal waters and bays and large estuaries (Rogers and Van Den Avyle 1989). Spawning occurs in ocean waters, although there is evidence that in the northern half of the species' range some spawning may occur in large bays and sounds (e.g., Long Island Sound and Narragansett Bay). Some degree of spawning is believed to occur almost all months of the year; spawning intensity tends to peak during the fall migration south, in winter off the Carolinas, and again in spring as the adults move north; in the Gulf of Maine some spawning occurs during summer (Ahrenholz 1991). Egg hatching times vary as a function of temperature, but are generally less than 48 hrs at 18°C (Ahrenholz 1991). Larvae, which are estaurine dependent, ingress and settle in the upper reaches of coastal estuaries and are reliant on winds and currents for inshore transport (ASMFC 2010); temperature, salinity and other physical cues are no doubt important in this process. Juveniles utilize estuaries as nursery grounds; they may spend up to their first full year in these areas, moving farther down-estuary as they grow, after which they tend to join the adult stock in coastal migrations as age-1 fish (Ahrenholz 1991). Since juveniles and adults are dependent on the estuaries during various phases of their life histories, detrimental effects to estuarine habitats will have negative impacts on Atlantic Menhaden. Based on extensive tagging studies (Nicholson 1978) and genetics work (Lynch et al. 2010a), Atlantic Menhaden are believed to be a unit stock and are treated as such for stock assessment purposes. Juvenile and adult Atlantic Menhaden are obligate filter feeders and they strain phyto- and zooplankton from the water column by the sieving properties of their gill rakers (Friedland et al. 2006). The size and quality of plankton in the diet of Atlantic Menhaden changes ontogenetically. Juvenile menhaden tend to consume larger quantities of phytoplankton (Friedland et al. 2006; Lynch et al. 2010b), while adults tend to graze more on zooplankton, including copepodites and adult copepods (Friedland et al. 2011). Vascular marsh detritus and cellulose may also enter into the menhaden diet (Lewis and Peters 1984). As one of the most abundant filter feeders on the US East Coast, Atlantic Menhaden form an important link between the primary producers and various piscivorous fish, seabirds and marine mammals. Preferred water temperature range of Atlantic Menhaden is reported as 7.5 - 24.4°C with a mean of 13.2°C (OBIS; Fishbase.org). Maximum age for Atlantic Menhaden is about eight years, although most fish in the commercial catch are less than age-6; many reach sexual maturity at age-1 (ASMFC 2010). The most recent published stock assessment for Atlantic Menhaden reports that the stock is not overfished, nor is overfishing occurring (ASMFC 2017).

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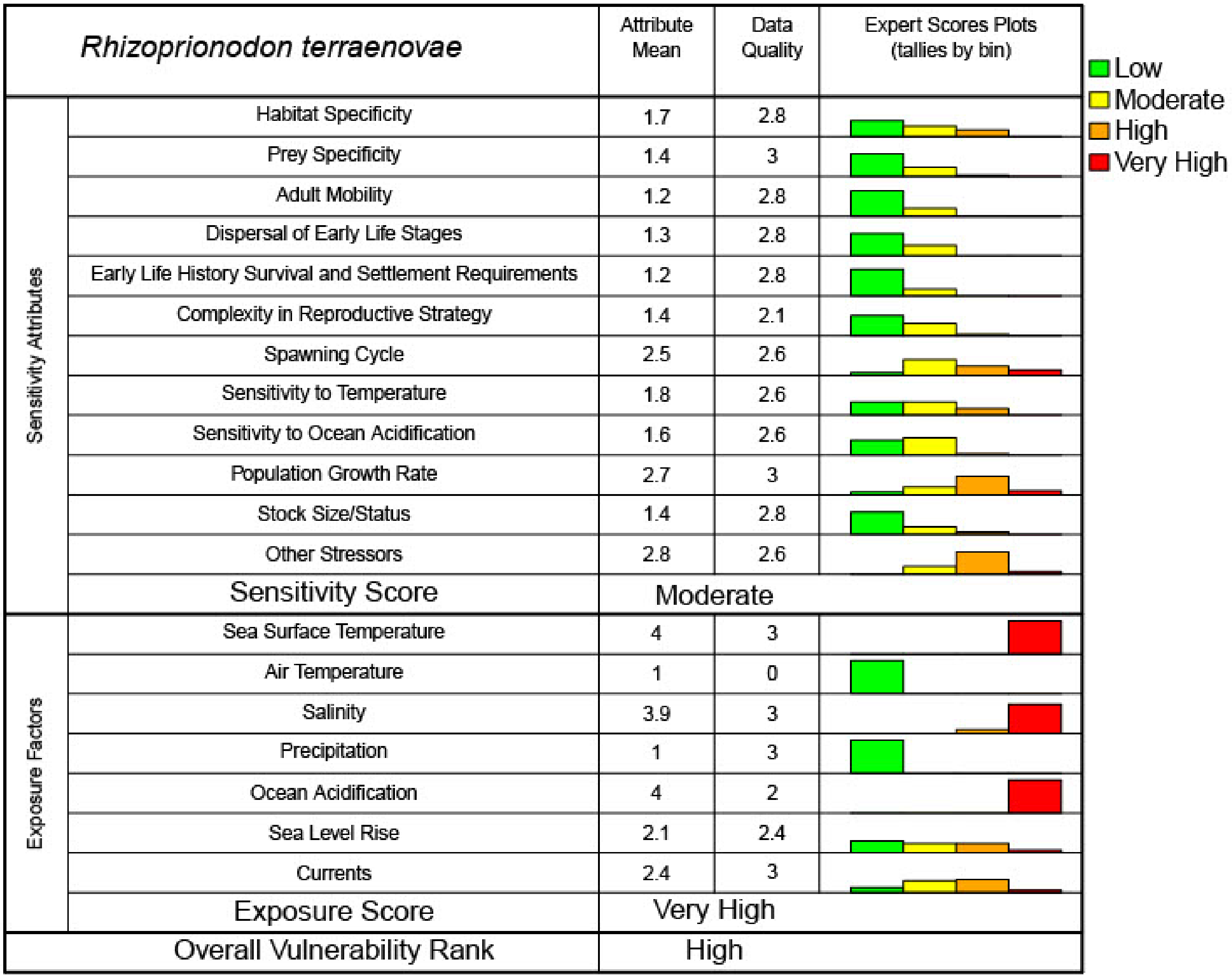
Atlantic Sharpnose Shark − *Rhizoprionodon terraenovae*

Overall Vulnerability Rank = High 🟧

Biological Sensitivity = Moderate 🟨
Climate Exposure = Very High 🟥

Data Quality = 100% of scores≥ 2



	Rhizoprionodon terraenovae	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.7	2.8	
	Prey Specificity	1.4	3	
	Adult Mobility	1.2	2.8	
	Dispersal of Early Life Stages	1.3	2.8	
	Early Life History Survival and Settlement Requirements	1.2	2.8	
	Complexity in Reproductive Strategy	1.4	2.1	
	Spawning Cycle	2.5	2.6	
	Sensitivity to Temperature	1.8	2.6	
	Sensitivity to Ocean Acidification	1.6	2.6	
	Population Growth Rate	2.7	3	
	Stock Size/Status	1.4	2.8	
	Other Stressors	2.8	2.6	
	Sensitivity Score	Moderate		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	3.9	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	2.1	2.4	
	Currents	2.4	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Atlantic Sharpnose Shark (*Rhizoprionodon terranovae*)

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

Climate Exposure: Very High**.** Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Salinity (3.9). Exposure to all three factors occurs during the life stages. Atlantic Sharpnose Sharks use estuarine, nearshore coastal and offshore habitats throughout their life stages, and an inclusion of molluscs and crustaceans in their diet may make them moderately vulnerable to increasing ocean acidification.

Biological Sensitivity: Moderate. Three sensitivity attributes scored ≥ 2.5: Spawning Cycle (2.5), Population Growth Rate (2.7), and Other Stressors (2.8). The species is moderately long-lived (18 years) and grows relatively fast, but has a gestation period of almost a year. Adults undergo inshore-offshore seasonal movements, and are likely subjected to environmental stressors while in their juvenile estuarine areas.

Distributional Vulnerability Rank: High. Three attributes indicated increased potential for distribution shift: high adult mobility, early life stage dispersal, and a habitat generalist habit.

Directional Effect on the Southeast U.S. Shelf: The effect of climate change on Atlantic Sharpnose Shark is estimated to be neutral. The species is widely distributed along the eastern seaboard and inhabits waters from inshore estuaries out to the continental shelf. There is no information suggesting either negative or positive directional effects of climate change.

Data Quality: 100% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution: Atlantic Sharpnose Shark may be moderately affected by ocean acidification due to the inclusion of crustaceans, molluscs and copepods in their diets (Bethea et al. 2006), although they likely have the flexibility to switch to teleosts if necessary. Rosa et al. (2014) found that rising temperatures and decreasing pH (increasing ocean acidity) significantly affected the routine metabolic rates of juvenile bamboo sharks and led to a rapid decline in survival.

Life History Synopsis**:** Atlantic Sharpnose Shark is relatively small (max. length approx. 120 cm) coastal shark with a ubiquitous distribution ranging from high-salinity waters of estuaries, across the continental shelf, and to offshore depths up to 280 m along the US South Atlantic coast (Branstetter 1981; Compagno 1984; Gelsleichter et al. 1999; Cortes et al. 2009; Carlson et al. 2008). Nursery and birthing 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; Carlson et al. 2008); as such, inshore juvenile habitats may be prone to anthropogenic degradation, development, and exploitation. Young-of-the-year consume mostly teleosts (sciaenids) and shrimps (Bethea et al. 2006); adults tend to feed on cephalopods, crustaceans, and teleosts (sciaenids), although diet composition may vary by locale (Bethea et al. 2006; Gelsleichter et al. 1999; Plumlee and Wells 2016). Given that crustaceans are a component of their diet, Atlantic Sharpnose Shark may be moderately sensitive to the effects of ocean acidification. Adults are highly mobile and undergo a seasonal inshore-offshore migration with their winter habitat being deeper, offshore waters (Compagno 1984; Parsons and

Hoffmayer 2005). In summer adult males tend to move to offshore waters, although the extent of their vertical migrations is unknown (Parsons and Hoffmayer 2005). Atlantic Sharpnose Sharks are viviparous with a gestation period of 10-12 months; parturition occurs May to July and pups are about 30 cm at birth (Parsons 1983; Loefer and Sedberry 2003). Atlantic Sharpnose Sharks are fast growers with von Bertalanffy growth rates of 0.61 for females and 0.49 for males; females mature between 2.8-3.9 years and males between 2.4-3.5 years; maximum age is reported to be 18 years and natural mortality is relatively low at 0.209-0.256 (Branstetter 1981; Loefer and Sedberry 2003; Parsons 1985; SEDAR34 2013). 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 were higher than the 0.5-ppm threshold deemed safe for human consumption (Adams and McMichael 1999).

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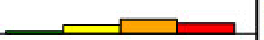
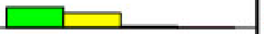
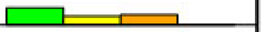
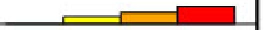
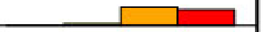
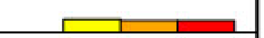
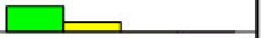
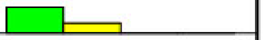
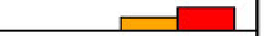
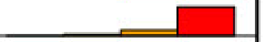
Atlantic and Gulf Sturgeon − *Acipenser oxyrinchus*

Overall Vulnerability Rank = Very High 🟥

Biological Sensitivity = Very High 🟥
Climate Exposure = High 🟧

Data Quality = 100% of scores≥ 2

	Acipenser oxyrinchus	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.9	3	
	Prey Specificity	1.5	2.8	
	Adult Mobility	1.8	3	
	Dispersal of Early Life Stages	3.6	3	
	Early Life History Survival and Settlement Requirements	3.3	2.2	
	Complexity in Reproductive Strategy	3.4	2.8	
	Spawning Cycle	3	3	
	Sensitivity to Temperature	1.3	2.4	
	Sensitivity to Ocean Acidification	1.3	2.4	
	Population Growth Rate	3.6	2.4	
	Stock Size/Status	3.8	2.4	
	Other Stressors	3.3	2.8	
	Sensitivity Score	Very High		
Exposure Factors	Sea Surface Temperature	1	0	
	Air Temperature	4	3	
	Salinity	3.4	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	3.4	2.8	
	Currents	1.8	2.8	
	Exposure Score	High		
Overall Vulnerability Rank		Very High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Atlantic sturgeon (*Acipenser oxyrhinchus*)

Overall Climate Vulnerability Rank: Very High. (91% bootstrap results in, Very High, 9% bootstrap results in High).

Climate Exposure: High. Four exposure factors contributed to this score: Air Temperature (4.0), Ocean Acidification (4.0), Salinity (3.4) and Sea Level Rise (3.4). Exposure to all factors occurs during the life stages. Atlantic Sturgeon are estuarine dependent, with adults spawning in the estuarine/riverine areas and juveniles remaining there for as long as 5 years.

Biological Sensitivity: Very High. Three sensitivity attributes scored ≥ 3.5: Dispersal of Early Life Stages (3.6),Population Growth Rate (3.6), and Stock Size/Status (3.8). Juvenile Atlantic Sturgeon remain in their natal river for a lengthy period of time; the species is long-lived and slow growing, and most populations on the East Coast have been classified as depleted.

Distributional Vulnerability Rank: Low. Three attributes indicated limited ability to undergo a distribution shift: sensitivity to temperature, limited early life stage dispersal, and relatively high habitat specialization.

Directional Effect in the Southeast U.S. Shelf: The effect of climate change on Atlantic Sturgeon is projected to be negative. Three climate factors have the potential to decrease productivity (sea level rise, increasing temperature, and increasing salinity). Sensitive biological attributes (low population growth rate, stock size/status) likely interact with climate exposure factors to affect productivity.

Data Quality: 100% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution: Several studies indicate that Atlantic Sturgeon will be impacted by climate change. Water temperature affects rate of maturation, timing of spawning migrations, and incubation time for fertilized eggs. Increasing temperature makes Atlantic Sturgeon more susceptible to hypoxia (Secor and Gunderson 1998). Changes in timing of larval/juvenile development could lead to mismatches in prey occurrence. Multivariable bioenergetics and survival modelling studies found that a 1°C temperature increase reduced productivity by 65% in Chesapeake Bay (Niklitschek and Secor 2005). Increasing salinity in estuarine habitat could limit suitable spawning habitat (Smith 1985) and cause increasing mortality of egg, larval and juvenile life stages, which are not tolerant of salinities above 5 ppt (Bain 1997).

Life History Synopsis**:** Atlantic Sturgeon is a large diadromous fish species found in marine and estuarine waters from Canada to Cape Canaveral, Florida (ASMFC 2009, Bigelow and Schroeder 1953). Juveniles are estuarine dependent, mostly associated with areas that are soft or silty. Subadults and adults utilize the marine environment, typically in waters less than 50 m in depth, inhabiting coastal bays, sounds, and ocean waters (Murawski and Pacheco 1977).

Juvenile Atlantic Sturgeon are considered omnivores that feed on aquatic insects, insect larvae, and other invertebrates. Adults are benthic feeders. Diets of adult and migrant subadult Atlantic Sturgeon include mollusks, gastropods, amphipods, annelids, decapods, isopods, and some fish such as sand lance (Bigelow and Welsh 1924, Guilbard et al. 2007, McLean et al. 2013). Adults are highly mobile, undertaking yearly movements generally described as into estuaries in spring and returning to ocean waters in fall, although detections in either ocean or estuarine environments have occured in all seasons. Additionally, tagging studies have shown ocean migrations of up to 1,450 km (Dovel and Berggren 1983). Atlantic Sturgeon migrate to spawning areas within a specific time period triggered by water temperature, with males migrating first and females arriving later. Males and females do not necessarily spawn every year, and while tagging studies and genetic analyses provide evidence that Atlantic Sturgeon return to their natal rivers for spawning, fish may occur on the spawning grounds during spawning season but may not spawn. Migrations into coastal tidal rivers begin as early as February in the southern portion of the range and continue through June and July in northernmost waters. Spawning occurs in freshwater or brackish estuarine rivers with sufficient flow, DO, and suitable substrate for successful egg development, when water temperatures reach 13-18°C. Fertilized eggs become sticky and adhere to the bottom substrate (i.e., no planktonic stage). Hatching occurs after 4-5 days. Larval stage lasts approximately 4 weeks. Larval Atlantic Sturgeon are thought to remain in the same habitat they were spawned in, and juveniles may remain in the rivers for 2-5 years before migrating out into the marine environment (Jones et al. 1978). Atlantic Sturgeon occupy a broad temperature range from 4-24°C, with mean temperature occurrence of 17°C (Fishbase). Several life history characteristics, such as timing of spawning migrations, rate of maturation, and incubation time of fertilized eggs, are all dependent upon water temperature, and climate-mediated changes to water temperature profiles could affect Atlantic Sturgeon. Atlantic Sturgeon should be affected minimally by increases in ocean acidification, as their diets are not reliant on diet items with calcium carbonate shells. Atlantic Sturgeon exhibit life history traits that make them vulnerable to population disturbances (low growth coefficient, delayed age-at-maturity, large asymptotic length, extended longevity, low natural mortality rate), and the species is likely to be slow to recover. A recent stock assessment by the ASMFC classified all East Coast populations as depleted based on the total mortality estimates and biomass/abundance status relative to historical levels (ASMFC 2018). Overfishing was likely the initial cause, but in recent decades habitat destruction and alteration has had more of an effect. Potential stressors for Atlantic Sturgeon include alteration of their riverine/estuarine habitat, dredging, dam construction, upstream water withdrawals, and decreased water quality (pollution). Spawning and nursery habitat has likely been lost in many river systems on the East Coast. Lowered oxygen events in estuarine waters would be detrimental to eggs, larvae and juveniles. Altered stream flows could affect survival of early life history stages. Mortality of Atlantic Sturgeon by a red tide event has been documented (Fire et al. 2012).

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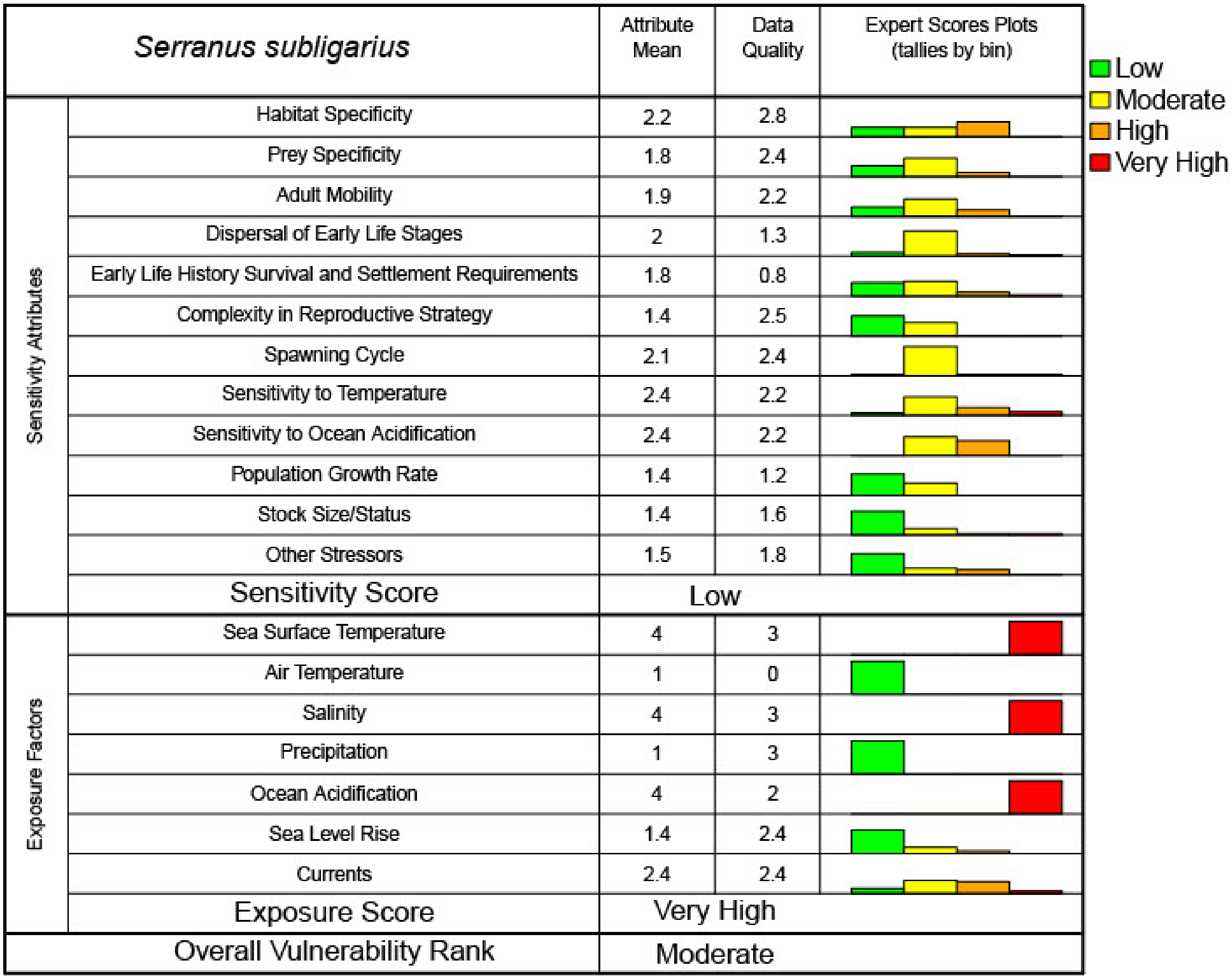
Belted Sandfish − *Serranus subligarius*

Overall Vulnerability Rank = Moderate 🟨

Biological Sensitivity = Low 🟩
Climate Exposure = Very High 🟥

Data Quality = 58% of scores ≥ 2



Serranus subligarius		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.2	2.8	
	Prey Specificity	1.8	2.4	
	Adult Mobility	1.9	2.2	
	Dispersal of Early Life Stages	2	1.3	
	Early Life History Survival and Settlement Requirements	1.8	0.8	
	Complexity in Reproductive Strategy	1.4	2.5	
	Spawning Cycle	2.1	2.4	
	Sensitivity to Temperature	2.4	2.2	
	Sensitivity to Ocean Acidification	2.4	2.2	
	Population Growth Rate	1.4	1.2	
	Stock Size/Status	1.4	1.6	
	Other Stressors	1.5	1.8	
	Sensitivity Score	Low		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	4	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	1.4	2.4	
	Currents	2.4	2.4	
	Exposure Score	Very High		
Overall Vulnerability Rank		Moderate		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Belted Sandfish (*Serranus subligarius*)

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

Climate Exposure: Very High. Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Salinity (4.0). Exposure to all three factors occur during the life stages. Belted Sandfish are found in nearshore and coastal habitats ranging from jetties to artificial reefs to rocky hardbottom.

Biological Sensitivity: Low. No sensitivity attributes ≥ 2.5, although Sensitivity to Temperature (2.4) and Sensitivity to Ocean Acidification (2.4) were borderline.

Distributional Vulnerability Rank: Moderate. Three attributes indicated a moderate potential for distribution shift: adult mobility, dispersal of early life stages, and a preference for solid substrate as the habitat of adults.

Directional Effect on the Southeast U.S. Shelf: The effect of climate change on Belted Sandfish on the Southeast U.S. Shelf is estimated to be neutral . While there may be moderate indirect effects of ocean acidification through preferred diet items, the species is a resident of mid-depth rocky hardbottom environments out to 42 m and not expected to be impacted by nearshore shallow water temperature increases.

Data Quality: 58% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution: There have been no targeted studies of the effects of climate change on Belted Sandfish. The species may be moderately affected by ocean acidification. The species has a fairly narrow preferred temperature range, 23-27°C (Fishbase.org) and fitness and survival might be impacted by increasing temperatures.

Life History Synopsis**:** Belted Sandfish are small, territorial sea bass reported from North Carolina, rare in FL Keys, occurs throughout the Gulf of Mexico to Mexico and the Yucatan Peninsula. It is also known from Cuba and Belize (Fishbase; Claro, 1994; ReefNet, 2007). Both juvenile and adults display facultative habitat utilization and occur near the bottom over rocky and mixed habitats, near jetties, artificial reefs, and rock outcroppings from one to 42 m (Fishbase; Hastings & Bortone 1980; Oliver 1997; Anderson et al. 2015). It is an efficient colonizer of artificial reef habitats and often dominates the fish fauna on inshore jetties and offshore platforms (Hastings and Bortone 1980; Anderson et al. 2015). Adults reach a maximum length of 10 cm total length (TL) and a maximum age of 4-5 years (Robins and Ray 1986; Oliver 1997). In individuals less than 40 mm SL, copepods were the most numerous food item, but gammaridean amphipods and shrimp were the most important items by weight. In individuals larger than 40 mm SL, gammaridean and caprellid amphipods were the most numerous food items, however, crabs, shrimp, and fishes were the most important food items by weight. Of the 15 fishes consumed, seven were *Hypleurochilus geminatus*. Other identifiable fishes were *Opsanus beta*, *Eucinostomus argenteus*, and one *S. subligarius* (Hastings & Bortone 1980).

Belted Sandfish are generally not highly mobile. They are rarely observed over sand more than one meter away from solid substrate (Hastings 1972; Hastings & Bortone 1980). However, Hastings (1972) and Hastings and Bortone (1980) observed the sudden appearance of large (age 2-4) individuals at inshore localities in spring and surmised that *S. subligarius* probably leaves inshore locations during the coldest part of the year, moves to offshore reefs, and may return or 'home' back to their residence of the previous year. Evidence indicates that a migration occurs in spring and fall of most years, depending on temperature extremes (Hastings and Bortone 1980). Belted Sandfish do not form large spawning aggregations, but do display a complex reproductive strategy. First year fish (age-1) function as both males and females and thus are functional synchronous hermaphrodites. Every hermaphrodite can spawn in three roles over the course of the daily spawning period: female pair spawn, male pair spawn, and male streak spawn (parasitizing pair spawns). Pair spawning fish trade eggs, taking turns fertilizing one another's eggs. Egg trading is not symmetrical; the smaller fish in a pair spawns more often in the female role than the larger fish. Although age-1 individuals have fully mature spermatozoa and eggs, on the jetties in the northeastern Gulf of Mexico most spawning involved larger, older individuals (Clark 1959; Hastings and Bortone 1980; Oliver 1997). The spawning season lasts from April through September. The presence of all oocyte stages within most individuals from spring and summer apparently indicates that an individual spawns repeatedly throughout this time (Hastings and Bortone 1980). The planktonic larval duration (PLD) and early life history (larval) requirements of Belted Sandfish are unknown. A congener, the Comber (Serranus cabrilla), is known to have a PLD of approximately 26 days (Raventos and Macpherson 2001), similar to the majority of reef fishes that have PLDs of 20-30 d, although PLDs can range from 8-150 d (Victor 1991). Larvae are known to recruit to adult habitats, as recently-settled (1-2 cm TL) juveniles have been observed together with adults on hard bottom reefs in depths of 16-21 m at Gray's Reef National Marine Sanctuary, off the coast of Georgia (RC Muñoz, pers. obs.). Belted Sandfish occur from 23.3-27.5℃ (preferred temperature, Kaschner et al. 2016) and can be found distributed across two zoogeographic provinces. They occupy habitats in 1– 42 m depths. Belted Sandfish may be indirectly affected by ocean acidification, as adults and juveniles have been found to consume prey (copepods, amphipods, crabs, shrimp; Hastings and Bortone 1980) that are negatively affected by ocean acidification (Kurihara et al. 2008; Bhadury 2015; Long et al. 2013; Cripps et al 2015). Evidence suggests that Belted Sandfish have a relatively rapid population growth rate. They breed in the first year, have a maximum life span of four to five years, reach a small maximum length of 10 cm, and have a Von Bertalanffy growth coefficient (*K*) estimated at 0.57. Although the stock has never been assessed, it is highly productive, extremely abundant, is not fished, and is thought to be stable over time, so the workshop scorers thought the population would be at or above B_{MSY}. This widely distributed species is common to abundant where it occurs over shallow rocky reefs. There are no known major threats, therefore, it is listed as Least Concern (Anderson et al. 2015). Other potential stressors for Belted Sandfish are not readily apparent. It has been recorded as a prey item of the invasive lionfish, however, it is not likely that this will drive significant population declines on a global level (Muñoz et al. 2011, Dahl and Patterson 2014; Anderson et al. 2015).

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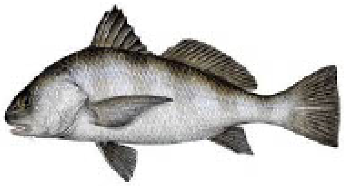
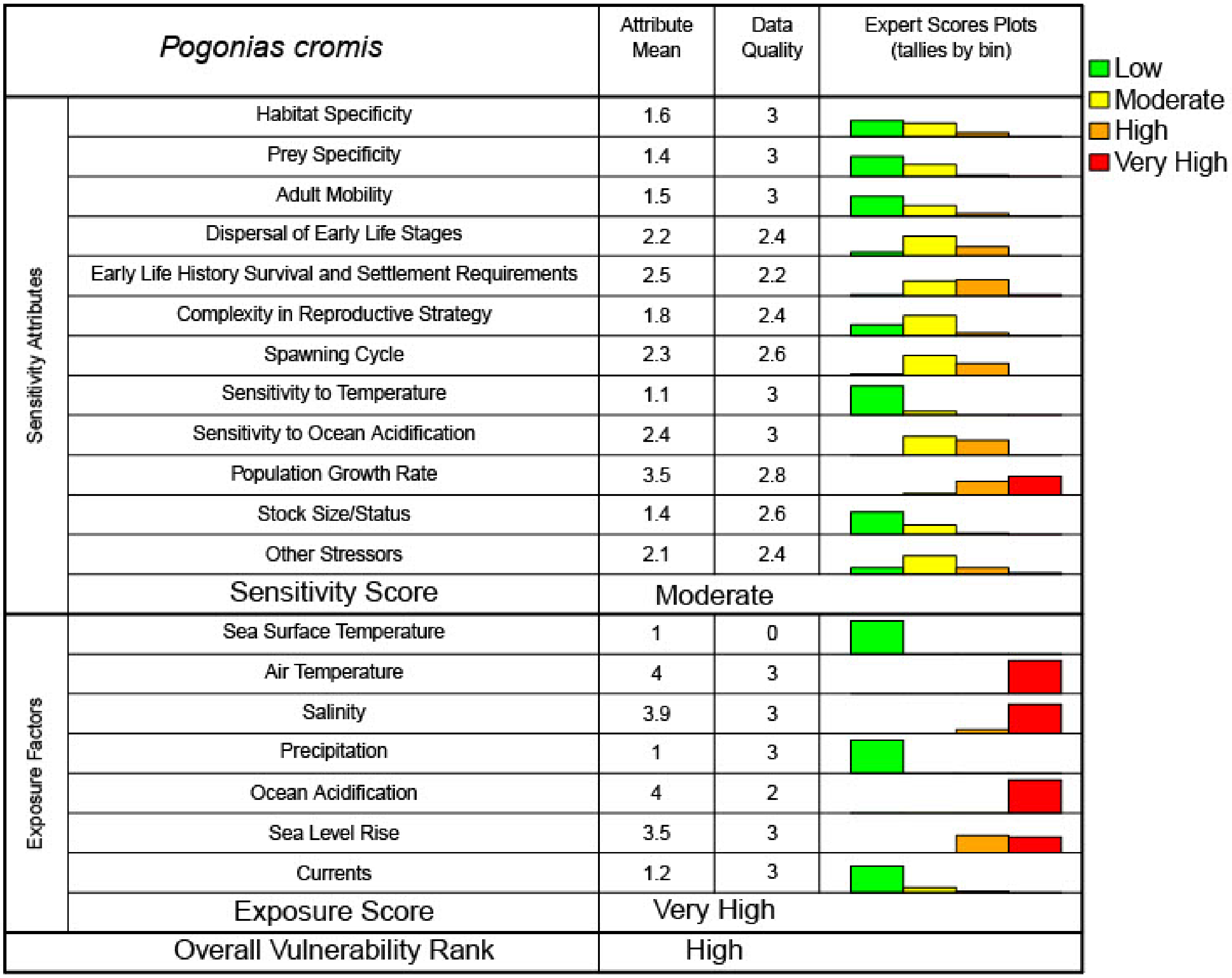
Black Drum − *Pogonias cromis*



Overall Vulnerability Rank = High 🟧

Biological Sensitivity = Moderate 🟨
Climate Exposure = Very High 🟥

Data Quality = 100% of scores≥ 2



Pogonias cromis		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.6	3	
	Prey Specificity	1.4	3	
	Adult Mobility	1.5	3	
	Dispersal of Early Life Stages	2.2	2.4	
	Early Life History Survival and Settlement Requirements	2.5	2.2	
	Complexity in Reproductive Strategy	1.8	2.4	
	Spawning Cycle	2.3	2.6	
	Sensitivity to Temperature	1.1	3	
	Sensitivity to Ocean Acidification	2.4	3	
	Population Growth Rate	3.5	2.8	
	Stock Size/Status	1.4	2.6	
	Other Stressors	2.1	2.4	
	Sensitivity Score	Moderate		
Exposure Factors	Sea Surface Temperature	1	0	
	Air Temperature	4	3	
	Salinity	3.9	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	3.5	3	
	Currents	1.2	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Common Name (*Species Name*) - Black drum - *Pogonias cromis*

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

Climate Exposure: Very High. Four exposure factors contributed to this score: Air Temperature (4.0), Ocean Acidification (4.0), Salinity (3.9), and Sea Level Rise (3.5). Black Drum use nearshore coastal as well as shallow estuarine/riverine habitats making them susceptible to fluctuating environmental conditions as well as sea level rise.

Biological Sensitivity: Moderate. Two sensitivity attributes scored ≥ 2.5: Early Life History Survival and Settlement Requirements (2.5) and Population Growth Rate (3.5). Black Drum are a relatively long-lived, moderately late-maturing fish with slow population growth rates. Their estuarine habitat could be affected by changing environmental conditions brought on by climate change, as well as by anthropogenic alteration.

Distributional Vulnerability Rank: High. Two attributes indicated increased potential for distribution shift: high adult mobility, low habitat specialization. Additionally, early life stage dispersal was borderline between moderate and high potential for distribution shift.

Directional Effect on the Southeast U.S. Shelf: The effect of climate change on Black Drum on the Southeast U.S. Shelf is estimated to be neutral. The effect of ocean acidification will likely be moderate to impactful, as crustaceans and molluscs are a significant diet component. This is somewhat offset by the finding that sea level rise increased occupancy probability of Black Drum in a study from the Gulf of Mexico (Fujiwara et al. 2019). Black Drum do enjoy wide thermal and salinity tolerances, although sudden and sustained air temperature drops may cause mass mortality events.

Data Quality: 100% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution: Black Drum feed primarily on crustaceans and molluscs and are likely to be negatively impacted by increasing ocean acidification. Increasing salinity in estuarine areas is likely to have a negative effect on small juveniles, although larger juveniles and adults should tolerate moderate increases in salinity. Sea level rise may impact the amount of suitable nursery habitat available.

Life History Synopsis**:** : Black Drum are a coastal and estuarine species widely distributed from Nova Scotia to Brazil. Along the southeastern United States it is found from North Carolina through south Florida and through the Gulf of Mexico to the Yucatan Peninsula. Adults are 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. Beaumarriage (1969) reported similar results for Black Drum in Florida. 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 that juvenile Black Drum, while occurring over widely varying temperatures and salinities, were collected most often 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 off Florida occurs November-April with peak spawning in February and March), so reproduction may be temperature dependent. Black Drum spawn in bays, estuaries, and coastal waters near the mouths of estuaries. 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 eat molluscs, gastropods, bivalves, small shrimps and crabs. Adults consume benthic crustaceans (crabs, shrimp), clams and oysters, and some small fishes. Effects of Increasing ocean acidification on diet items could have an effect on fitness of Black Drum in future changing climate scenarios. Black Drum prefer waters where temperatures range from 12 - 33°C (McIlwain 1978). Sudden temperature drops during winter cause them to migrate to deeper waters. Mass mortality is common when sudden, sustained temperature drops occur (Simmons and Breuer 1962). Black Drum are not overfished or undergoing overfishing based on a 2014 benchmark stock assessment (ASMFC 2015). Genetic studies have found distinct subpopulations (genetic heterogeneity) in the Gulf of Mexico and western Atlantic, with limited dispersal beyond the natal estuary (Leard et al. 1993).

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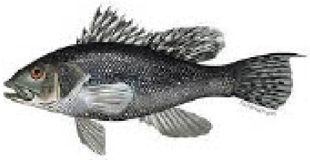
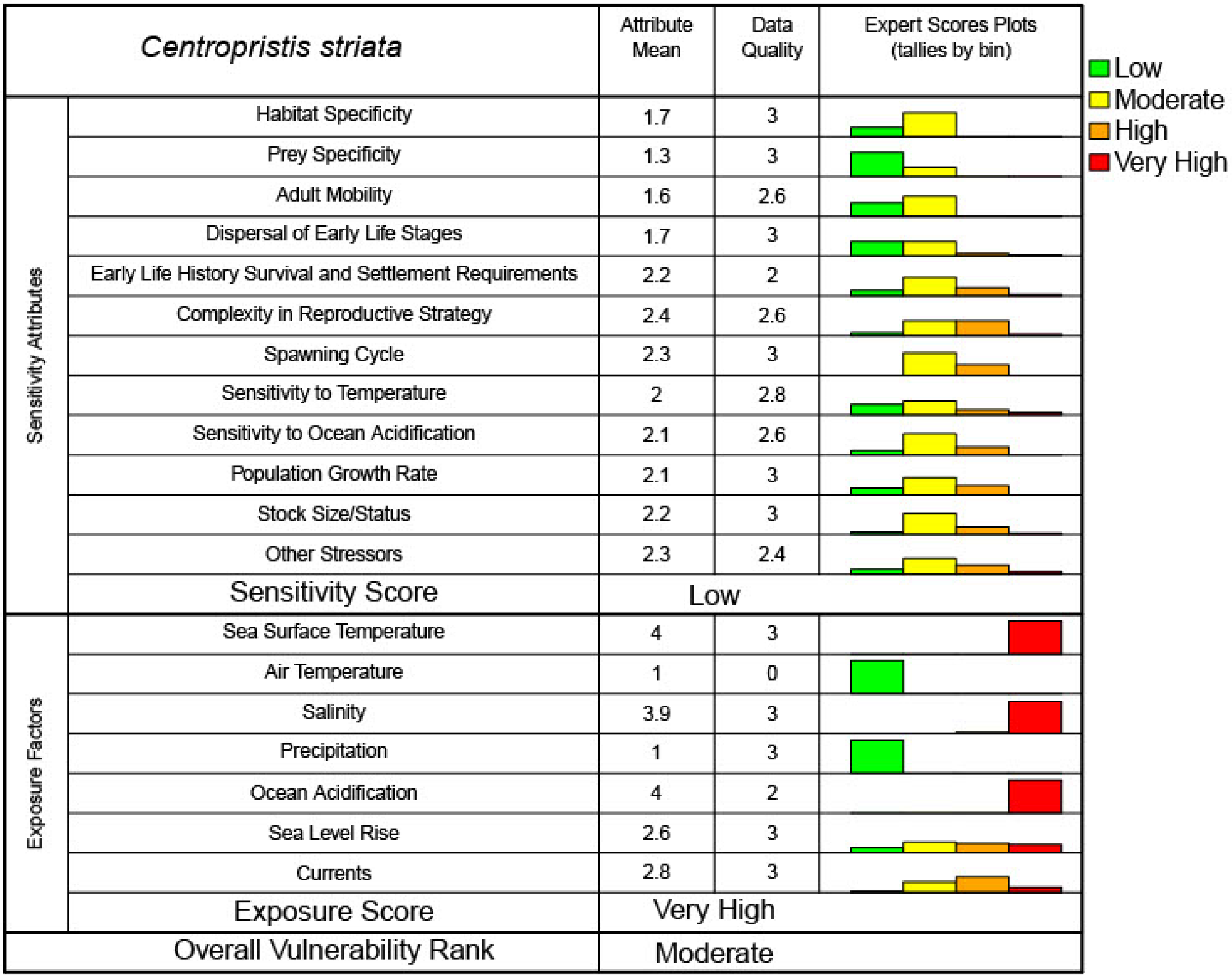
Black Sea Bass − *Centropristis striata*



Overall Vulnerability Rank = Moderate 🟨

Biological Sensitivity = Low🟩
Climate Exposure = Very High 🟥

Data Quality = 100% of scores≥ 2



	Centropristis striata	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.7	3	
	Prey Specificity	1.3	3	
	Adult Mobility	1.6	2.6	
	Dispersal of Early Life Stages	1.7	3	
	Early Life History Survival and Settlement Requirements	2.2	2	
	Complexity in Reproductive Strategy	2.4	2.6	
	Spawning Cycle	2.3	3	
	Sensitivity to Temperature	2	2.8	
	Sensitivity to Ocean Acidification	2.1	2.6	
	Population Growth Rate	2.1	3	
	Stock Size/Status	2.2	3	
	Other Stressors	2.3	2.4	
	Sensitivity Score	Low		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	3.9	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	2.6	3	
	Currents	2.8	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		Moderate		

Black Sea Bass (*Centropristis striata*)

Overall Climate Vulnerability Rank: Moderate. 94% bootstrap results in Moderate, 4% bootstrap results in High.

Climate Exposure: Very High. Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Salinity (3.9). Black Sea Bass are an offshore marine species, with younger life stages reported from some estuarine areas.

Biological Sensitivity: Low. No sensitivity attributes scored above 2.5: Complexity in Reproductive Strategy (2.4), Spawning Cycle (2.3) and Other Stressors (2.3) were rated borderline moderate vulnerability, likely due to a protogynous reproductive life cycle, and exposure of early life history stages utilizing inshore estuarine areas to anthropogenic disturbances.

Distributional Vulnerability Rank: High. Three attributes indicated increased potential for distribution shift: high adult mobility, widespread potential for early life stage dispersal, and relatively low habitat specialization.

Directional Effect on the Southeast U.S. Shelf: The effect of climate change on Black Sea Bass on the Southeast U.S. Shelf is predicted to be neutral. Increased recruitment as a result of warming temperatures in the region will be offset somewhat by emigration northward in response to warming. There may be minor impacts from ocean acidification.

Data Quality: 100% of the data quality scores were 2 or greater. Black Sea Bass are a well-studied species.

Climate Effects on Abundance and Distribution: Changes in distribution of Black Sea Bass have been linked to warming in the Northeast U.S. Shelf (Bell et al. 2014), and increases in abundance in Long Island Sound over the last several decades were linked to warming waters (Howell and Auster 2012). Black Sea Bass may be moderately affected by increasing ocean acidification due to inclusion in their diets of decapod crustaceans.

Life History Synopsis**:** Black Sea Bass are a medium-sized temperate demersal reef fish distributed in the western Atlantic Ocean from Canada to northeast Florida and the Gulf of Mexico. Early juveniles utilize habitat ranging from estuaries to offshore reefs. Adult Black Sea Bass are strongly associated with structurally complex habitats, including inshore piers, inshore, nearshore, and offshore rocky reefs and low-relief hardbottom, cobble and rock fields, stone coral patches, exposed stiff clay, and mussel beds (Kolek 1990; Able et al. 1995; Drohan et al. 2007). Black Sea Bass are protogynous hermaphrodites, reaching maturity first as females at age 2-3 years and then transitioning to males around age 5 (Drohan et al. 2007). Larger fish occur in deeper water. Potential overwintering habitat may be defined by bottom water temperatures > 7.5 °C (Able and Fahay 2010). Fish have been collected at relatively low salinities (range: 1-36 ppt) in North Carolina estuaries but are most frequent where values exceed 14 ppt. Salinity ranges for fish in Gulf of Mexico and South Atlantic Bight estuaries are similar. Black Sea Bass typically spawn in the south Atlantic from January through June with a peak from March through May (Wenner et al. 1986; Mercer 1989). Larvae are pelagic and drift for 2-4 weeks prior to settlement on shell beds (Drohan et al. 2007) and potentially other habitats. Juveniles, which are diurnal visual predators, prey on benthic and epibenthic crustaceans (isopods, amphipods, small crabs, sand shrimp, copepods, mysids) and small fish, and their diets appear to change with body size. Decapods are the dominant prey item for all size classes of Black Sea Bass (Bowman et al. 2000). Adults are generalist carnivores that feed on a variety of infaunal and epibenthic invertebrates, especially crustaceans (including juvenile American lobster *Homarus americanus*, crabs, and shrimp) small fish, and squid. Fish become a more significant component of the adult diet, particularly for the largest Black Sea Bass (> 40 cm), where sand lance (*Ammodytes dubius*) and scup (*Stenotomus chrysops*) were prominent (Bowman et al. 2000). The species is managed as three separate stocks: a Mid-Atlantic stock (north of Cape Hatteras), a South Atlantic Bight stock (south of Cape Hatteras to Florida), and a Gulf of Mexico stock (Drohan et al., 2007; Able and Fahay, 2010). The most recent assessment for Black Sea Bass in the south Atlantic region (SEDAR 2018) concluded that with $SSB_{2016}/MSST = 1.15$ and $F_{2014\text{-}2016}/FMSY = 0.64$, the stock was not overfished and not undergoing overfishing. Juveniles using inshore habitats may be affected by habitat degradation and pollution; adults are likely resilient to such anthropogenic effects given their usual offshore habitat.

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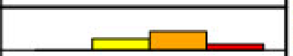
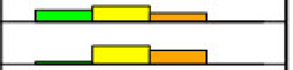
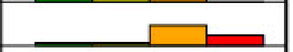
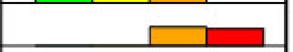
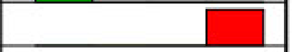
Blueback Herring – *Alosa aestivalis*

Overall Vulnerability Rank = Very High 🟥

Biological Sensitivity = High 🟧
Climate Exposure = Very High 🟥

Data Quality = 92% of scores ≥ 2

	Alosa aestivalis	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.8	2.6	
	Prey Specificity	1.8	2.8	
	Adult Mobility	1.9	2.8	
	Dispersal of Early Life Stages	2.3	2.4	
	Early Life History Survival and Settlement Requirements	3	2.4	
	Complexity in Reproductive Strategy	3.1	2.8	
	Spawning Cycle	3.2	3	
	Sensitivity to Temperature	2.6	3	
	Sensitivity to Ocean Acidification	1.6	3	
	Population Growth Rate	1.8	2.2	
	Stock Size/Status	3.5	1.9	
	Other Stressors	3.2	2.4	
	Sensitivity Score	High		
Exposure Factors	Sea Surface Temperature	1	0	
	Air Temperature	4	3	
	Salinity	3.8	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	3.7	3	
	Currents	1.5	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		Very High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Blueback Herring (*Alosa aestivalis*)

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

Climate Exposure: Very High. Four exposure factors contributed to this score: Salinity (3.8), Ocean Acidification (4.0), Air Temperature (4.0), and Sea Level Rise (3.7). Exposure to all three factors occurs during the life stages. Blueback Herring occupy coastal marine waters as adults and undertake migrations into riverine-estuarine systems to spawn.

Biological Sensitivity: High. Five sensitivity attributes were ≥ 3.0 and contributed to the High ranking: Early Life History Survival and Settlement Requirements (3.0), Spawning Cycle (3.2), Complexity in Reproductive Strategy (3.1), Stock Size/Status (3.5) and Other Stressors (3.2). Blueback Herring are a diadromous species that move from offshore marine waters into rivers during spawning season, where they likely encounter a degraded environment due to anthropogenic influences.

Distributional Vulnerability Rank: Moderate. Two attributes indicated limited vulnerability to distribution shift: moderate habitat specialization, and sensitivity to temperature, especially for early life history stages.

Directional Effect in the Southeast U.S. Shelf: The effect of climate change on Blueback Herring is projected to be negative. Blueback Herring is distributed within the region south to Florida, and warming seawater temperatures in the southern portion of the range may cause a shift northward in distribution and decreases in survival and productivity. Changes to streamflow, caused by either changes in precipitation patterns or anthropogenic alterations, also may negatively affect productivity and survival.

Data Quality: 92% of the data quality scores were 2 or greater. Stock Size/Status is the biggest data gap for Blueback Herring in most river systems in the southeast.

Climate Effects on Abundance and Distribution: Blueback Herring will be affected by climate-driven changes in productivity and distribution. Distribution will likely shift more northward due to warming. Ocean acidification is unlikely to have a major effect on the species. Tommasi et al. (2015) indicated that recruitment was affected by stream temperatures and river flow, both of which will be impacted by climate change. Natal homing is an important element in Blueback Herring life history, thus the marine distribution may be changing faster than the spawning distribution.

Life History Synopsis**:** Blueback Herring is an anadromous species distributed in the western Atllantic from Nova Scotia to the St. Johns River in Florida. Juveniles utilize both freshwater riverine and brackish estuarine habitat. Adults can utilize estuarine habitat but outside of spawning runs are usually found in coastal and offshore marine waters up to 55m depth and 200 km offshore. Juvenile Blueback Herring feed on zooplankton (copepods, cladocerans) and larval dipterans. Adults are size-selective zooplankton feeders, primarily eating ctenophores, calanoid copepods, amphipods, mysids, and small fish (Domeruth and Reed 1980; Loesch 1987; Burbidge 1974; Klauda et al. 1991; Bigelow and Shroeder 1953). Blueback Herring, like many clupeids, likely evolved to synchronize the larval stage with optimal timing of plankton production cycles (Crecco and Blake 1983). Blueback Herring are highly mobile, conducting offshore-inshore migrations during late winter and early spring for spawning in freshwater rivers and creeks. Adults have been known to migrate up to 248 km upstream in spawning rivers. Juveniles often leave the estuarine nursery habitat after a month or two, but in some areas stay until the next spring. After migrating in from the ocean, spawning occurs in fresh or brackish water, in tidally influenced portions of coastal rivers (Bozeman and Van Den Avyle 1989). Spawning occurs in deep swift water over hard substrates (Lee et al. 1980) or in shallow vegetated areas, old rice fields, river swamps, and small tributaries above tidal influence (Bozeman and Van Den Avyle 1989). These inshore areas could be negatively affected by human activities, and dams are an impediment to spawning migrations. Eggs incubate in 3-4 days at 20°C. Larval survival is minimal above 28°C. Changes in water flow rates may have an effect on larval survival. For example, year class size decreased with increasing discharge events (O'Rear 1983; Dixon 1996; Jones 1978; Edsall 1970; Marcy 1973). Yolk sac larvae drift passively downstream to slower moving water, where they grow into juveniles. Eggs and larvae can survive in salinities as high as 18-22 ppt. Optimal salinity range is 0-2 ppt for eggs (Johnston and Cheverie 1988; Klauda et al. 1991; Loesch 1987). All life stages are important prey for fish, birds, amphibians, reptiles, and mammals, but there is no evidence that predation pressure affects the stock (Klauda et al. 1991). Blueback Herring diet is not dependent on shell-forming animals and thus are not likely to be severely impacted by indirect effects of increasing ocean acidification. Little information is available on Blueback Herring's intrinsic population growth rate. Based on a moderate age at maturity, a relatively low maximum age and overall small maximum size, the ability of the species to recover from population disturbances could be moderately affected. A 2017 stock assessment of combined river herring (Blueback Herring and Alewife) population status found the majority of stocks in east coast river systems were either depleted relative to historical status or too data-deficient to make a determination. NOAA Fisheries determined the species did not warrant listing under the Endangered Species Act in 2019. Nonetheless, the species are the subject of conservation efforts. Potential stressors for Blueback Herring are many, including riverine habitat alteration/degradation, changing precipitation and river flow patterns that could affect eggs/larvae; increasing water temperatures, and salinity intrusion into the estuaries during egg/larval phases.

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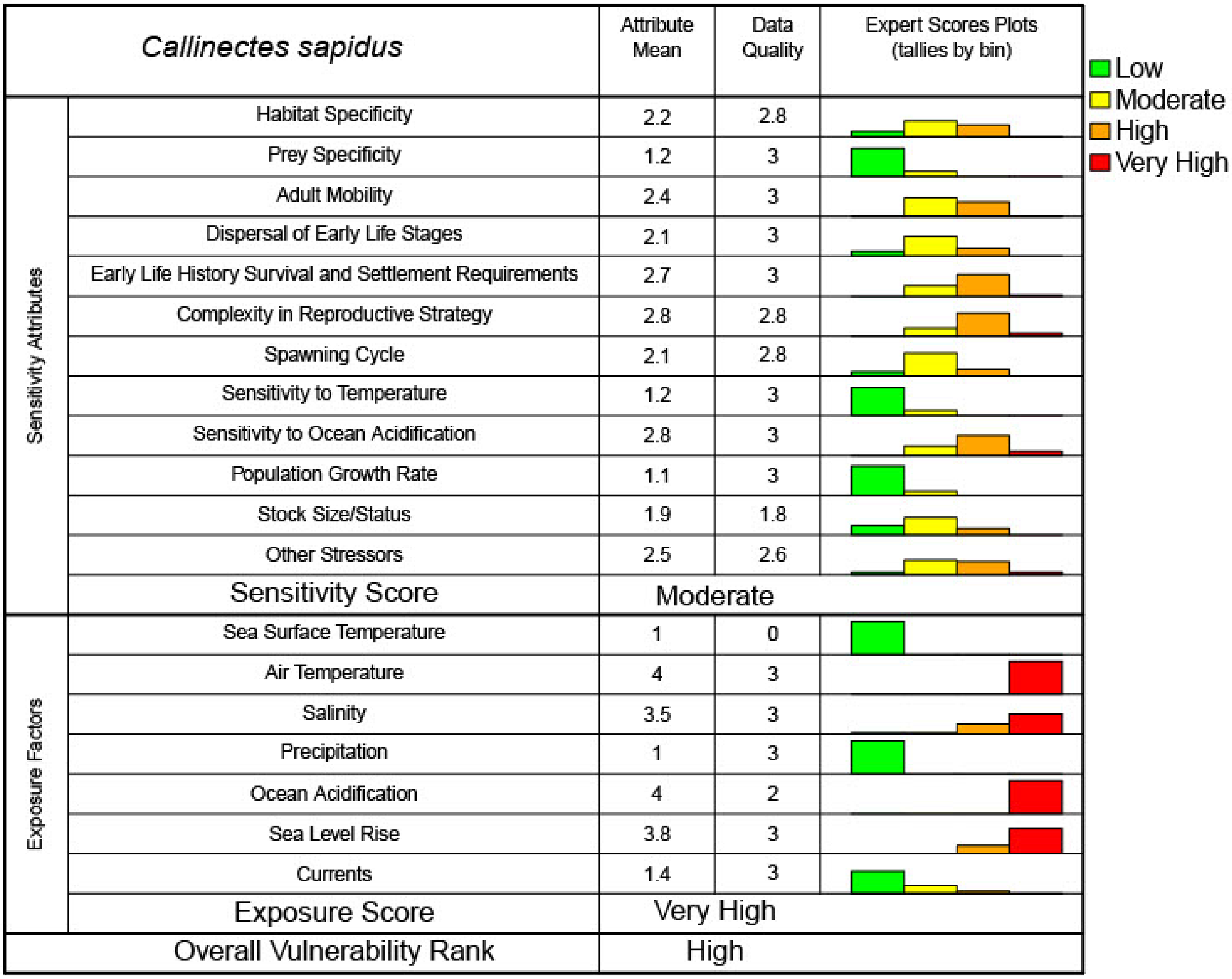
Blue Crab − *Callinectes sapidus*

Overall Vulnerability Rank = High 🟧

Biological Sensitivity = Moderate 🟨
Climate Exposure = Very High 🟥

Data Quality = 92% of scores ≥ 2



Callinectes sapidus		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.2	2.8	
	Prey Specificity	1.2	3	
	Adult Mobility	2.4	3	
	Dispersal of Early Life Stages	2.1	3	
	Early Life History Survival and Settlement Requirements	2.7	3	
	Complexity in Reproductive Strategy	2.8	2.8	
	Spawning Cycle	2.1	2.8	
	Sensitivity to Temperature	1.2	3	
	Sensitivity to Ocean Acidification	2.8	3	
	Population Growth Rate	1.1	3	
	Stock Size/Status	1.9	1.8	
	Other Stressors	2.5	2.6	
	Sensitivity Score	Moderate		
Exposure Factors	Sea Surface Temperature	1	0	
	Air Temperature	4	3	
	Salinity	3.5	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	3.8	3	
	Currents	1.4	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Blue Crab (*Callincetes sapidus*)

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

Climate Exposure: Very High. Four exposure factors contributed to this score: Air Temperature (4.0), Ocean Acidification (4.0), Sea Level Rise (3.8) and Salinity (3.5). Blue Crab are estuarine-obligate, thus their early life stage habitat could be affected by increasing sea level or temperatures, while ocean acidification has the potential to affect Blue Crab directly (shell formation) and indirectly (reliance on mollusks/crustaceans in their diet).

Biological Sensitivity: Moderate. Four sensitivity attributes scored ≥ 2.5: Sensitivity to Ocean Acidification (2.8), Complexity in Reproductive Strategy (2.8), Early Life History Survival and Settlement Requirements (2.7), and Other Stressors (2.5). Blue Crab females undergo a single spawning event in their life. Early life stages spend up to a year in estuarine-riverine nursery areas that are often anthropogenically disturbed.

Distributional Vulnerability Rank: Moderate. Three attributes indicated a potential for distribution shift: high adult mobility, widely dispersing early life stages, and a habitat generalist quality.

Directional Effect in the Southeast U.S. Shelf: The effect of climate change on Blue Crab on the Southeast U.S. Shelf is estimated to be neutral. Research suggests that crustaceans may be negatively impacted by ocean acidification. This negative impact is offset by the possibility that warming may lead to increased productivity and northward shifts in the region, both of which would represent positive effects of climate change. The species is both eurythermal and euryhaline, and effects of projected temperature and salinity increases are likely to be neutral in the short term.

Data Quality: 92% of the data quality scores were 2 or greater. Stock size/Status results were conflicting between various states but most managers felt blue crab stocks were not significantly overfished.

Climate Effects on Abundance and Distribution: While higher winter temperatures have been linked to increased survival in Blue Crab in Chesapeake Bay (Rome et al., 2005), there is concern that warming temperatures could lead to changes in the timing of reproduction, which could lead to a mismatch of availability of necessary larval food. While there is some disagreement in the literature on the direct effect of ocean acidification on the formation of Blue Crab exoskeletons (Ries et al. 2009, Mustafa et al. 2015), there will still likely be a negative effect on shell formation in molluscs, a primary diet item of Blue Crab. Increasing salinity could affect the amount of preferred low-salinity/freshwater estuarine habitat available for larval/juvenile Blue Crab.

Life History Synopsis: Blue Crab are a decapod crustacean (family Portunidae) distributed in the western Atlantic from Cape Cod MA to Argentina and throughout the Gulf of Mexico. The area of highest population density is the area from South Carolina through the Chesapeake Bay. Juvenile Blue Crab utilize shallower, less saline waters in upper estuaries and rivers, where they grow and mature (Fischler and Walburg 1962). Males prefer low-salinity waters and generally migrate farther upstream than females, which tend to stay in the lower rivers and estuaries (Dudley and Judy 1971, Music 1979). Adults may utilize low-saline upper estuarine waters, estuaries, bays, and coastal oceanic waters in the course of a year, indicating a habitat generalist habit. Blue Crab utilize most estuaries on the east coast, and while this habitat is not rare, it is often disturbed. Post-larval and juvenile crabs are considered general scavengers, bottom carnivores, detritivores, and omnivores (Hay 1905; Darnell 1959; Adkins 1972) with common diet items including dead and live fish, crabs, organic debris, shrimp, mollusks (including mussels, clams, oysters, and snails), and aquatic plants. Adult Blue Crab prey is very similar to juveniles, and adults will consume most available prey and freely switch among preferred prey types (Hill et al. 1998). Adults can be highly mobile and are considered strong swimmers and the species is known to undertake seasonal spawning migrations (Hill et al. 1989). Blue Crab spawning is variable by latitude. In Chesapeake Bay spawning occurs in May and June, with a second spawning in August. In North Carolina and South Carolina, spawning occurs from March through October, with peaks from April to August. Near the St. John's River in Florida, spawning occurs from February to October, with peak spawning occurring from March through September. Females mate only one time in their lives, following the terminal molt. Blue crabs are highly fecund, with females producing from 2 - 8 million eggs per spawn. Eggs are brooded 14-17 days (Hill et al. 1989), during which time females migrate to the mouths of estuaries. Larval release is often timed to occur at the peak of high tide, thus assuring that larval abundance is greatest when the tide begins to ebb. Blue Crab larvae are advected offshore and complete development in coastal shelf waters. Larvae have a salinity requirement of at least 20 ppt. Time for development through the seven zoeal stages is between 30-50 days before metamorphosis to the megalopae stage. The megalopae then persists between 6-58 days, returning to estuaries for settlement and eventual recruitment to adult populations. Blue Crab are eurythermal, with growth occurring at temperatures from 15-30°C. Growth does not occur at temperatures below 10°C, and a hibernative state is induced at temperatures below 5°C. Larvae require salinities of at least 20 ppt, but as the crabs grow they become increasingly euryhaline, inhabiting both fresh water and saline ocean waters. Blue Crab will be affected by increased ocean acidification because they both have a chitin shell, which can be affected by ocean acidification (Mustafa et al. 2015) and rely on mollusks and crustaceans in their diets, although they are likely able to opportunistically change prey items if necessary. Blue Crab have a rapid population growth rate, including a high growth coefficient (Bunnell and Miller 2005), a young age-at-maturity (UMCES 2011), a low longevity (MIllikin and Williams 1984), and a high natural mortality (UMCES 2011). The species is likely to be able to recover from population depletions fairly rapidly. A 2011 stock assessment indicated that Blue Crab in North Carolina was not overfished. A Florida stock assessment, also completed in 2011, indicated the species was neither overfished nor undergoing overfishing on the Atlantic coast of Florida. A more recent analysis of landings and survey data in Georgia found declines in crab catches in both commercial landings and fishery-independent surveys, but attributed the decline to changing climatic conditions, including cooler than normal fall water temperatures and increased spring rains occurring in 2014. South Carolina does not perform a stock assessment for Blue Crab but reports declining commercial landings over the last several years. Genetic diversity in Blue Crab populations was found to be high (McMillen-Jackson and Bert 2004). As an estuarine-dependent species, Blue Crab are subject to stresses from degradation of habitats through eutrophication and hypoxia, reduction in seagrass beds, changes in timing and volume of freshwater inputs, drought, and pollution. No indication of recent increases in parasitism or disease was found in the literature, but the species is known to be susceptible to numerous parasites. Frequent molting may mitigate some of this problem however.

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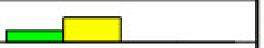
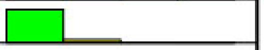
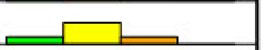
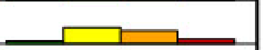
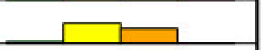
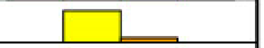
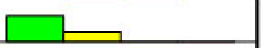
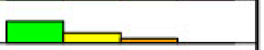
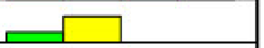
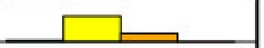
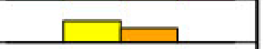
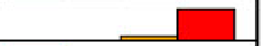
Bluefish – *Pomatomus saltatrix*

Overall Vulnerability Rank = Moderate 🟨

Biological Sensitivity = Low 🟩
Climate Exposure = Very High 🟥

Data Quality = 100% of scores≥ 2

	Pomatomus saltatrix	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.7	2.8	
	Prey Specificity	1.8	3	
	Adult Mobility	1.1	2.8	
	Dispersal of Early Life Stages	2	2.8	
	Early Life History Survival and Settlement Requirements	2.5	2.6	
	Complexity in Reproductive Strategy	2.4	2.6	
	Spawning Cycle	2.1	3	
	Sensitivity to Temperature	1.3	2.8	
	Sensitivity to Ocean Acidification	1.5	2.2	
	Population Growth Rate	1.7	2.8	
	Stock Size/Status	2.2	2.8	
	Other Stressors	2.4	2.6	
	Sensitivity Score	Low		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	3.9	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	2.5	3	
	Currents	2.2	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		Moderate		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Bluefish (*Pomatomus saltatrix*)

Overall Climate Vulnerability Rank: Moderate. (86% bootstrap results in Moderate, 14% bootstrap results in High).

Climate Exposure: Very High. Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Salinity (3.9) and Ocean Acidification (4.0). Exposure to all three factors occurs during the life stages. Bluefish use coastal and nearshore habitats as juveniles, and live in continental shelf waters as adults.

Biological Sensitivity: Low. A single sensitivity attribute scored ≥ 2.5: Early Life History Survival and Settlement Requirements (2.5). Changes in currents needed to transport larvae to nursery areas or increasing temperatures in these estuaries might negatively affect survival of bluefish.

Distributional Vulnerability Rank: High. Three attributes indicated increased potential for distribution shift: high adult mobility, widespread dispersal of early life stages, and the fact that bluefish are habitat generalists.

Directional Effect in the Southeast U.S. Shelf: The effect of climate change on Bluefish on the Southeast U.S. Shelf is estimated to be neutral (although the expert scorers were almost equally split between the three categories). Warming seawater temperatures in the southeast will make nursery habitats less productive, while at the same time making more habitat in the mid-Atlantic and Northeast habitable. The effect of ocean acidification is expected to be minimal.

Data Quality: 100% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution: There are multiple ways in which climate change might negatively impact the abundance of Bluefish off the southeast U.S. coast. First, optimal growth temperature for juvenile Bluefish is ~20° C (Hartman & Brandt 1995), so as temperatures in nursery habitats in the southeast increase, this region might become less productive. Second, larvae spawned during the spring in the southeast are transported a great distance in the Gulf Stream, and may rely on eddies originating from the Gulf Stream in order to recruit to mid-Atlantic nurseries (Hare & Cowen 1996). Therefore, changes in Gulf Stream dynamics might impact recruitment in the mid-Atlantic, which also would affect the southeast U.S. region where all juvenile Bluefish overwinter. Finally, many age-1 Bluefish remain in the southeast following their first winter, but abundance of these fish is related to temperatures during the overwintering period (Morley et al. 2017). As winter temperatures become milder, a larger portion of this age-1 cohort might migrate northward to the mid-Atlantic region.

Life History Synopsis**:** Bluefish is a globally widespread schooling predator that occupies pelagic habitats on the continental shelf and in estuaries. In the U.S., a genetically homogenous population exists across the Gulf of Mexico and Atlantic coast, although little is known about the level of connectivity between these two regions. Bluefish migrate seasonally along the Atlantic coast and movement patterns of adult fish change with size. Fish less than 45 cm typically occupy the New England and Mid-Atlantic regions during the summer and migrate to overwinter off the southeast U.S. as far south as Florida (Shepherd et al. 2006). Fish larger than 45 cm typically follow a seasonal inshore-offshore migration off the northeast U.S.

Bluefish live up to 13 years and may reach over 80 cm in fork length (Robillard et al. 2009). There is a tendency for larger fish to occur farther from shore (Shepherd et al. 2006), but schools of adult fish may forage in a variety of habitats that occur in ocean or higher salinity estuarine areas. Due to their abundance and high feeding rates, Bluefish are of high trophic importance to Atlantic coast ecosystems (Buckel et al. 1999a and 1999b). They are adaptable predators and feed on abundant forage species from an early stage of ontogeny, often including anchovy, menhaden, spot, pinfish and squid (Binion-Rock et al. 2019; Buckel et al. 1999).

Mean age at maturity for 1.9 years for females and 1.2 years for males (Salerno et al. 2001; Robillard et al. 2008). Bluefish are batch spawners and highly fecund, with larger females capable of releasing over a million eggs per batch (Robillard et al. 2008). While bluefish spawn throughout much of the year, a majority of reproductive output comes during two time periods. The first is during the late-winter and spring off the southeast U.S., on the outer continental shelf (Hare & Cowen 1993). Offspring from this spawning period recruit to coastal habitats along the entire U.S. east coast (Wuenschel et al. 2012). The second spawning period occurs on the mid-Atlantic continental shelf during the summer. Offspring from this spawning period mostly recruit to coastal waters of the mid-Atlantic region (Hare & Cowen 1993; Wuenschel et al. 2012). The degree to which individual fish participate during each spawning period is not known.

Juvenile Bluefish from both the spring and summer spawning periods use a variety of estuarine and near-shore habitats during their first year (Wuenschel et al. 2012). Juveniles switch from zooplankton to fish prey at a relatively small size and grow rapidly during their first year (Juanes et al. 1994). During the fall, juveniles migrate south, often in large schools along a coastal near-shore corridor, and overwinter on the continental shelf of the southeast U.S. (Morley et al. 2007; Wuenschel et al. 2012).

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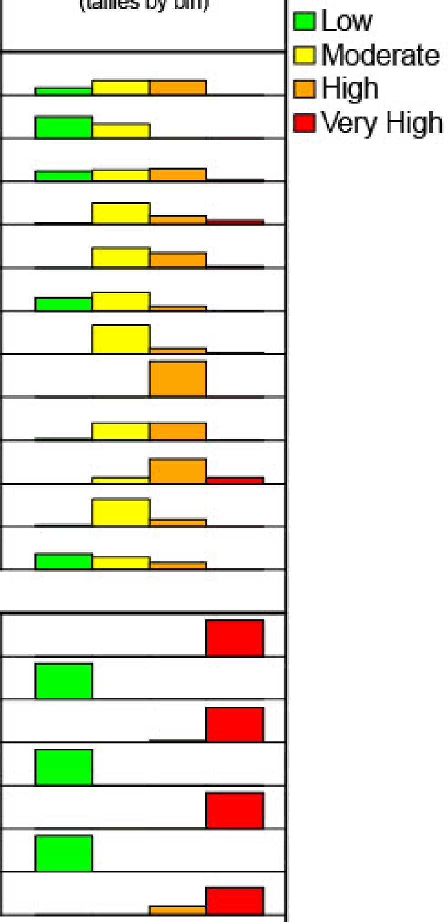
Blueline Tilefish − *Caulolatilus microps*

Overall Vulnerability Rank = Very High 🟥

Biological Sensitivity = High 🟧
Climate Exposure = Very High 🟥

Data Quality = 67% of scores ≥ 2

Caulolatilus microps		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.2	2.7	
	Prey Specificity	1.4	2.6	
	Adult Mobility	2.2	2.3	
	Dispersal of Early Life Stages	2.4	1.5	
	Early Life History Survival and Settlement Requirements	2.5	1	
	Complexity in Reproductive Strategy	1.8	1.9	
	Spawning Cycle	2.2	3	
	Sensitivity to Temperature	3	2.6	
	Sensitivity to Ocean Acidification	2.4	2	
	Population Growth Rate	3	2.6	
	Stock Size/Status	2.2	2.8	
	Other Stressors	1.8	1.6	
	Sensitivity Score	High		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	3.9	3	
	Precipitation	1	0	
	Ocean Acidification	4	2	
	Sea Level Rise	1	0	
	Currents	3.8	2.8	
	Exposure Score	Very High		
Overall Vulnerability Rank		Very High		



Blueline Tilefish (*Caulolatilus microps* Goode & Bean, 1878)

Overall Climate Vulnerability Rank: Very High. 56% bootstrap results in Very High, 44% bootstrap results in High.

Climate Exposure: Very High. Four exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0), Salinity (3.9), and Currents (3.8). Blueline Tilefish are residents of the outer continental shelf and have exposure to all of these environmental factors (Ocean Surface Temperature serves as a proxy for Bottom Temperature in these assessments).

Biological Sensitivity: High. Two sensitivity attributes scored ≥ 3.0: Sensitivity to Temperature (3.0) and Population Growth Rate (3.3). Blueline Tilefish are long-lived, slow growing, and subject to overfishing.

Distributional Vulnerability Rank: Moderate. Three attributes indicated limited vulnerability to distribution shift: limited adult mobility, limited early life stage dispersal, and relatively high habitat specialization.

Directional Effect in the Southeast U.S. Shelf: The effect of climate change on Blueline Tilefish on the Southeast U.S. Shelf is predicted to be neutral. Increased productivity could result from warming temperatures in the region. This gain could be offset somewhat by impacts from ocean acidification on prey items. Changes to oceanic circulation could affect dispersal of larvae out of the southeast to suitable nursery habitat further north.

Data Quality: 67% of the data quality scores were 2 or greater. Dispersal of Early Life Stages and Early Life History Survival and Settlement Requirements both scored low in Data Quality and moderate to high in sensitivity.

Climate Effects on Abundance and Distribution: Climate changes are predicted to have a significant effect on the productivity of Blueline Tilefish. They consume a wide variety of shell-forming invertebrates and could be affected by increasing ocean acidification. Golden Tilefish (*Lopholatilus chameoleonticeps*) productivity is increased in warmer water and decreased by colder water (Fisher et al. 2014), and changes in oceanic currents could have similar effects on Blueline Tilefish (southern intrusions of very cold Labrador Current water could suppress productivity or cause die-offs (Marsh et al. 1999)). Changes in currents could also affect transport of pelagic eggs and larvae from both the southwest Florida shelf to the east coast of Florida as well as up the southeastern U.S. coast. Blueline Tilefish inhabit a fairly specific habitat type as well as a narrow temperature range so their ability to expand their range significantly may be limited.

Life History Synopsis:

Blueline Tilefish is a relatively slow-growing, moderately late maturing (six years to 100% maturity in females), and long-lived (about 40 years) oceanic species that occurs from New Jersey to Campeche Bank, Mexico (Harris et al. 2004, SEDAR 2017). They are found along the outer continental shelf, shelf break, and upper slope on irregular bottom such as ledges, crevices or rock/rubble piles and shipwrecks at depths of 48-236 m (Harris et al. 2004, Ross et al. 2015). Blueline Tilefish are landed in commercial and recreational fisheries off all states along the southeast U.S. Atlantic coast. Sexes in Blueline Tilefish are separate, and spawning occurs from February to October, with peak spawning from April through September (Sedberry et al. 2006, Farmer et al. 2017). Potential annual fecundity ranges from 1.9 to 11.4 million eggs for specimens 300-700 mm total length (Harris et al. 2004, SEDAR 2017). This species has a very long spawning season resulting in a high number of spawning events per year, ranging from 57 - 102 for females, with spawning occurring about every three days (Harris et al. 2004, SEDAR 2017). Little is known of the early life history. The mean size of males is significantly larger than that of females (Harris et al. 2004). Principal prey taxa include benthic invertebrates such as copepods, ophiuroids, gastropods, polychaetes, natantian decapods and urochordates (Belsa and Labisky 1987). Blueline Tilefish are caught predominately by the commercial sector, although the proportion harvested by the recreational sector has increased in recent years, particularly north of Cape Hatteras NC (Schertzer et al. 2019; Crosson et al. in prep.). The stock is currently neither overfished or undergoing overfishing (https://www.fisheries.noaa.gov/national/population-assessments/fishery-stock-status-updates).

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Blue Runner – *Caranx crysos*

Overall Vulnerability Rank = Moderate 🟨

Biological Sensitivity = Low 🟩
Climate Exposure = Very High 🟥

Data Quality = 67% of scores ≥ 2

	Caranx crysos	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.7	2.6	
	Prey Specificity	1.8	2.8	
	Adult Mobility	1.1	2.8	
	Dispersal of Early Life Stages	2.2	1.6	
	Early Life History Survival and Settlement Requirements	2.2	1.4	
	Complexity in Reproductive Strategy	1.8	1.8	
	Spawning Cycle	2.4	2.6	
	Sensitivity to Temperature	1.8	2.8	
	Sensitivity to Ocean Acidification	1.5	2.2	
	Population Growth Rate	1.6	2.6	
	Stock Size/Status	1.7	1	
	Other Stressors	1.6	2	
	Sensitivity Score	Low		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	3.9	3	
	Precipitation	1	0	
	Ocean Acidification	4	2	
	Sea Level Rise	1	0	
	Currents	3.4	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		Moderate		

Blue Runner (*Caranx crysos*)

Overall Climate Vulnerability Rank: Moderate. 100% bootstrap results in Moderate.

Climate Exposure: Very High. Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Salinity (3.9). Currents (3.4) was a borderline contributor to the overall ranking. Blue Runner are distributed in the open ocean and thus affected by the first three exposure factors, and larvae/juveniles may rely on ocean currents for transport to sargassum habitat for refuge.

Biological Sensitivity: Low. No sensitivity attributes scored ≥ 2.5. Three attributes, all having to do with reproductive success, scored ≥ 2.0: Early Life History Survival and Settlement Requirements (2.2), Dispersal of Early Life Stages (2.2) and Spawning Cycle (2.4).

Distributional Vulnerability Rank: High. Two attributes indicated increased potential for distribution shift: high adult mobility and limited habitat specialization. Blue Runner are free-swimming oceanic animals.

Directional Effect in the Southeast U.S. Shelf: The effect of climate change on Blue Runner on the Southeast U.S. Shelf is estimated to be neutral. While Blue Runner consume crustaceans and shrimp, their diets are dominated by fishes; thus, impacts of ocean acidification should be minimal. The species is eurythermal and effects of projected warming are likely to be neutral, as they already enjoy a widespread temperate to tropical distribution (Nova Scotia to Brazil).

Data Quality: 67% of the data quality scores were 2 or greater. Data quality was low for Stock Size/Status (the species has not been assessed by managers), as well as for Early Life History Survival and Settlement Requirements and Dispersal of Early Life Stages.

Climate Effects on Abundance and Distribution: There are no specific studies on the effects of climate change on Blue Runner. As pelagic oceanic dwellers they will be exposed to an environment that is warming and becoming more saline and acidic. There may be some indirect effects on their fitness from ocean acidification, as they prey in part on crustaceans. Changes to oceanic currents might affect transport of larvae to sargassum mats for food and refuge. While Blue Runner of all sizes were captured over a fairly broad temperature range, newly hatched larvae were found only within a narrow range, 28.8 - 30.1°C, and most larvae were captured at salinities <33 ppt.

Life History Synopsis**:** Blue runner is a medium-sized schooling species distributed in the western Atlantic from Nova Scotia (Canada), Brazil, Bahamas, throughout the Caribbean (including Antilles) and the Gulf of Mexico (latitude 46°N-26°S). Juveniles exhibit an open ocean habitat and are often found beneath floating mats of sargassum, which serve as a refuge from predation as well as a source for prey (Wells and Rooker 2004). Pre-adults were commonly found on shallow reefs (0-15 m) in Jamaica, but absence of larger Blue Runner on inshore reefs suggest movement to outer shelf margins at/before maturity (Thompson and Munro 1974).

Adults are pelagic in the oceanic neritic environment, forming schools primarily nearshore. While not thought to be common around reefs, divers often observe large schools of Blue Runner over reef/hardbottom habitat in the SEUS, and the species is commonly observed around petroleum platforms in the Gulf of Mexico (Herdson 2010). Blue Runner feed on zooplankton throughout larval/juvenile life, primarily cyclopoid and calanoid copepods (McKenney et al. 1958). Adults feed primarily on meso- and macro-plankton, including decapod crustaceans, chaetognaths, amphipods, other invertebrates and small fishes (Keenan and Benfield 2002). Blue Runner are highly mobile, and are not constrained behaviorally or physically in their movements.Tagging returns from a Florida study showed movements up to 155 km by one individual (Beaumarriage 1964). Thompson and Munro (1974) suggested Blue Runner aggregated to spawn in Jamaican waters, but separating these observations from the normal schooling behavior exhibited by the species is problematic. Spawning is thought to take place in nearshore coastal waters. Goodwin and Finucane (1985) reported peak spawning in the Gulf of Mexico to be June-August, confirmed by histology, while McKenney et al. (1958) suggested spawning occurs year round. Recently hatched larvae were captured at temperatures 28.8 - 30.1°C and salinities from 25.0 - 36.2 ppt (Shaw and Drullinger 1990). While juveniles may enter estuaries they are not thought to be obligatory residents, but proximity to floating sargassum mats is likely advantageous to juvenile survival. Blue Runner may be somewhat affected by increased ocean acidification because they prey upon some invertebrate species (shrimp and crabs) that may be affected by ocean acidification. Blue Runner have a moderate to high population growth rate, based on an early age-at-maturity, low reported maximum age (11 years), a moderate maximum body size, and a relatively high growth coefficient. These characteristics would allow Blue Runner to recover fairly quickly from population declines. There is little information about the stock status of Blue Runner, as they have not been assessed. They are considered a species of least concern by the IUCN, as harvest is somewhat limited and does not occur throughout the range of the species. Any disruption to ocean currents that aggregate sargassum mats could impact survival of the juvenile phase of blue runner. Some larvae and juveniles that get carried into estuarine areas could be impacted by anthropocentric pollution and habitat alteration.

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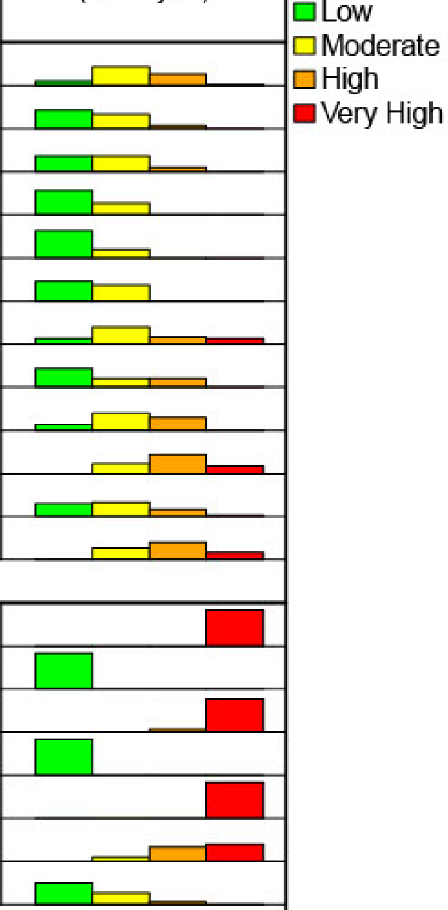
Bonnethead Shark − *Sphyrna tiburo*

Overall Vulnerability Rank = High 🟧

Biological Sensitivity = Moderate 🟨
Climate Exposure = Very High 🟥

Data Quality = 100% of scores≥ 2

Sphyrna tiburo		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.3	3	
	Prey Specificity	1.6	3	
	Adult Mobility	1.7	2.8	
	Dispersal of Early Life Stages	1.3	2.8	
	Early Life History Survival and Settlement Requirements	1.2	3	
	Complexity in Reproductive Strategy	1.4	2.5	
	Spawning Cycle	2.4	2.6	
	Sensitivity to Temperature	1.7	3	
	Sensitivity to Ocean Acidification	2.2	2.8	
	Population Growth Rate	2.9	3	
	Stock Size/Status	1.9	2.6	
	Other Stressors	2.9	2.4	
	Sensitivity Score	Moderate		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	3.9	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	3.4	3	
	Currents	1.5	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		High		



Bonnethead (*Sphyrna tiburo*)

Overall Climate Vulnerability Rank: High. (92% bootstrap results in High, 7% bootstrap results in Very High).

Climate Exposure: Very High. Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Salinity (3.9). Exposure to all three factors occurs during the life stages. Bonnethead use nearshore seagrass habitats as nursery and feeding areas, but are known to move to deeper coastal waters during winter months.

Biological Sensitivity: Moderate. Two sensitivity attributes scored above 2.5: Other Stressors (2.9) and Population Growth Rate (2.9). Bonnethead are a moderately long-lived fish (Frazier et al. 2014) with relatively low population growth rates (Cortes and Parsons 1996), and the species is late-maturing (Frazier et al. 2014). Their use of inshore seagrass areas makes them vulnerable to anthropogenic stressors such as pollutants, habitat alteration, etc.

Distributional Vulnerability Rank: High. Three attributes indicated high potential for distribution shift: high adult mobility, widespread dispersal of early life stages, and a high tolerance for warmer temperatures.

Directional Effect in the Southeast U.S. Shelf: The effect of climate change on Bonnethead on the southeast U S. shelf is estimated to be neutral. The species is a mobile temperate shark, found from seagrass habitats to continental shelf depths of 90 m. Crustaceans and bivalves are a major diet component, indicating potential negative effects from ocean acidification. The effects of increasing water temperature in the southeast may be obviated by their ability to move to cooler offshore waters.

Data Quality: 100% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution: Bonnethead rely heavily on invertebrates in their diet and may be affected by increasing ocean acidification. They have a tolerance for warm temperatures, especially juveniles (>30°C; Ward-Paige et al. 2015). Distribution is linked to salinity as well as temperature and proximity to tidal inlets (Froeschke et al. 2010; Bethea et al. 2014). The quality of estuarine seagrass areas as juvenile habitat could be affected by increasing ocean salinity, changes in precipitation patterns, and/or sea level rise.

Life History Synopsis**:** Bonnethead sharks are small coastal sharks of the family Sphyrnidae that can reach a maximum size of 150 cm TL (Ebert et al. 2013), but typically are smaller in the southeastern United States (~ 80 cm maximum length?) (Frazier et al. 2014). The species is distributed from North Carolina to Brazil, including the Gulf of Mexico and throughout the Caribbean (Ebert et al. 2013). Juvenile Bonnethead utilize near-coastal shallow seagrass beds. Adults occur in shallow estuaries along the coast over the summer, likely using them as feeding and nursery areas. Adults have been found to move to deeper beach areas during the colder winter months. These areas are prone to human disturbance from boating, hurricane disturbance, and pollution. Little is known of the Bonnethead diet in the southeastern United States, although it likely includes crustaceans as was observed in a Gulf of Mexico study (Harrington et al. 2016). Important prey categories found were penaeid shrimp, portunid crabs, xanthid crabs, stomatopods, cephalopods, and small amounts of algae. Seagrass present in stomachs suggests specialization/preference for feeding in seagrass areas. Adults are mobile, moving offshore during the winter to deeper beach habitats (versus shallow coastal estuaries), while 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 (Driggers et al. 2014). Sharks have no planktonic stage. Seagrass beds/estuarine areas are used as nursery grounds by young of year bonnetheads, although there does not appear to be specific nursery areas, just general usage of seagrass habitat (Heupel et al. 2006). Shark distribution and abundance appears to be most closely linked to salinity (Ubeda et al. 2016, Foeschke et al. 2010, Bethea et al. 2014), water temperature (Ward-Paige et al. 2014), water clarity (Bethea et al. 2014) and proximity to tidal inlets (Froeschke et al. 2010). Bonnetheads are viviparous, reproducing annually. Gestation lasts ~4.5-5 months; litter size averages 8.8 pups in the Atlantic Ocean off the southeast United States (SEDAR 2013). The timing of parturition 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; Lombardi-Carlson et al. 2003). Size at birth ranges from an average of 21.5 cm FL in Florida Bay to 29.7 cm FL in Tampa Bay (Lombardi-Carlson et al. 2003). Parsons (1993) and Manire et al. (1995) found that mating occurs in November and sperm is stored until ovulation/fertilization the following March or April. Fishbase reports a preferred temperature range for Bonnethead of 21 - 28°C (mean 25°C). The species is known to move from shallow-water estuarine nursery areas to deeper coastal waters as temperature drops. The species utilizes depths in the water column from 1-80 m, and is most often found from 10-80 m (Compagno 1984). Bonnethead are likely to be affected by increasing ocean acidification due to reliance on crustaceans (primarily callinectid crabs and penaeid shrimp in their diet (Bethea 2007). Bonnethead exhibit high population growth rates (mean=1.304 yr-1; 95% confidence interval=1.150-1.165 yr-1; Cortes 2002), with short generation times (mean = 3.9 years, 95% CI=2.6-4.5 years). Annual survivorship for Tampa Bay, Florida bonnethead was high (0.489 (95% confidence limits: 0.393-0.631) for 1-year-old females (Cortés and Parsons 1996). 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). A 2013 SEDAR stock assessment update found that $SSB_{curr}/SSB_{MSY} = 1.13$, indicating the stock is not overfished (SEDAR 2013). Other stressors include degradation of shallow seagrass nursery areas due to anthropogenic pollution. Lower fertility levels in Bonnethead in Tampa Bay populations have been hypothesized due to pollution (Gelsleichter et al. 2005). Brevotoxins have been detected in Bonnethead embryos in association with a *Karenia brevis* red tide bloom (Flewelling et al. 2010).

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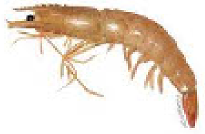
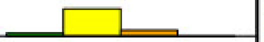
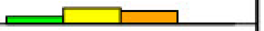
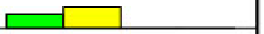
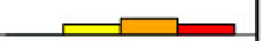
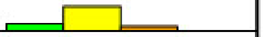
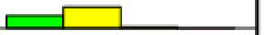
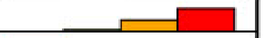
Brown Shrimp − *Farfantepenaeus aztecus*



Overall Vulnerability Rank = Very High 🟥

Biological Sensitivity = High 🟧
Climate Exposure = Very High 🟥

Data Quality = 100% of scores≥ 2

	Farfantepenaeus aztecus	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.1	3	
	Prey Specificity	1.1	3	
	Adult Mobility	2.2	3	
	Dispersal of Early Life Stages	1.6	3	
	Early Life History Survival and Settlement Requirements	3	2.6	
	Complexity in Reproductive Strategy	2.5	2.2	
	Spawning Cycle	1.9	3	
	Sensitivity to Temperature	1.7	3	
	Sensitivity to Ocean Acidification	3.4	3	
	Population Growth Rate	1	2.6	
	Stock Size/Status	1.1	3	
	Other Stressors	3.1	2.6	
	Sensitivity Score	High		
Exposure Factors	Sea Surface Temperature	1	0	
	Air Temperature	4	3	
	Salinity	3.6	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	3.6	3	
	Currents	1.6	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		Very High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Brown Shrimp (*Farfantapenaeus aztecus*)

Overall Climate Vulnerability Rank: Very High. (14% bootstrap results in High, 86% bootstrap results in Very High).

Climate Exposure: Very High. Four exposure factors contributed to this score: Salinity (3.9), Ocean Acidification (4.0), Air Temperature (4.0), and Sea Level Rise (3.6). Brown Shrimp are estuarine-obligate during their early life stages, when they could be affected by changes in air temperature as well as the effects of sea level rise on the nursery habitats.

Biological Sensitivity: High. Three sensitivity attributes scored ≥ 3.0: Sensitivity to Ocean Acidification (3.4), Other Stressors (3.1), and Early Life History Survival and Settlement Requirements (3.0). Brown Shrimp are residents of estuarine habitat during early life stages where they would be affected by anthropogenic disruptions. The species will likely be affected by increasing ocean acidification due both to their shells and their dependence on small crustaceans and mollusks in their diet.

Distributional Vulnerability Rank: Moderate. Three attributes indicated limited to moderate potential for distribution shift: moderate adult mobility, limited early life stage dispersal, and limited habitat specialization.

Directional Effect in the Southeast U.S. Shelf: The effect of climate change on Brown Shrimp is estimated to be negative. Increasing temperatures in estuarine nurseries could lead to reductions in survival or growth, as well as leading to changes in abundance and distribution (northward migration in search of more suitable temperatures). Increasing ocean acidification could also affect fitness and survival (Mustafa et al. 2015).

Data Quality: 100% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution: Multiple stressors are likely to influence Brown Shrimp abundance and distribution. Increasing ocean acidification will have both indirect (diet items; molluscs and crustaceans) and direct (changes in shell transparency and exoskeleton function due to decreasing pH may have consequences for crypsis and survival; Taylor et al. 2015). Marsh fragmentation (caused by sea level rise) and changes to inundation (caused by anthropogenic hydrology alterations) both may affect productivity (Roth et al. 2008). Increasing temperature and salinity may also affect productivity.

Life History Synopsis**:** Brown Shrimp is a commercially important species of penaeid shrimp exploited along the eastern coast of the United States, ranging from Massachusetts to Florida and through the Gulf of Mexico to the Yucatan Peninsula, Mexico (Williams 1984). Postlarval Brown Shrimp settle and develop through the juvenile stage within the estuary, preferring shallow vegetated *Spartina* marsh edge habitat and submerged aquatic vegetation, but also occurring in non-vegetated mud and sandy-mud bottoms. They migrate offshore as subadults. Juvenile productivity is linked to salinity and temperature regime as modified by freshwater discharges. Adult Brown Shrimp inhabit littoral zones along coasts. Primary habitats are muddy bottom areas to approximately 110 m deep, but the greatest density occurs at depths between 27 - 55 m. This species is rarely observed at depths exceeding 165 m. Brown Shrimp juveniles are omnivorous and generalist in diet, consuming diatoms, harpacticoid copepods, amphipods, tanaids, other shrimps, polychaetes, nematodes, chironomid larvae, and mysids (Perez-Farfante et al. 1969, McTigue and Zimmerman, 1991, 1998). Adults have a similar diet, exhibiting a more predatory nature. Brown Shrimp exhibit relatively high mobility, as recently matured shrimp 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, although not without energetic implications and harvest effects (Craig and Crowder 2005). Brown Shrimp become reproductively active after reaching a size of 140 mm (Renfro 1964). Spawning season likely varies in different geographic areas of its range. Gonads mature in August (Broad 1950). Brown Shrimp spawn offshore at depths that generally exceed 18 m (Larson et al. 1989). Data on sex ratios by depth from Gulf of Mexico waters (Burkenroad 1939) suggest that spawning sites for Brown Shrimp are likely to be further offshore in deeper waters than occurs in other penaeid shrimp such as pink shrimp and white shrimp. Fertilization is external in the open ocean, with eggs being demersal (sinking to the bottom after release), and measuring approximately 0.26 - 0.28 mm in diameter (Larson et al. 1989). Hatching occurs within 24 hours. Larvae develop offshore through five naupliar, three protozoeal, and three mysis stages before metamorphosing into postlarvae (Cook and Murphy 1969, 1971). Several postlarval stages occur prior to metamorphosis to the juvenile stage. Larval development takes approximately 11 days at a temperature of 32°C, and approximately 17 days at a temperature of 24°C (Cook and Murphy 1969). Brown Shrimp larvae are most commonly sampled below mid-depth in the wild. Protozoea of this species are likely to occur nearest the bottom, while postlarval stages occur at, or slightly above mid-depth. However, all stages ascend to surface waters with the onset of darkness. Larval stages use tidal currents (selective tidal stream transport) and wind generated advection to assist with immigration to nursery areas. Postlarvae return to coastlines on surface current during late winter and spring (Bearden 1961). Brown Shrimp postlarvae began entering sounds in North Carolina from October through May, with peak recruitment in March and April (Zamora and Trent 1968). In South Carolina, P. aztecus postlarvae are found in all months of the year, with recruitment peaking during February and March (Bearden 1961). Juveniles are collected beginning in mid-April and continuing throughout the summer months (Williams 1955). Postlarvae enter estuaries on flood tides and migrate to shallow, low-salinity waters. Growth is rapid during the warmer summer months, up to 46 mm per month (Williams 1955). After spending approximately six months in the nursery area, subadults begin migration into progressively more saline waters, eventually returning to offshore areas. The preferred Brown Shrimp temperature range is 9-27℃ (mean 22℃). Brown Shrimp have been observed to burrow at temperatures below 12 - 17°C, re-emerging from sediments when temperatures rose above 18 - 21.5° C (Aldrich et al. 1968). Postlarval shrimp growth and survival is compromised at temperatures above 32°C, and temperatures above 36.6°C are lethal. Brown Shrimp may be affected directly by increasing ocean acidification (formation of thicker exoskeletons may affect transparency and thus crypsis and survival; Taylor et al. 2015) and indirectly (reliance on molluscs in their diet). Brown Shrimp have a high population growth rate, with rapid individual growth and high fecundity, early age-at-maturity (0.5 years), short lifespan (approximately two years), a high natural mortality rate, and a low maximum size. They are likely to respond fairly rapidly to population disturbances or depletion events based on these life history characteristics. Brown Shrimp are neither overfished nor undergoing overfishing, according to a 2018 stock assessment. Genetically, Brown Shrimp showed no significant phylogenetic structure or population subdivision, and closely related haplotypes were geographically dispersed (McMIllen-Jackson and Bert 2003). Other potential stressors for Brown Shrimp include marsh fragmentation due to Sea Level Rise and anthropogenic alteration of estuarine habitat (pollution, hypoxic events).

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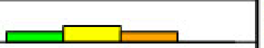
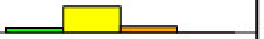
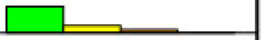
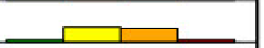
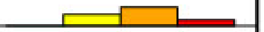
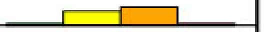
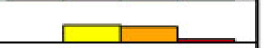
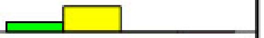
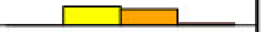
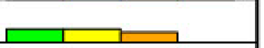
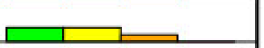
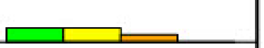
Cobia – *Rachycentron canadum*

Overall Vulnerability Rank = High 🟧

Biological Sensitivity = Moderate 🟨
Climate Exposure = Very High 🟥

Data Quality = 100% of scores≥ 2

Rachycentron canadum		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2	2.6	
	Prey Specificity	2	2.6	
	Adult Mobility	1.4	2.8	
	Dispersal of Early Life Stages	2.5	2.2	
	Early Life History Survival and Settlement Requirements	2.8	2	
	Complexity in Reproductive Strategy	2.6	2.4	
	Spawning Cycle	2.6	2.8	
	Sensitivity to Temperature	1.7	2.8	
	Sensitivity to Ocean Acidification	2.5	2.2	
	Population Growth Rate	1.9	3	
	Stock Size/Status	1.8	2.8	
	Other Stressors	2.2	2.4	
	Sensitivity Score	Moderate		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	3.9	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	2.5	2.4	
	Currents	1.8	2.8	
	Exposure Score	Very High		
Overall Vulnerability Rank		High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Cobia, (*Rachycentron canadum*)

Overall Climate Vulnerability Rank: High**.** (2% bootstrap results in Moderate, 98% bootstrap results in High).

Climate Exposure: Very High. Three exposure factors ≥ 3.5 contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Salinity (3.9). Exposure to all three factors occurs during the life stages. Cobia use coastal and nearshore habitats during all life stages.

Biological Sensitivity: Moderate. Five sensitivity attributes scored ≥ 2.5: Dispersal of Early Life Stages (2.5), Early Life History Survival and Settlement Requirements (2.8), Reproductive Complexity (2.6), Spawning Cycle (2.6) and Sensitivity to Ocean Acidification (2.5). Little is known of Cobia early life history survival and settlement requirements other than a frequent association with floating structures. Cobia are known to form spawning aggregations (Rodger and von Zharen 2012), which could make them susceptible to exploitation. They rely heavily on crustaceans in their diet, making them vulnerable to increasing ocean acidification.

Distributional Vulnerability Rank: High. Cobia are habitat generalists that are mobile, and have dispersive early life stages.

Directional Effect in the Southeast U.S. Shelf: The effect of climate change on Cobia on the Southeast U.S. Shelf is estimated to be neutral. Warming seawater temperatures in the mid-Atlantic and northeast may lead to Cobia migrating from the southeast to these regions. Minor effects of Ocean Acidification are possible, but a generally opportunistic diet may offset this.

Data Quality: 100% of the data quality scores were 2 or greater. Early Life History Survival and Settlement Requirements was the lowest score at 2.0.

Climate Effects on Abundance and Distribution: Cobia feed on crustaceans and thus may be affected by ocean acidification. Their eggs and larvae rely on tidal transport into suitable estuarine nursery habitat and changes in oceanic currents, as well as changes to environmental variables such as temperature and salinity in those estuaries, could affect survival (Lefebvre and Denson 2012).

Life History Synopsis**:** Cobia is a pelagic species with a circumtropical distribution, except for the Eastern Pacific (Shaffer and Nakamura 1989). Cobia is a monotypic species in the Family Rachycentridae. Along the U.S. East and Gulf coasts, Cobia occur from Massachusetts to the Florida Keys and throughout the northern Gulf of Mexico (Shaffer and Nakamura 1989). Along the Eastern Seaboard of the U.S. Cobia are most abundant from Chesapeake Bay south through Florida coastal waters. 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). Little is known of the diet of larval or juvenile Cobia. Adults consume a wide variety of teleost fishes, portunid crabs, shrimps, cephalopods, and even juvenile elasmobranchs (Smith 1995). Adult Cobia are highly migratory; they tend to migrate south to Florida in winter while some may overwinter on the outer portions of the continental shelf along the southeast U.S. coast (Shaffer and Nakamura 1989; Smith 1995; Hendon 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 (Rodger and Zharen 2012). 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. 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. According to Richards (1967), Cobia do not appear in the Chesapeake Bay until water temperatures exceed 19°C. Smith (1995) reports Cobia first appear in inshore waters of North Carolina when water temperatures reach about 20°C; they usually occur in water depths 0 to 50 m. In recent years, anecdotal information suggests Cobia have been more abundant north of Chesapeake Bay in coastal waters of New Jersey. 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).

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SEDAR 28. 2013. South Atlantic cobia stock assessment report. SEDAR No. Charleston SC, 420 p.

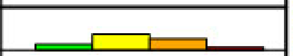
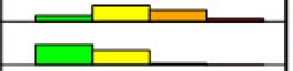
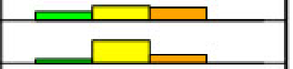
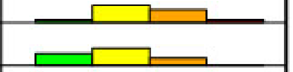
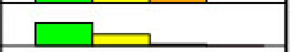
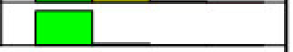
SEDAR 58, 2020. Atlantic Cobia Stock Assessment Report. SEDAR, North Charleston SC. 500 pp. available online at: http://sedarweb.org/sedar-58

Cubbyu – *Pareques umbrosus*

Overall Vulnerability Rank = Moderate 🟨

Biological Sensitivity = Low 🟩
Climate Exposure = Very High 🟥

Data Quality = 67% of scores ≥ 2

Pareques umbrosus		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.3	2.6	
	Prey Specificity	1.5	2.6	
	Adult Mobility	2.1	2	
	Dispersal of Early Life Stages	2.1	2.4	
	Early Life History Survival and Settlement Requirements	2.4	1.8	
	Complexity in Reproductive Strategy	1.9	1.6	
	Spawning Cycle	1.6	2.2	
	Sensitivity to Temperature	1.8	2.7	
	Sensitivity to Ocean Acidification	2.3	3	
	Population Growth Rate	1.8	1.5	
	Stock Size/Status	1.4	1.6	
	Other Stressors	1	2.1	
	Sensitivity Score	Low		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	4	3	
	Precipitation	1	0	
	Ocean Acidification	4	2	
	Sea Level Rise	1.1	3	
	Currents	2.8	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		Moderate		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Cubbyu (*Pareques umbrosus*)

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

Climate Exposure: Very High. Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Salinity (4.0). Cubbyu are exposed to all of these factors during their life span, utilizing coastal soft and hardbottom marine habitats. Their diet consists in large part of crustaceans (Lindquist et al. 1994), and the species is likely to be affected by increasing ocean acidification.

Biological Sensitivity: Low. No sensitivity attributes scored ≥ 2.5. Ocean Acidification (2.3) and Early Life History Survival and Settlement Requirements (2.4) were the attributes scorers deemed most affected by changing climate.

Distributional Vulnerability Rank: Moderate. Three attributes indicated moderate potential for distribution shift: adult mobility, early life stage dispersal, and low habitat specialization.

Directional Effect in the Southeast U.S. Shelf: The effect of climate change on Cubbyu on the Southeast U.S. Shelf is estimated to be neutral. There is little information in the literature on Cubbyu biology and environmental preferences, making an estimate of directional effect of climate change difficult.

Data Quality: 67% of the data quality scores were ≥ 2.

Climate Effects on Abundance and Distribution: Cubbyu will likely be most affected by increasing ocean acidification because of their reliance on crustaceans in their diet. There is little information in the literature about temperature or salinity preferences. Based on the proximity of newly settled larvae to adult habitat, it was surmised that cubbyu larvae remain close to the spawning grounds (Holt and Riley 1999), and thus early life stages would be impacted by any climate-forced changes in environmental variables such as temperature and salinity.

Life History Synopsis**:** Cubbyu is a relatively small drum reported from North Carolina and Bermuda, through Florida, throughout the Gulf of Mexico, the Yucatan Peninsula, through French Guiana to Brazil. It is also known from Puerto Rico and Barbados (Fishbase; Robins & Ray 1986; Humann & DeLoach 2002; ReefNet 2007; Kells & Carpenter 2011; Chao et al. 2015). Both juvenile and adults occur near the bottom in shallow coastal waters over sandy and mud bottoms, but can also be found on temperate hard bottom reefs where they are common on the underside of and closely associated with ledges that provide structural relief (Chao et al. 2015). Adults reach a maximum length of 25 cm total length (TL), whereas no information is available concerning maximum age (FishBase; Robins & Ray 1986). Off the coast of North Carolina in Onslow Bay, cubbyu ranging in size from 6.3 – 16.5 cm standard length (SL) were observed to prey on a variety of hard- and soft-bodied invertebrates. Stomachs contained predominantly crabs, penaeid shrimp, caridean shrimp, and smaller amounts of amphipods, mysids, tanaids, polychaetes, and flatworms. Small amounts of teleost fishes were also found in the diet (Lindquist et al. 1994). Adult mobility of Cubbyu is unknown. Their close association with ledges and overhangs suggests limited mobility, although nocturnal forays over sand adjacent to reefs has been observed, and Cubbyu were found to positively select sand-associated prey compared with reef-associated prey (Lindquist et al. 1994). No information is currently available regarding the formation of spawning aggregations by Cubbyu. Cubbyu were observed to spawn in aquaria 3-5 times weekly, or every 1.5-2.3 d (Holt & Riley 1999). The congener, high hat (*Pareques acuminatus*), was observed to spawn in pairs in aquaria (Thresher 1984). Regarding the spawning season, Holt & Riley (1999) collected fish for their study and raised them in culture until 'natural spawning first occurred in November 1993, and …spawning continued at a frequency of 3-5 times weekly through November 1996.' Cubbyu spawned best under conditions of 25–26°C, salinity of 35‰, and 15:9 h light/dark photoperiod (Holt & Riley 1999). Darovec (1983) found juvenile Cubbyu most abundant in the Gulf of Mexico in late spring-early summer, but present all year long. From this evidence it appears possible the species could be a year-round spawner if conditions remained favorable. The planktonic larval duration (PLD) of Cubbyu can be inferred from controlled conditions in aquaria, where metamorphosis to the juvenile stage occurred between 10-15 mm and 26 to 30 d posthatch (Holt & Riley 1999). Cubbyu PLD is similar to the majority of reef fishes that have PLDs of 20-30 d, although PLDs can range from 8-150 d (Victor 1991). Early life history (larval) requirements of Cubbyu are unknown. Larvae may recruit to adult habitats, as recently-settled (<3 cm TL) juveniles have been observed together with adults on hard bottom reefs in depths of 16-21 m at Gray's Reef National Marine Sanctuary, off the coast of Georgia (RC Muñoz, pers. obs). Cubbyu occur from 23-27.9° C (preferred temperature, Kaschner et al. 2016). They occupy habitats from 5-110 m depth. Cubbyu may be indirectly affected by ocean acidification, as adults have been found to consume prey (amphipods, crabs, shrimp; Lindquist et al. 1994) that are negatively affected by ocean acidification (Kurihara et al. 2008; Bhadury 2015; Long et al. 2013; Cripps et al 2015). No information is available regarding population growth rate of cubbyu. Although the stock has never been assessed, it is relatively abundant, is not heavily fished, and is thought to be stable over time, so the workshop scorers thought the population would be at or above B_{MSY}. This widely distributed species is generally uncommon. There are no known major threats, therefore, it is listed as Least Concern (Chao et al. 2015). Other potential stressors for Cubbyu are not readily apparent. There are no known major threats. It occurs as bycatch and juveniles are collected for the aquarium trade. It may also be susceptible to invasive lionfish predation (Chao et al. 2015).

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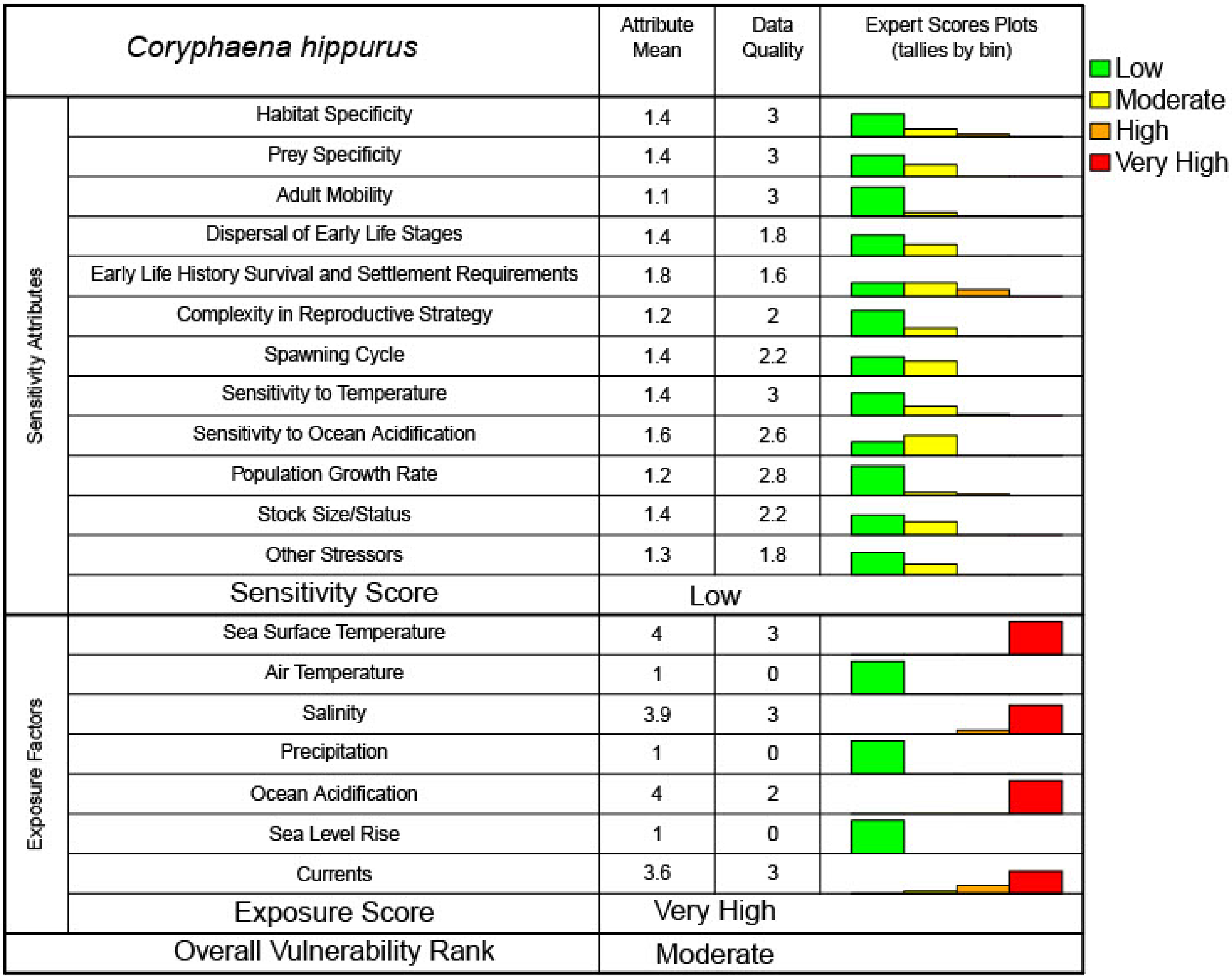
Dolphin – *Coryphaena hippurus*

Overall Vulnerability Rank = Moderate 🟨

Biological Sensitivity = Low 🟩
Climate Exposure = Very High 🟥

Data Quality = 75% of scores ≥ 2



	Coryphaena hippurus	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.4	3	
	Prey Specificity	1.4	3	
	Adult Mobility	1.1	3	
	Dispersal of Early Life Stages	1.4	1.8	
	Early Life History Survival and Settlement Requirements	1.8	1.6	
	Complexity in Reproductive Strategy	1.2	2	
	Spawning Cycle	1.4	2.2	
	Sensitivity to Temperature	1.4	3	
	Sensitivity to Ocean Acidification	1.6	2.6	
	Population Growth Rate	1.2	2.8	
	Stock Size/Status	1.4	2.2	
	Other Stressors	1.3	1.8	
	Sensitivity Score	Low		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	3.9	3	
	Precipitation	1	0	
	Ocean Acidification	4	2	
	Sea Level Rise	1	0	
	Currents	3.6	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		Moderate		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Common Name (*Species Name*) - Dolphinfish - *Coryphaena hippurus*

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

Climate Exposure: Very High. Four exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0), Salinity (3.9) and Currents (3.6). Dolphinfish are oceanic dwellers exposed to all these factors and rely on currents for larval dispersal.

Biological Sensitivity: Low. No sensitivity attributes scored above 2.0: Adults are a fast growing, rapidly maturing, and short-lived species dwelling in offshore marine waters.

Distributional Vulnerability Rank: Very High. Dolphinfish are habitat generalists that are highly mobile and have widely dispersed early life stages.

Directional Effect on the Southeast U.S. Shelf: The effect of climate change on Dolphinfish on the Southeast U.S. Shelf is estimated to be positive. The species is a pelagic oceanic resident and enjoys a tropical to temperate distribution and will likely not be impacted by moderate seawater temperature increases. The effect of ocean acidification is expected to be minimal.

Data Quality: 75% of the data quality scores were ≥ 2. Little is known about Early Life History Settlement and Survival Requirements.

Climate Effects on Abundance and Distribution: Distribution of Dolphinfish into more northern waters could occur with a warming climate. Ocean acidification will likely have a negligible effect on Dolphinfish, as they are fairly opportunistic predators and can switch from crustaceans found in sargassum mats to squid and fishes. Changes in oceanic currents might have some effect if transport of larvae to sargassum mats used for refuge and foraging is disrupted.

Life History Synopsis**:** Dolphinfish is an inhabitant of open ocean and coastal waters. The species has a circumglobal distribution (between 47 degrees N and 40 degrees S latitude) and is found in tropical and subtropical waters (Fishbase). Juveniles and adults are often found in association with floating sargassum mats and other floating debris. Dolphinfish are found in warm oceanic and coastal waters, usually at temperatures above 21°C. Unpublished pop-up satellite tag data has shown Dolphinfish to occur in temperatures from 18-31°C and to depths of 250 m (Schlenker et al. 2020). Dolphinfish are commonly found in open ocean salinities up to 36 ppt. Dolphinfish are not limited in their mobility, and are capable of lengthy migrations. Schlenker et al. (2020) reported that pop-up satellite archival tag data showed movement of over 100 km per day in fish tagged in the Florida Straits. Dolphinfish are opportunistic predators feeding on a wide variety of fish and invertebrates found associated with floating mats of sargassum on the ocean surface. They are also capable of feeding on mobile prey such as flyingfishes and mackerels (Collette et al. 2011; Manooch et al. 1984). Adult diets are equally generalist, consisting of fishes, zooplankton, crustaceans such as crabs and shrimp, and squid (Oxenford and Hunte 1999). Spawning is probably year-round at water temperatures greater than 21°C, and spawning occurs in the open ocean when water temperature rises. In temperate areas such as North Carolina, peak spawning occurs from April through July. The species spawns from spring through late fall in the northern Gulf of Mexico and possibly year-round in tropical Atlantic (Gibbs and Collette 1959) and southern Gulf waters where water temperatures remain above 24°C. Beardsley (1967) found spawning in the Florida Straits occurred January through March. Batch spawning occurs at least two or three times per spawning period. Batch fecundity estimates in the west central Atlantic range from 58,000 to 1.5 million eggs and are strongly influenced by size (Gibbs and Collette 1959, Ditty 2005, Schwenke and Buckel 2008, Oxenford 1999). Eggs and larvae are pelagic (Collette 1986), and likely remain in the open ocean, relying on currents to transport them to proximal sargassum mats which they may use for refuge and foraging. The species is fast-growing and short-lived, attaining a maximum age of 4 years, usually less than 2 years (Oxenford and Hunte 1983). Age at first maturity is three to four months in the Gulf of Mexico, four months in the Caribbean (Oxenford 1999). In Puerto Rico, 50% maturity is reached at 45 cm FL (≥ 7 months) (Perez and Sadovy 1991). Off North Carolina, males reach 50% maturity at 476 mm, 100% at 645 mm; females reach 50% maturity at 458 mm, 100% at 560 mm. Growth is rapid, as exhibited by a von Bertalanffy growth coefficient of K = 1.08/yr for North Carolina fish (Schwenke and Buckel 2008). Earlier studies found K = 0.68 from the Straits of Florida (Beardsley 1967). Dolphinfish have not been assessed from the southeastern U. S. Atlantic coast under the SEDAR protocol, as there is limited data. Prager (2000) computed a B_{1998} /B_{MSY} value of 1.56, indicating the stock was not overfished, but cautioned that inputs into the model were dated and there was considerable uncertainty. There is some evidence of stock structure based on biological and morphological characteristics (Oxenford and Hunte 1986, Lessa et al. 2008, Duarte-Neto et al. 2008), however there is genetic connectivity between migratory groups in the Atlantic, Caribbean and Gulf of Mexico (Wingrove 2000). Since Dolphinfish live in the open-ocean pelagic realm, effects of other stressors will be limited. They are not likely to be impacted by the anthropocentric habitat degradation likely to be encountered by estuarine species. Their pelagic habit , as well as their rapid growth habit, should preclude excessive lionfish predation.

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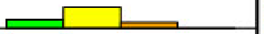
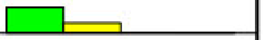
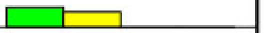
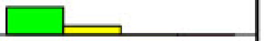
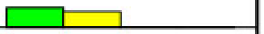
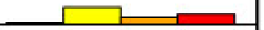
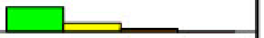
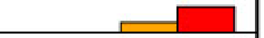
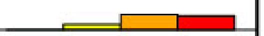
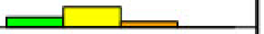
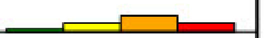
Dusky Shark – *Carcharhinus obscurus*

Overall Vulnerability Rank = Very High 🟥

Biological Sensitivity = High 🟧
Climate Exposure = Very High 🟥

Data Quality = 92% of scores ≥ 2

	Carcharhinus obscurus	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.9	3	
	Prey Specificity	1.2	3	
	Adult Mobility	1.3	2.7	
	Dispersal of Early Life Stages	1.4	2.4	
	Early Life History Survival and Settlement Requirements	1.2	2.6	
	Complexity in Reproductive Strategy	1.4	1.8	
	Spawning Cycle	2.7	2.2	
	Sensitivity to Temperature	1.4	3	
	Sensitivity to Ocean Acidification	1.1	2.8	
	Population Growth Rate	3.7	2.6	
	Stock Size/Status	3.2	2.8	
	Other Stressors	1.9	2.4	
	Sensitivity Score	High		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	3.9	3	
	Precipitation	1	0	
	Ocean Acidification	4	2	
	Sea Level Rise	1	0	
	Currents	2.8	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		Very High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Dusky Shark (*Carcharhinus obscurus*)

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

Climate Exposure: Very High. Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (3.9) and Salinity (4.0). Dusky Sharks are highly migratory species occupying the water column from the surf zone to pelagic waters > 400 m depth.

Biological Sensitivity: High. Two sensitivity attributes were ≥ 3.0: Population Growth Rate (3.7) and Stock Size/Status (3.2).Dusky Sharks are a relatively long-lived fish (40+ years; NMFS 2016), with a low population growth rate and a late age at maturity (19 years; Natonson et al. 1995; Steimle and Shaheen 1999). The species was determined to be historically overfished and undergoing overfishing in a recent stock assessment (SEDAR 2016).

Distributional Vulnerability Rank: High. Three attributes indicated high potential for distribution shift: high adult mobility, widespread dispersal of early life stages, and a habitat generalist habit.

Directional Effect on the Southeast U.S. Shelf: The effect of climate change on Dusky Shark on the Southeast U.S. Shelf is projected to be neutral. The species is a highly mobile inhabitant of warm temperate and tropical waters and effects of ocean acidification is expected to be minimal. There is little evidence to suggest either positive or negative directional effects of climate change.

Data Quality: 92% of the data quality scores were 2 or greater. Attributes for which data was identified as lacking included Complexity in Reproductive Strategy (1.8) and, to a slightly lesser degree, Spawning Cycle (2.2).

Climate Effects on Abundance and Distribution: There is very little information on the effect of climate change on Dusky Shark. In a vulnerability assessment from Australia, Dusky Shark exposure rankings were determined to be highly influenced by water temperature even though sensitivity to temperature was ranked low (Chin et al. 2010). Similarly, in our assessment the high exposure rankings of Ocean Surface Temperature, Salinity, and Ocean Acidification were in opposition to the low sensitivity rankings for those sensitivity attributes. The main drivers of the overall very high vulnerability ranking for Dusky Shark in southeastern U. S waters were growth rate and stock size/status.

Life History Synopsis**:** The Dusky Shark is a large coastal and pelagic shark species found in subtropical continental shelf waters of the U. S. Atlantic Ocean from Western Atlantic from southern Massachusetts to Florida (including the Bahamas and Cuba, through the Gulf of Mexico and as far south as southern Brazil and Uruguay. Juvenile Dusky Sharks generally avoid low salinities but have been found in shallow estuarine areas along the US. southeast coast (e.g., Bulls Bay, South Carolina; Castro 1993). Adults are highly migratory and occupy habitats from the surf zone out to depths of 500 m (Weigmann 2016). Juvenile Dusky Shark diets consist predominantly of small pelagic teleosts and squid, and it is thought they are somewhat generalist, able to switch to available fare. Adult diets are fairly diverse, including a wide variety of reef, bottom, and pelagic bony fishes, as well as other elasmobranchs, crustaceans, octopi, cuttlefish, squid, starfish, barnacles, bryozoans, whale meat, and occasional garbage . Dusky Sharks can likely expand their dietary preferences to suit prey availability (Castro 1983; Gelsleichter et al. 1999; Smale 1991). Both adult and juvenile Dusky Sharks are highly migratory and thus highly mobile, with one tagged individual from South Africa documented to migrate 742 nautical miles (Dudley et al. 2005). The species undergoes annual seasonal migrations along the east coast of the U. S., southward in winter and northward in summer (Castro 1983). Low salinity habitats are generally not utilized by adults, although some juvenile usage of shallow estuaries is known from South Carolina (Castro 1993). Dusky Sharks exhibit viviparity, giving live birth to a litter of between 2-18 pups (mean 7), with a gestation period of 22 months, two to three years between reproductive cycles, and a size at birth of 70-100 cm (Branstetter and Burgess 1996). Dusky Sharks mature very late with females maturing at age-19 and males at age-21. Dusky Sharks are found in temperatures from 8.7-18.6°C (mean 12.6°C). They begin to return from the northernmost point of their migrations in the fall when seawater temperature begins to decrease. Dusky Sharks are not likely to be affected by ocean acidification as their diet is primarily teleosts, elasmobranchs and cephalopods. Dusky Sharks have a very slow maximum intrinsic rate of increase (0.02) and would thus likely be unable or slow to recover from population depletions such as overfishing. Life history characteristics corroborating this conclusion include a maximum age of 40, a large body size (42 cm), a low growth coefficient $K = 0.039$, and an age-at-maturity of 19-21 years. Generation length for Dusky Sharks is calculated at 29.8 years (Natanson et al. 2014). Dusky Sharks are classified as endangered by the IUCN. A recent stock assessment update found the species to be overfished and undergoing overfishing (SEDAR 2016). All life stages are exploited by fisheries. There is no evidence of genetic structure between east coast and Gulf of Mexico populations (Benavides et al. 2011, McCandless et al. 2014). Fishing pressure is the primary stressor for Dusky Sharks, while there may be some minor effects of pollution or development on estuarine areas used as nursery grounds by some populations.

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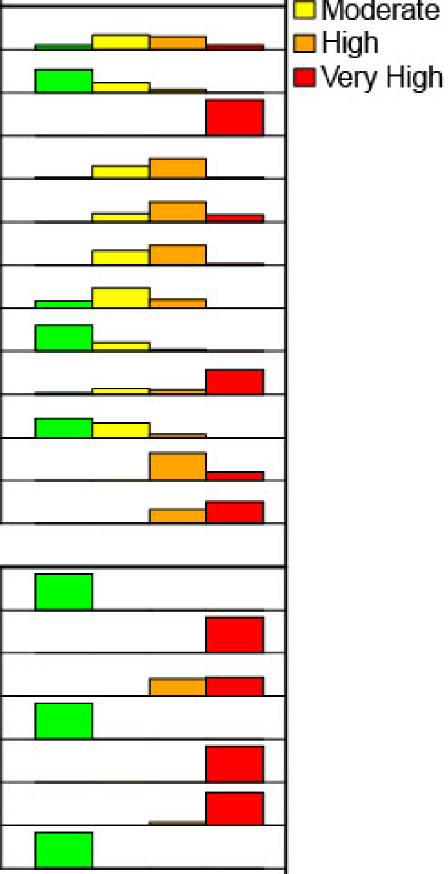
Eastern Oyster – *Crassostrea virginica*

Overall Vulnerability Rank = Very High 🟥

Biological Sensitivity = High 🟧
Climate Exposure = Very High 🟥

Data Quality = 92% of scores ≥ 2

	Crassostrea virginica	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.5	3	
	Prey Specificity	1.4	2.6	
	Adult Mobility	4	3	
	Dispersal of Early Life Stages	2.6	2.6	
	Early Life History Survival and Settlement Requirements	3	2.8	
	Complexity in Reproductive Strategy	2.6	2.6	
	Spawning Cycle	2	3	
	Sensitivity to Temperature	1.3	2.8	
	Sensitivity to Ocean Acidification	3.4	2.6	
	Population Growth Rate	1.6	2.4	
	Stock Size/Status	3.2	1.4	
	Other Stressors	3.6	3	
	Sensitivity Score	High		
Exposure Factors	Sea Surface Temperature	1	0	
	Air Temperature	4	3	
	Salinity	3.5	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	3.9	3	
	Currents	1	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		Very High		



Eastern Oyster (*Crassostrea virginica*)

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

Climate Exposure: Very High. Four exposure factors were scored ≥ 3.5: Salinity (3.5), Ocean Acidification (4.0), Air Temperature (4.0), and Sea Level Rise (3.9). Eastern Oysters are shell-forming invertebrates inhabiting estuarine, lagoonal and intertidal habitats where they are exposed to potential fluctuations in all of these factors.

Biological Sensitivity: High. Five sensitivity attributes scored ≥ 3.0: Adult Mobility (4.0,) Early Life History Settlement and Survival Requirements (3.0), Ocean Acidification (3.4), Stock Size/Status (3.2) and Other Stressors (3.6). Eastern Oysters are immobile and can not get away from harmful algal blooms or anthropogenic stressors such as pollution, and their shell-forming habit makes them vulnerable to an increasingly acidic ocean.

Distributional Vulnerability Rank: Low. Three attributes indicated extremely limited potential for distribution shift: no adult mobility, limited early life stage dispersal, and high habitat specialization.

Directional Effect on the Southeast U.S. Shelf: The effect of climate change on Eastern Oyster on the Southeast U.S. Shelf is estimated to be negative. Ocean acidification will likely impact molluscs such as Eastern Oyster. Increasing temperature and salinity may work synergistically to make oysters more susceptible to impacts from disease and pollutants.

Data Quality: 92% of the data quality scores were 2 or greater. Data gaps exist for Stock Size/Status, an attribute which scorers determined had high sensitivity.

Climate Effects on Abundance and Distribution: Eastern Oyster is a species that completes its life cycle in estuaries, which results in high exposure to anthropogenic stressors. Multiple threats to Eastern Oyster are known. Historically, diseases such as MSX and dermo, which are caused by single-celled parasites, have had major population impacts and continue to be problematic (Hofmann et al. 2009). Further, parasitic boring sponge has been recognized as having negative impacts on restoration efforts (Dunn et al. 2014). Invasive species that inhabit oyster reefs, including tropical invaders from the south (e.g., green porcelain crab), have the potential to impact oyster population dynamics in the southeast U.S. (Hollebone and Hay 2008). Ocean acidification might negatively impact multiple developmental and metabolic processes in Eastern Oyster (Beniash et al. 2010), although oysters may be more resilient to acidification than other bivalve species (Gobler and Talmage 2014). Despite all the above stressors, Eastern Oysters do appear to be resilient to projected sea level rise (Ridge et al. 2017; Rodriguez et al. 2014).

Life History Synopsis**:** Eastern Oyster is a widespread estuarine species that occurs along the entire Atlantic and Gulf of Mexico coasts of the U.S. Oysters are intertidal or subtidal reef building species, recognized for valuable ecosystem services including seafood, fisheries habitat, water filtration, and shoreline protection (Grabowski et al. 2012). Three major genetically distinct geographic groups are known: North Atlantic, South Atlantic, and Gulf Coast (Wakefield 1997). Within these broader groups, significant local scale genetic differentiation also occurs with this species (Varney et al. 2016), suggesting the potential for local environmental adaptation. Thus, climate change may influence discreet oyster populations differently, based on potentially unique responses to local environmental change. Oysters are filter feeders, consuming phytoplankton from the water column. Oyster reefs grow through processes of new recruitment and growth and survival of individuals that make up the reef. The elevation (i.e., amount of tidal exposure) where oyster reefs grow varies spatially within an estuarine system based on a complex interaction between salinity and predation pressure (Johnson and Smee 2014; Ridge et al. 2017). At higher salinity locations, predators including oyster drills, multiple crab species and certain fishes may reduce survival of subtidal oysters, thus restricting them to intertidal elevations. Adult oysters are sessile and may reach harvestable size within 2-5 years, depending on water temperature. While individuals probably live 10+ years (Powell et al. 2013), few age-4 or older individuals may occur on a reef (Mann et al. 2009). Oysters are sequential protandrous hermaphrodites and start out life as males, reaching maturity within several months of settling. While a portion of oysters will remain as males throughout life, the sex ratio will gradually shift towards a majority (~75%) of females by age-3 or 4 (Harding et al. 2013). Fecundity of oysters increases exponentially with oyster size and a single female is capable of broadcast spawning tens of millions of eggs in a single event (Mann et al. 2014). The spawning season in the southeast may last 7 months, ranging from spring to fall (O'Beirn et al. 1995) and individuals may spawn multiple times (Mann et al. 2014). Offspring pass through several free-swimming larval stages that feed on phytoplankton and last for two to five weeks depending on temperature (Dekshenieks et al. 1993). Although larvae are capable of vertical swimming behavior, dispersal is primarily the result of wind and tidal driven currents (Haase et al. 2012; Kroll et al. 2018). However, retention of larvae within the natal area occurs and is probably important for the persistence of many oyster reefs and for allowing local genetic adaptation (Varney et al. 2016). Spat, or juvenile oysters, may settle on a variety of hard substrata. Larvae preferentially settle on existing oyster reefs by responding to sounds produced by live reefs (Lillis et al. 2013). Eastern Oyster is a species that completes its life cycle in estuaries, which results in high exposure to anthropogenic stressors. Multiple threats to Eastern Oyster are known. Historically, diseases such as MSX and dermo, which are caused by single-celled parasites, have had major population impacts and continue to be problematic (Hofmann et al. 2009). Further, parasitic boring sponge has been recognized as having negative impacts on restoration efforts (Dunn et al. 2014). Invasive species that inhabit oyster reefs, including tropical invaders from the south (e.g., green porcelain crab), have the potential to impact oyster population dynamics in the southeast U.S. (Hollebone and Hay 2008). Ocean acidification might negatively impact multiple developmental and metabolic processes in eastern oyster (Beniash et al. 2010), although oysters may be more resilient to acidification than other bivalve species (Gobler and Talmage 2014). Despite all the above stressors, oysters do appear to be resilient to projected sea level rise (Ridge et al. 2017; Rodriguez et al. 2014).

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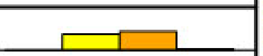
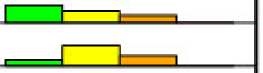
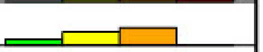
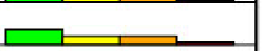
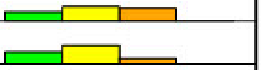
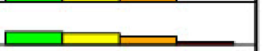
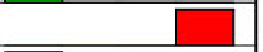
Emerald Parrotfish – *Nicholsina usta*

Overall Vulnerability Rank = High 🟧

Biological Sensitivity = Moderate 🟨
Climate Exposure = Very High 🟥

Data Quality = 42% of scores ≥ 2

	Nicholsina usta	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.6	2.7	
	Prey Specificity	1.7	2.6	
	Adult Mobility	2.1	1.9	
	Dispersal of Early Life Stages	2.3	1.9	
	Early Life History Survival and Settlement Requirements	2.6	1.8	
	Complexity in Reproductive Strategy	2.3	2	
	Spawning Cycle	2.2	1.8	
	Sensitivity to Temperature	2	2.6	
	Sensitivity to Ocean Acidification	2.1	1.9	
	Population Growth Rate	1.8	1.5	
	Stock Size/Status	2	2	
	Other Stressors	2.1	1.5	
	Sensitivity Score	Moderate		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	4	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	1	0	
	Currents	2.6	2.2	
	Exposure Score	Very High		
Overall Vulnerability Rank		High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Emerald Parrotfish (*Nicholsina usta*)

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

Climate Exposure: Very High. Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Salinity (4.0). Exposure to these factors occurs during the life cycle, in which Emerald Parrotfish reside on reef/rocky habitat as well as shallow seagrass beds (Westneat 2002)

Biological Sensitivity: Moderate. Two sensitivity attributes scored ≥ 2.5: Habitat Specialization (2.5) and Early Life History Survival and Settlement Requirements (2.6). Emerald Parrotfish are known to associate with specific microhabitats, including live scleractinian corals (Bellwood & Choat 1989, Tolimieri 1998; Hamilton et al. 2017). Little information is available about other early life history requirements.

Distributional Vulnerability Rank: Moderate. Emerald Parrotfish are habitat specialists that, while mobile, tend to exhibit site-association (Bellwood & Choat 1989) and thus are not scored as likely to expand their distribution.

Directional Effect on the Southeast U.S. Shelf: The effect of climate change on Emerald Parrotfish on the Southeast U.S. Shelf is estimated to be neutral. There is little information available to assess directional effects of climate change on Emerald Parrotfish.

Data Quality: 42% of the data quality scores were 2 or greater. Data gaps were identified for the following attributes: Adult Mobility, Early Life History Survival and Settlement Requirements, Dispersal of Early Life Stages, Spawning Cycle, Sensitivity to Ocean Acidification, Population Growth Rate, and Other Stressors.

Climate Effects on Abundance and Distribution: There are no directed studies on the effects of climate change on distribution and productivity of Emerald Parrotfish. Ocean Acidification could have a major effect on the species in the form of habitat loss due to coral degradation; while some Emerald Parrotfish are found in seagrass beds and mangroves, they also rely on specific species of scleractinian corals for food and habitat (Tolimieri 1998), and there is some limited evidence that the species consumes sessile and encrusting invertebrates (Westneat 2002).

Life History Synopsis**:** Emerald Parrotfish (family Labridae, subfamily Scarinae) is a relatively small parrotfish reported from New Jersey through Florida, the Gulf of Mexico, the Yucatan Peninsula, to southeastern Brazil (Rio de Janeiro). It also occurs in the Greater Antilles but is absent from Bermuda, the Bahamas, and the Lesser Antilles (Fishbase; Robins & Ray 1986; Humann & DeLoach 2002; ReefNet 2007; Bertoncini et al. 2012). Adults are found in seagrass beds, rocky coastal areas (temperate hard bottom reefs), deep reefs, sandy areas, macroalgae, and open hard bottom, mostly in very shallow water, but also to depths of 73-80 m. Large adults are said to live in deeper water (Bertoncini et al. 2012). Juveniles have been observed together with adults on hard bottom reefs in depths of 16-21 m at Gray's Reef National Marine Sanctuary, off the coast of Georgia (RC Muñoz, pers. obs). Adults reach a maximum length of 30 cm total length (TL), whereas no information is available concerning maximum age (FishBase; Robins & Ray 1986). Emerald Parrotfish are believed to be largely herbivorous, feeding on seagrass, but probably also gain nutrients from small invertebrates as well (Bellwood 1994; Westneat 2002). Adult mobility of Emerald Parrotfish is unknown. However, parrotfishes display a great diversity of mating systems and alternative reproductive behavior (Robertson & Warner 1978), and their movements are known to be influenced by their social strategy and time of the year (Robertson & Warner 1978; Clifton & Robertson 1993; Afonso et al. 2008). For example, the larger (max 50 cm TL) temperate parrotfish, *Sparisoma cretense*, displays a median home range size of 37,000 m^2, but with territorial individuals showing greatly restricted movements and limited mobility relative to individuals living in groups that show greater mobility and make reproductive migrations during the spawning season (Afonso et al. 2008). No information is currently available regarding the formation of large spawning aggregations by Emerald Parrotfish. However, many parrotfishes are protogynous hermaphrodites, and the group displays a great diversity of mating and social systems (Robertson & Warner 1978; Thresher 1984; Colin & Bell 1991). Reproductive and social behavior can include pair spawns, harems, alternative reproductive behavior, group spawns, territoriality, roving bachelors, and large spawning aggregations (Robertson & Warner 1978; Sadovy & Colin 2012; Roff et al. 2017). Regarding the spawning season, since the subfamily is largely tropical and associated with coral reefs, many species of parrotfishes are known to spawn year round on a daily basis, with frequency of spawning likely decreasing with increasing latitude. The temperate parrotfish, *Sparisoma cretense*, has a distinct summer spawning season, with most individuals spawning from June-September (Afonso et al. 2008). No information is currently available regarding the planktonic larval duration (PLD) of Emerald Parrotfish. However, other species of parrotfishes have PLDs ranging from 28-91 days (Lou 1993; Schultz & Cowen 1994; Muñoz 2002). Early life history (larval) requirements of Emerald Parrotfish are unknown. Newly settled juvenile parrotfishes are site-attached and associated with specific microhabitats, including particular live scleractinian corals (Bellwood & Choat 1989, Tolimieri 1998; Hamilton et al. 2017), although stoplight parrotfish (*Sparisoma viride*) were shown to facultatively recruit to areas with high cover of the macroalgae *Dictyota* spp., which may provide an alternative recruitment refuge (Paddack & Sponaugle 2008). In the eastern Mediterranean Sea, newly settled juveniles of the temperate parrotfish (*S. cretense*) settled in protected shallow areas offering hard substrates and algal communities (Bariche et al. 2004). Emerald Parrotfish occur from 22.8-28°C (preferred temperature, Kaschner et al. 2016) and can be found distributed across five zoogeographic provinces. They occupy habitats from seagrass beds located in very shallow water (1 m) to rocky reefs at 80 m depth. While believed to be largely herbivorous, Emerald Parrotfish may be indirectly affected by ocean acidification, as parrotfish are believed to gain some nutrients from the consumption of invertebrate epifauna on seagrass and macroalgae, as well as encrusting and sessile invertebrates that are part of the epilithic algal matrix on reefs (e.g., copepods, amphipods, ostracods; Kramer et al. 2013; Bonaldo et al. 2014; Dromard et al. 2017). These invertebrates may be negatively affected by ocean acidification (Bhadury 2015; Cripps et al 2015). No information is available regarding population growth rate of Emerald Parrotfish. Although the stock has never been assessed, it is rare but can be locally common and geographically widespread. In the Gulf of Mexico, there is evidence that populations are increasing (Fodrie et al. 2010). In the western Atlantic, there are no major threats known to this species. IUCN Red List classifies it as Least Concern. However, as this species is caught in large-scale trap and mult-species fisheries, more research is needed on the population status and harvest levels (Bertoncini et al. 2012). Given the above, the workshop scorers thought the population would be at or above B_{MSY}. Other potential stressors for Emerald Parrotfish are not readily apparent. There are no known major threats. Habitat degradation may be an issue in the future as seagrass beds and macroalgal meadows face stressors from climate change (Duarte et al. 2018). Emerald Parrotfish may also be susceptible to invasive lionfish predation, as other species of parrotfish have been recorded in the diet of lionfish (Peake et al. 2018).

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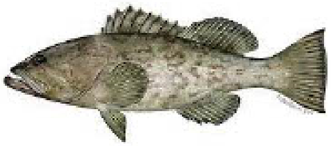
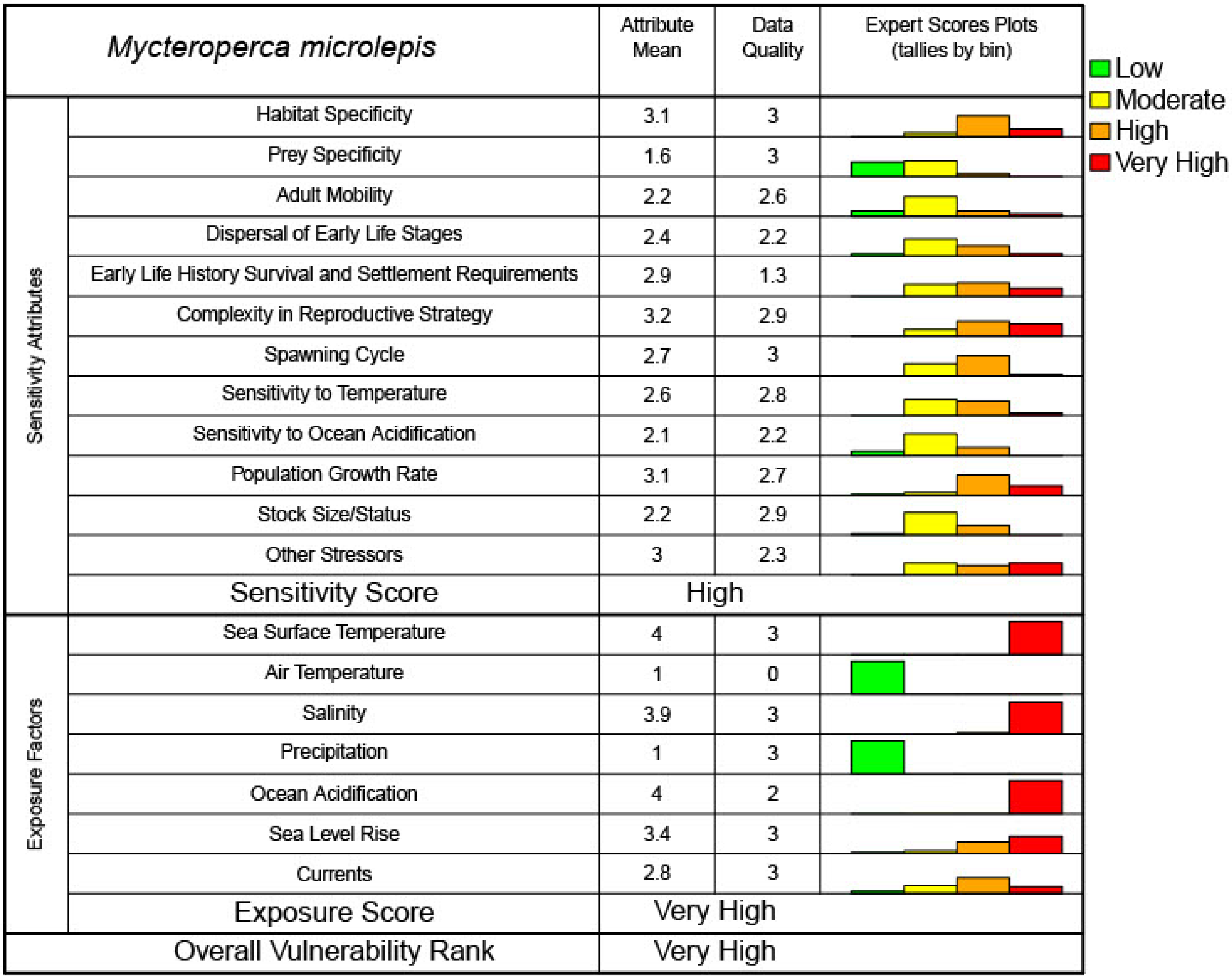
Gag Grouper − *Mycteroperca microlepis*



Overall Vulnerability Rank = Very High 🟥

Biological Sensitivity = High 🟧
Climate Exposure = Very High 🟥

Data Quality = 92% of scores ≥ 2



	Mycteroperca microlepis	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	3.1	3	
	Prey Specificity	1.6	3	
	Adult Mobility	2.2	2.6	
	Dispersal of Early Life Stages	2.4	2.2	
	Early Life History Survival and Settlement Requirements	2.9	1.3	
	Complexity in Reproductive Strategy	3.2	2.9	
	Spawning Cycle	2.7	3	
	Sensitivity to Temperature	2.6	2.8	
	Sensitivity to Ocean Acidification	2.1	2.2	
	Population Growth Rate	3.1	2.7	
	Stock Size/Status	2.2	2.9	
	Other Stressors	3	2.3	
	Sensitivity Score	High		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	3.9	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	3.4	3	
	Currents	2.8	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		Very High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Gag (*Mycteroperca microlepis*)

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

Climate Exposure: Very High. Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Salinity (3.9). Gag utilize marine coastal and nearshore habitats during all life stages and are exposed to all of these factors throughout their life cycle.

Biological Sensitivity: High. Four sensitivity attributes were ≥ 3.1: Habitat Specialization (3.1), Reproductive Complexity (3.2), Population Growth Rate (3.3), and Other Stressors (3.1). Gag are a moderately slow growing and late-maturing species. They prefer offshore habitats of structural complexity as adults but juveniles are known to occur in estuarine seagrass beds, where they are likely exposed to anthropogenic stressors. Gag are protogynous, forming spawning aggregations, which has led to overexploitation in the past, especially of larger males (McGovern et al.1998) reported the proportion of males decreased from 19.6% (1976-1982) to 5.5% (1994 to 1995), and also suggested that the size at first maturity decreased.

Distributional Vulnerability Rank: Moderate. Gag are mobile fish with widely dispersing larvae, but their need for specific habitat types likely is responsible for the potential for distribution shift being scored as moderate versus high.

Directional Effect in the Southeast U.S. Shelf: The effect of climate change on Gag on the Southeast U.S. Shelf is estimated to be neutral (although the expert scorers were equally split between the three categories). Warming seawater temperatures in the southeast may make nursery habitats less productive, while adults in deeper water habitats are not expected to be greatly impacted by increasing temperatures . The effect of ocean acidification is expected to be minimal, as Gag are flexible in prey selection.

Data Quality: 92% of the data quality scores were 2 or greater. Early Life History Survival and Settlement Requirements was identified as the sole sensitivity attribute for which data is lacking.

Climate Effects on Abundance and Distribution: Gag are likely to be affected by Ocean Acidification, as they prey on crustaceans both as juveniles and adults. Adult Gag prefer structures of maximum complexity, such as *Oculina* reefs, which are likely to be degraded by increasing acidification. Changing Ocean Surface Temperature could affect recruitment success of gag (Sedberry et al. 2001). While not documented in the literature, it is feasible that changing temperature could also alter timing of onset of spawning season.

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). The species 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). 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). Gag are 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 Scamp (*M. phenax)* consisting of hundreds of individuals 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). 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). 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. Gag may 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). Gag exhibit a moderate to high vulnerability to population growth rate being affected by climate change. Natural mortality is estimated as high vulnerability (M=0.20), age at maturity of females is 3-6 years (high vulnerability), age at transition to males is 5-9 years (high-very high vulnerability), and maximum length is >1000 mm (high, approaching very high vulnerability). The last completed SEDAR stock assessment for Gag found $SSB_{2012}/SSB_{MSY} = 0.97$. SSB_{2012}/MSST

= 1.13, indicating the stock was not overfished in the South Atlantic. A new stock assessment (2021) is ongoing, and new results (not yet published) indicate there have been 10 successive years of poor recruitment which have pushed Gag populations to the lowest levels in history. The stock is overfished 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 populations, reflecting the offspring would be more likely to be genetically related due to inbreeding. Other potential stressors for Gag include possible anthropocentric degradation of inshore estuarine habitat, temperate reef degradation (e.g., destruction of Oculina reefs by fishing gear), and potential lionfish predation.

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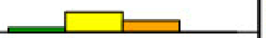
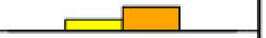
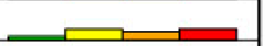
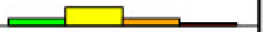
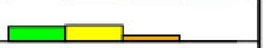
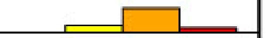
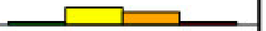
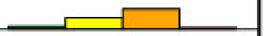
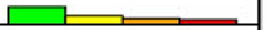
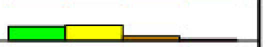
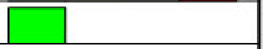
Golden Crab − *Chaceon fenneri*

Overall Vulnerability Rank = High 🟧

Biological Sensitivity = Moderate 🟨
Climate Exposure = Very High 🟥

Data Quality = 25% of scores ≥ 2

	Chaceon fenneri	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.2	1.8	
	Prey Specificity	1.3	1	
	Adult Mobility	2.7	1.8	
	Dispersal of Early Life Stages	2.8	1	
	Early Life History Survival and Settlement Requirements	2.2	0.6	
	Complexity in Reproductive Strategy	1.8	0.6	
	Spawning Cycle	2.9	2.2	
	Sensitivity to Temperature	2.4	2.8	
	Sensitivity to Ocean Acidification	2.6	1.6	
	Population Growth Rate	1.9	0.8	
	Stock Size/Status	1.8	1	
	Other Stressors	1.2	2	
	Sensitivity Score	Moderate		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	4	3	
	Precipitation	1	0	
	Ocean Acidification	4	2	
	Sea Level Rise	1	0	
	Currents	3.7	2.4	
	Exposure Score	Very High		
Overall Vulnerability Rank		High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Golden Crab (*Chaeceon fenneri*)

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

Climate Exposure: Very High.Four exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0), Salinity (4.0) and Currents (3.7). Golden Crab residents of the deep continental shelf/slope, where they will be susceptible to changes in these environmental exposure factors. Changes in currents could affect the ability of larvae and juveniles to settle in appropriate habitat.

Biological Sensitivity: Moderate. Four sensitivity attributes scored ≥ 2.5: Adult Mobility (2.7), Spawning Cycle (2.9), Dispersal of Early Life Stages (2.8), and Sensitivity to Ocean Acidification (2.6). Golden Crab are likely limited behaviorally in their mobility, preferring to remain close to their preferred benthic habitat. Little is known of the dispersal of early life stages, and a shell-forming crustacean, the species may suffer decreased fitness, survival, or productivity due to increasing ocean acidification.

Distributional Vulnerability Rank: Low. Three attributes indicated limited potential for distribution shift: limited adult mobility (behavioral), limited early life stage dispersal (little known about fate of propagules, but it is thought they must remain close to preferred adult habitat), and relatively high habitat specialization.

Directional Effect in the Southeast U.S. Shelf: The effect of climate change on Golden Crab on the Southeast U.S. Shelf is estimated to be neutral (although the expert scorers were almost equally split between the three categories). While there may be some negative effects of Ocean Acidification, the species' deepwater habitat preferences may spare them from impacts from increasing sea surface temperature or salinity.

Data Quality: 25% of the data quality scores were ≥ 2. Attributes for which data was lacking and sensitivity was judged high include Adult Mobility, Dispersal of Early Life Stages, Spawning Cycle, and Sensitivity to Ocean Acidification.

Climate Effects on Abundance and Distribution: References to effects of climate change on Golden Crab are lacking in the scientific literature. Increasing Ocean Acidification will likely affect the species because of their exoskeleton, but little is known of their diet and any reliance on invertebrates. Changes in oceanic currents could have effects on both dispersal of larvae to suitable nursery habitat and the transport of nutrients and production to their deep ocean habitat. It is not known what effect increasing salinity or temperature will have.

Life History Synopsis**:** Golden Crab are distributed from North Carolina through southeast Florida and into the Gulf of Mexico. The species is a large non-swimming crustacean inhabiting the continental slope at depths of 275-915 m in the Florida Straits, and has been reported from depths of 786-1462 m from Bermuda. Males reach sizes of five pounds and are commercially valuable, while females are significantly smaller and have limited commercial value. Adult Golden Crab have been found in a variety of habitat types, including silt-clay molluscan shell fragments and foraminiferan shell, soft-bottom habitats between 458-549 m off SE Florida (flat foraminiferan ooze, rippled sediment, black pebble bottom and soft bioturbated substrate, Reed et al. 2017). Absence of Golden Crab at depths deeper than 550 m appeared to be related to unsuitable sediment type (coral fragments and rubble). Low outcrops, black pebble, rippled habitat, soft-bioturbated habitat, flat foraminiferan ooze, coral mounds, and dune habitat were preferred habitats off South Carolina (Wenner and Barans 1990, Wenner et al. 1987). There is no information in the literature about juvenile habitat preferences, but it is likely the same as adult habitat type. There is no information in the literature on the diet of Golden Crab. Given the limited nature of the deep water habitat they occupy and their limited mobility (non-swimming), it is likely their diet is limited and they are not able to opportunistically switch prey items easily. Adults likely have limited mobility, as they are not swimmers. They are capable of crawling but probably behaviorally stay close to their habitat, for both refuge and food. Examination of Golden Crab collected from southeast Florida indicates an annual reproductive cycle with a single batch of eggs produced each year, from August through October, with eggs retained on the female for approximately six months before hatching in February and March (Erdman and Blake 1988). No information on larval/juvenile development was found but it is likely that larval crabs remain proximal to where hatched, near preferred habitats on the continental slope. There is no information on presence of food for larvae, or specific environmental settlement cues. It is not likely that golden crab larvae depend on tidal transport/gyres, but more likely that they settle out where hatched on preferred continental slope habitat. Reed et al. (2017) found Golden Crab in temperatures ranging from 5.6 -16.7°C off Florida. This is similar to findings off South Carolina-Georgia from 7.0-15.5°C (Wenner and Barans 1990). Golden Crab is likely to be affected by an increasingly acidic ocean, as it is a crustacean with a calcium carbonate shell. There is little information available on the population growth rate of Golden Crab. Erdman and Blake (1988) reported size at maturity of between 85-100 mm carapace length, but no information on size at age was found. Golden Crab have not been assessed. There was no genetic differentiation found between the two *Chaeceon* species off Florida, golden and red deep-sea crabs, despite there being fairly significant ecological differences (Weinberg et al. 2003). There are no reports of variations in reproductive success or fluctuations in population size or local extinction. Golden Crab are not likely to be impacted by many other stressors given the deep offshore nature of their habitat. However, offshore oil exploration did impact individuals in the Gulf of Mexico during Deepwater Horizon.

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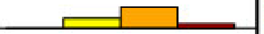
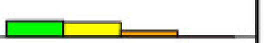
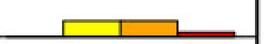
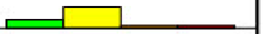
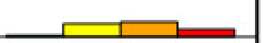
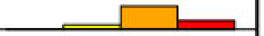
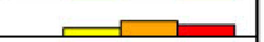
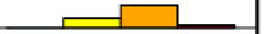
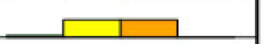
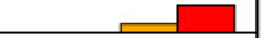
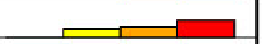
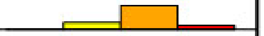
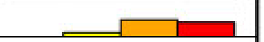
Goliath Grouper − *Epinephelus itajara*

Overall Vulnerability Rank = Very High 🟥

Biological Sensitivity = High 🟧
Climate Exposure = Very High 🟥

Data Quality = 92% of scores ≥ 2

	Epinephelus itajara	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.8	3	
	Prey Specificity	1.7	3	
	Adult Mobility	2.7	2.2	
	Dispersal of Early Life Stages	2	2.6	
	Early Life History Survival and Settlement Requirements	2.8	1.7	
	Complexity in Reproductive Strategy	3.1	2.8	
	Spawning Cycle	3.1	3	
	Sensitivity to Temperature	2.8	2.8	
	Sensitivity to Ocean Acidification	2.4	2.2	
	Population Growth Rate	3.8	2.8	
	Stock Size/Status	3.2	2	
	Other Stressors	2.9	2.5	
	Sensitivity Score	High		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	4	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	3.3	3	
	Currents	2.3	3	
	Exposure Score	Very High		
	Overall Vulnerability Rank	Very High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Goliath Grouper (*Epinephelus itajara*)

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

Climate Exposure: Very High. Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Salinity (4.0). As a coastal reef fish that also occurs in seagrass bed, mangroves, and other nearshore areas as juveniles, the species is exposed to all of these environmental factors during their life stages.

Biological Sensitivity: High. Four sensitivity attributes scored ≥ 3.0: Reproductive Complexity (3.1), Spawning Cycle (3.1), Stock Size/Ratio (3.2) and Population Growth Rate (3.8). Goliath Grouper are a relatively long-lived and slow growing fish with low population growth rates. The species was overexploited to the point of being protected from all harvest in 1990, and is thought to be slowly recovering but is not expected to achieve full recovery until the year 2020 or later.

Distributional Vulnerability Rank: Moderate. Three attributes indicated only moderate potential for distribution shift: a moderate degree of habitat specialization (a preference for estuarine mangrove nursery areas), behaviorally-limited adult mobility (known to exhibit site fidelity), and limited early life stage dispersal (propagules known to travel up to 100 Km; Lara et al. 2009). The species enjoys a temperate through tropical distribution, however, and increasing temperatures could be conducive to a range expansion.

Directional Effect in the Southeast U.S. Shelf: The directional effect of climate change on Goliath Grouper on the Southeast U.S. Shelf is estimated to be neutral (with scorers divided equally between the three categories). While Goliath Grouper has tropical to temperate thermal preferences, they do rely on mangrove habitats which are increasingly affected by anthropogenic degradation. Goliath Grouper consume a large quantity of crustaceans and are likely to be affected by Ocean Acidification.

Data Quality: 92% of the data quality scores were 2 or greater. Early Life History Survival and Settlement Requirements were identified by scorers as a data gap, followed by Stock Size/Status (likely because of an inability to conduct life history studies due to protected status).

Climate Effects on Abundance and Distribution: As stated above, increasing temperatures could positively affect distribution, although Goliath Grouper have specific habitat preferences (seagrass, mangroves) and range expansion of the fish would likely have to occur concurrently with expansion of the habitat. Increasing ocean acidification could affect Goliath Grouper because of their preference for crustaceans in their diet.

Life History Synopsis: Goliath Grouper is a large reef-associated grouper species found in nearshore 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 (Hostim-Silva et al. 2005). Juvenile Goliath Grouper are found primarily in inshore mangrove habitat (Koeing et al. 2007), but also inhabit seagrass beds, tidepools, shallow rocky areas, jetties and areas around 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, they generally move offshore to high-relief habitats such as coral reefs, wrecks, artificial reefs, or rocky ledges as they get older (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 (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), possibly due to severe overfishing. Spawning occurs offshore from July to October (Koenig and Coleman 2009), and 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). The distance traveled by larvae could be 100+ km. (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. Functional hermaphroditism has not been confirmed, however. Goliath Grouper enjoy a subtropical-tropical temperature range, found in waters from 22-28°C (mean 26°C (Fishbase). Cold temperature events in 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. 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, and 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-harvest regulations were imposed in 1990. The species appears to have recovered since then. A recent stock assessment (SEDAR 2016) found that Goliath Grouper were not overfished ($B_{curr}/B_{MSST} = 1.48$) and that overfishing was not occurring in most recent years ($F_{curr}/F_{MFMT} = 0.22$). 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 could be excessive fishing pressure, should regulations be relaxed.

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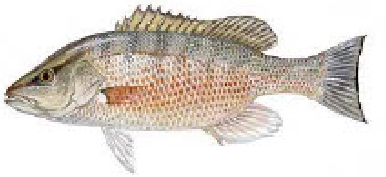
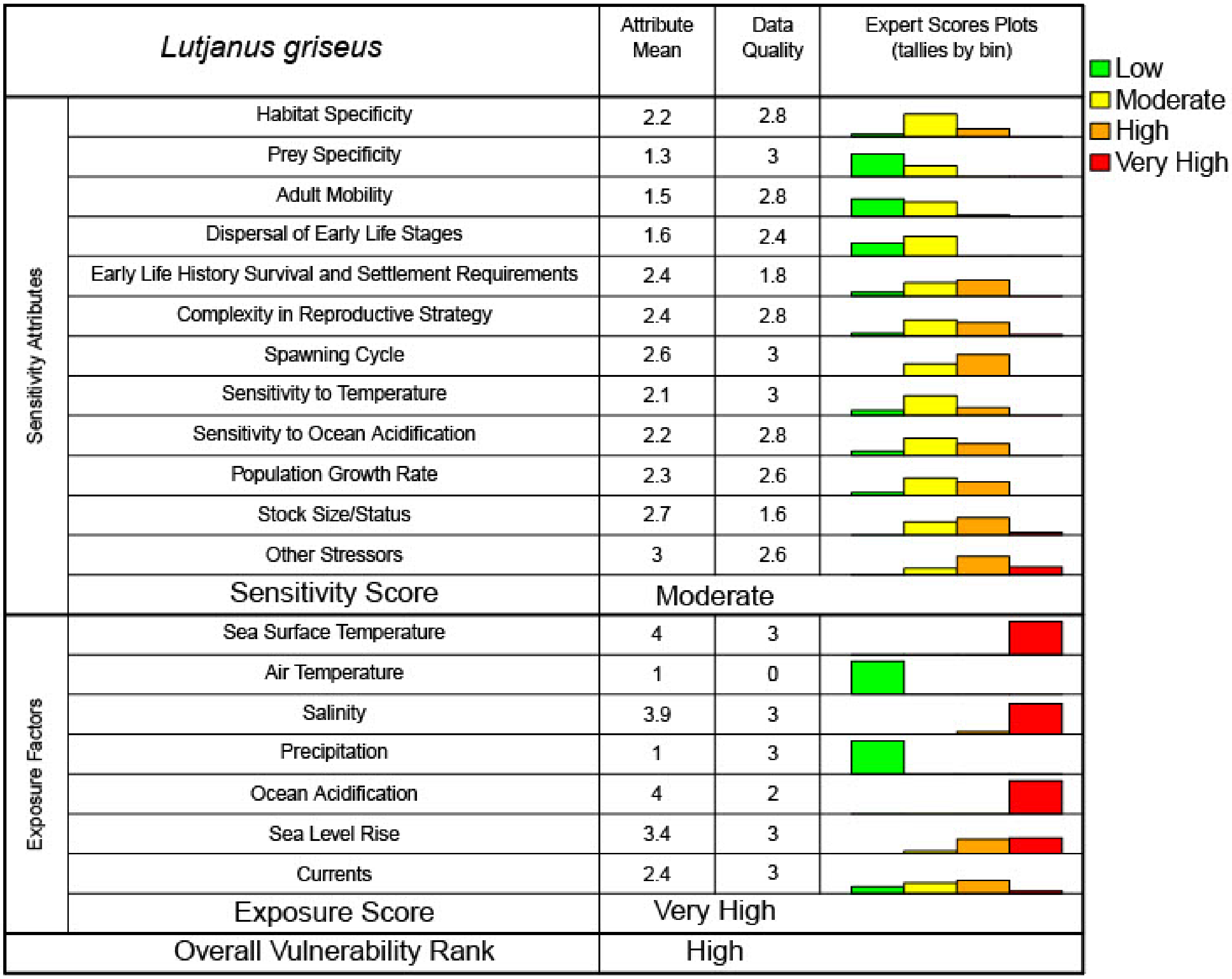
Gray Snapper − *Lutjanus griseus*



Overall Vulnerability Rank = High 🟧

Biological Sensitivity = Moderate 🟨
Climate Exposure = Very High 🟥

Data Quality = 83% of scores ≥ 2



	Lutjanus griseus	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.2	2.8	
	Prey Specificity	1.3	3	
	Adult Mobility	1.5	2.8	
	Dispersal of Early Life Stages	1.6	2.4	
	Early Life History Survival and Settlement Requirements	2.4	1.8	
	Complexity in Reproductive Strategy	2.4	2.8	
	Spawning Cycle	2.6	3	
	Sensitivity to Temperature	2.1	3	
	Sensitivity to Ocean Acidification	2.2	2.8	
	Population Growth Rate	2.3	2.6	
	Stock Size/Status	2.7	1.6	
	Other Stressors	3	2.6	
	Sensitivity Score	Moderate		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	3.9	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	3.4	3	
	Currents	2.4	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Gray Snapper (*Lutjanus griseus*)

Overall Climate Vulnerability Rank: High. (99% bootstrap results in High) .

Climate Exposure: Very High. Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Salinity (3.9). Gray Snapper are exposed to all three factors throughout their life stages. Gray Snapper uses coastal and nearshore habitats as nursery areas and reside further offshore on hardbottom habitat/reefs once mature.

Biological Sensitivity: Moderate. Three sensitivity attributes scored above 2.5: Complexity in Reproductive Strategy (2.6), Stock Size/Status (2.7) and Other Stressors (3.0). Gray Snapper are most common in the southern part of the range and are highly valued by anglers. During juvenile residency in mangroves, seagrass and other estuarine areas they are subject to anthropogenic disruptions.

Distributional Vulnerability Rank: High. Two attributes indicated high potential for distribution shift: adult mobility and dispersal of early life stages. Additionally, a tendency for Gray Snapper to be habitat generalists (occupying habitats including mangroves, seagrass beds, hardbottom habitats and coral reefs) contribute to this potential.

Directional Effect in the Southeast U.S. Shelf: The directional effect of climate change on Gray Snapper on the Southeast U.S. Shelf is estimated to be positive. Increased warming is expected to lead to a northward shift in distribution of Gray Snapper to at least New Jersey (Hare et al. 2012). Moderate effects of ocean acidification are expected due a substantial inclusion of crustaceans in their diet.

Data Quality: 83% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution: This study found that potential for changes in species distribution was high for Gray Snapper, however, as the species is highly mobile, has potentially widely dispersing larvae and is tolerant of moderate temperature fluctuations. 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 inhabitat 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 and 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 (Bacheler et al. 2020), 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 Shroeder, 1971; Erdman, 1976). Gray Snapper eggs are pelagic and hatch after approximately 20 hours at 27° C (Allen, 1985). Along the southeast United States Atlantic coast, eggs and larvae are transported by Gulf Stream currents to complex habitats in estuarine nurseries areas between Florida and North Carolina (Sumner et al., 1911; 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 moderate, but scorers noted that some biological traits of Gray Snapper suggested slow population growth rates (e.g., maximum age = 24; growth rate [k] = 0.10 – 0.17), while others (e.g., age at maturity = 2) suggested higher population growth rate (Manooch and Matheson, 1981; Burton, 2001). Gray Snapper have been considered overfished in the Florida Keys (Ault et al. 2005) and in the Gulf of Mexico (SEDAR 2018), but their stock status along the southeast US Atlantic coast is unknown. Given their moderate population growth rate and the fact they are heavily targeted by fishermen, Gray Snapper stock status was thought to be near or below B_{msy} by the expert scorers. Expert scorers also determined that Gray Snapper may be highly sensitivity to other potential stressors including habitat degradation in estuaries that may influence estuarine-dependent juveniles, myxozoan parasites (Holzer et al., 2013), coral bleaching that may influence reef-dependent adults, and possible lionfish predation.

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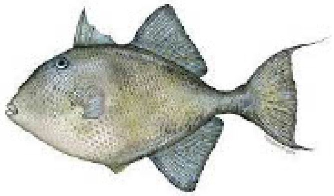
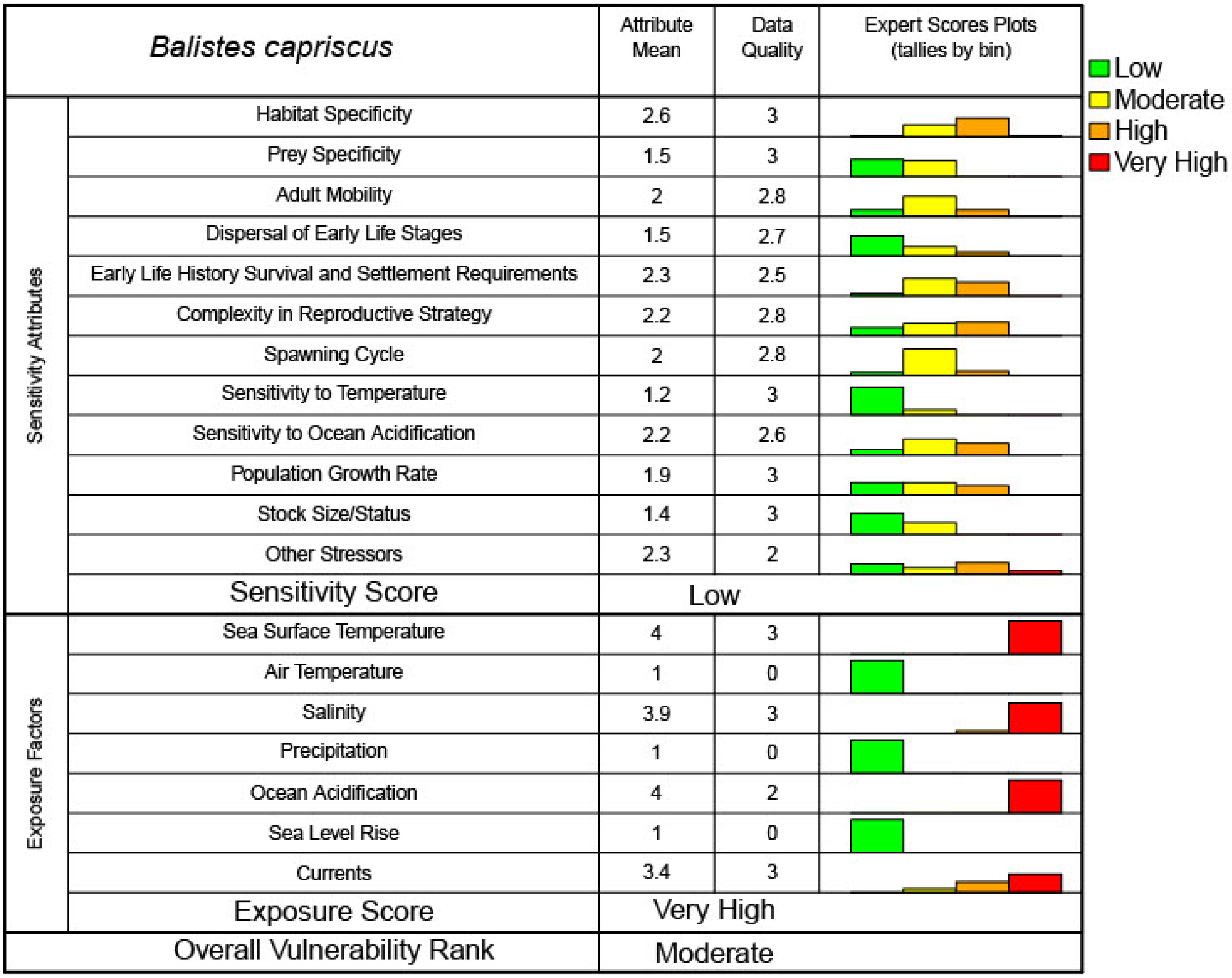
Gray Triggerfish − *Balistes capriscus*



Overall Vulnerability Rank = Moderate 🟨

Biological Sensitivity = Low 🟩
Climate Exposure = Very High 🟥

Data Quality = 92% of scores ≥ 2



	Balistes capriscus	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.6	3	
	Prey Specificity	1.5	3	
	Adult Mobility	2	2.8	
	Dispersal of Early Life Stages	1.5	2.7	
	Early Life History Survival and Settlement Requirements	2.3	2.5	
	Complexity in Reproductive Strategy	2.2	2.8	
	Spawning Cycle	2	2.8	
	Sensitivity to Temperature	1.2	3	
	Sensitivity to Ocean Acidification	2.2	2.6	
	Population Growth Rate	1.9	3	
	Stock Size/Status	1.4	3	
	Other Stressors	2.3	2	
	Sensitivity Score	Low		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	3.9	3	
	Precipitation	1	0	
	Ocean Acidification	4	2	
	Sea Level Rise	1	0	
	Currents	3.4	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		Moderate		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Gray Triggerfish (*Balistes capriscus*)

Overall Climate Vulnerability Rank: Moderate**.** (82% bootstrap results in Moderate, 18% bootstrap results in High).

Climate Exposure: Very High**.** Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Salinity (3.9). Adult Gray Triggerfish live in coastal marine habitats and juveniles are known to occur in association with pelagic seagrass beds, thus exposure to all three factors occur during all life stages.

Biological Sensitivity: Low. Only one sensitivity attribute scored above 2.5: Habitat Specificity (2.6; once settled, gray triggerfish tend to exhibit high site fidelity). Gray Triggerfish are a widely distributed, relatively long-lived fish with a moderately high population growth rate and recent assessments indicate they are neither overfished nor undergoing overfishing. They are diet generalists, and have a fairly robust reproductive output.

Distributional Vulnerability Rank: High. Two attributes indicated high potential for distribution shift: adult mobility and widespread early life stage dispersal. Additionally, a wide geographic distribution indicates Gray Triggerfish do not exhibit narrow thermal tolerances that would limit distributional shift.

Directional Effect on the Southeast U.S. Shelf: The directional effect of climate change on Gray Triggerfish on the Southeast U.S. Shelf is estimated to be neutral. Increased warming has resulted in an increasing occurrence of Gray Triggerfish in the northeastern U. S., while moderate effects of ocean acidification are anticipated because Gray Triggerfish diets include bivalves, barnacles and a variety of crustaceans.

Data Quality: 92% of the data quality scores were > 2.

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). Adults can be highly mobile, but often display relatively high site fidelity to particular reef habitats (Bacheler et al. 2019). 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). 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 not overfished and not undergoing overfishing (SEDAR 2016), but high discard mortality from fishing may be a concern (Runde et al. 2019). 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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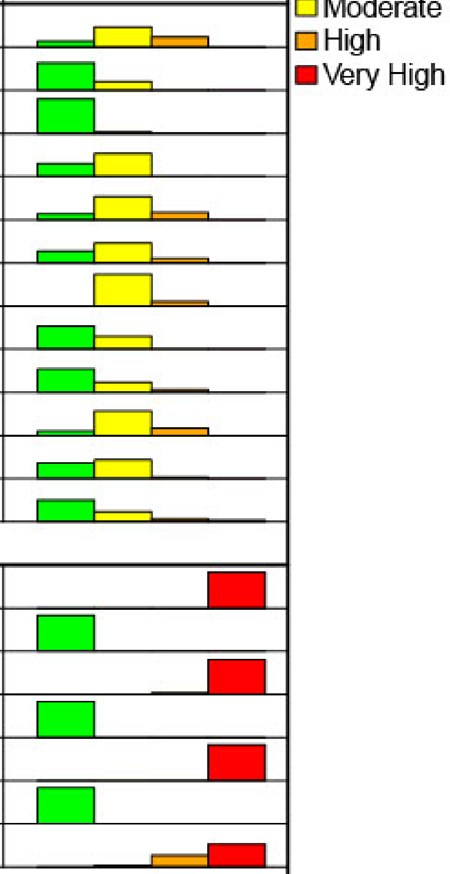
Greater Amberjack – *Seriola dumerili*

Overall Vulnerability Rank = Moderate 🟨

Biological Sensitivity = Low 🟩
Climate Exposure = Very High 🟥

Data Quality = 100% of scores≥ 2

	Seriola dumerili	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.1	3	
	Prey Specificity	1.2	3	
	Adult Mobility	1	2.6	
	Dispersal of Early Life Stages	1.6	2	
	Early Life History Survival and Settlement Requirements	2	2	
	Complexity in Reproductive Strategy	1.8	2.6	
	Spawning Cycle	2.1	3	
	Sensitivity to Temperature	1.4	2.8	
	Sensitivity to Ocean Acidification	1.4	2.6	
	Population Growth Rate	2.1	3	
	Stock Size/Status	1.6	3	
	Other Stressors	1.6	2.6	
	Sensitivity Score	Low		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	4	3	
	Precipitation	1	0	
	Ocean Acidification	4	2	
	Sea Level Rise	1	0	
	Currents	3.6	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		Moderate		



Greater Amberjack (*Seriola dumerili*)

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

Climate Exposure: Very High. Four exposure factors contributed to this score: Ocean Surface Temperature (4.0), Salinity (4.0), Ocean Acidification (4.0) and Currents (3.6). Exposure to all three factors occurs during the life stages. Greater Amberjack are pelagic oceanic dwellers often found in association with structure (e.g., reefs, rocky outcrops, wrecks).

Biological Sensitivity: Low. No sensitivity attributes scored ≥ 2.5.

Distributional Vulnerability Rank: High. Greater Amberjack are habitat generalists with high adult mobility and widely dispersing early life stages.

Directional Effect on the Southeast U.S. Shelf: The directional effect of climate change on Greater Amberjack on the Southeast U.S. Shelf is estimated to be positive. Higher seawater temperatures have been shown to lead to faster growth rates in aquaculture experiments (Fernandez et al. 2018). Ocean acidification is expected to have minimal effects on Greater Amberjack.

Data Quality: 100% of the data quality scores were 2 or greater. Attributes identified as marginally data-deficient include Dispersal of Early Life Stages and Early Life History Survival and Settlement Requirements.

Climate Effects on Abundance and Distribution: Greater Amberjack are widely distributed along the eastern U. S. seaboard, encountering a wide thermal distribution, and are likely to expand northward with warming temperatures. The species relies on oceanic currents for larval transport to points northward along the Atlantic coast (Lee and Williams 1999) and changes to oceanic circulation could affect recruitment success. Ocean acidification will likely not have a major effect on Greater Amberjack; despite inclusion of invertebrates in their diet, they are not solely dependent on these taxa and are capable of switching to other more available prey.

Life History Synopsis**:** Greater Amberjack enjoys a circumglobal distribution. In the western Atlantic Ocean it ranges from Nova Scotia, Canada south along the U.S., Bermuda, the Bahamas, throughout the Gulf of Mexico and Caribbean Sea, and along South America to southern Brazil. Juveniles may be solitary or form small schools; often associated with *Sargassum* and other floating objects (Richards 2005) in oceanic and offshore neritic waters (Bortone et al. 1977). Adults are found over reefs or at deep offshore holes or drop-offs, usually in small or moderate-sized schools, but may be solitary (Smith-Vaniz 2002). It is also found over rocky outcrops and wrecks (Harris et al. 2007). Larger fish usually occur between 18-72 m and have been taken as deep as 360 m. Greater Amberjack are known to be voracious opportunistic predators. Adult prey items include crabs, squid, round herring, round scad, filefish, little tunny and assorted other fishes (Richards 2005). Juveniles have a similar diet. Adults are highly mobile and not constrained either behaviorally or physically in their movements. Pair courtship has been observed in Belize in schools numbering ~120 individuals, primarily following during the full moon and waning moon periods between February and October (Graham and Castellanos 2005). Sexual dimorphism is evident, with females being larger than males. Peak spawning occurred primarily off Florida and the Florida Keys during April and May. This timing coincided with a predominantly eastward current flow, providing larval transport to points north along the Atlantic coast (Lee and Williams 1999). Spawning frequency was estimated as approximately every five days over a spawning season of ~60 days (12 March through 10 May) (Harris et al. 2007). Greater Amberjack are highly fecund, with an average female producing between 18-59 million eggs in a single spawning year (Harris et al. 2007). Eggs hatch at 35-37 hrs after spawning in temperatures between 23.1-24.6℃; eggs & larvae are pelagic, with eggs containing a single oil globule (Richards 2005). Greater Amberjack occurs across a fairly wide range of temperatures given their circumglobal distribution, found in waters from approximately 16 to 29℃, but averaging 27℃ (Fishbase). Even though Greater Amberjack diets do contain some invertebrate species, they are likely opportunistic carnivores that can switch diet items when necessary, thus it is not thought that ocean acidification will be a major problem for them. Greater Amberjack have a moderate population growth rate, based on a high growth coefficient and an early age at full maturity, a medium longevity, and a moderate natural mortality rate and large maximum size. Greater amberjack are not overfished, with SSB_{2017}/MSST = 2.80 (SEDAR 2020). There appears to be some genetic differentiation between Gulf of Mexico and Atlantic populations of Greater Amberjack, but the evidence is weak and further investigation is needed (Gold and Richardson 1998). Other potential stressors for Greater Amberjack include excessive fishing harvest. The species is highly mobile and pelagic and thus should be able to avoid harmful algal blooms and hypoxic events. The species does not rely on estuarine habitats which could be subject to anthropocentric degradation.

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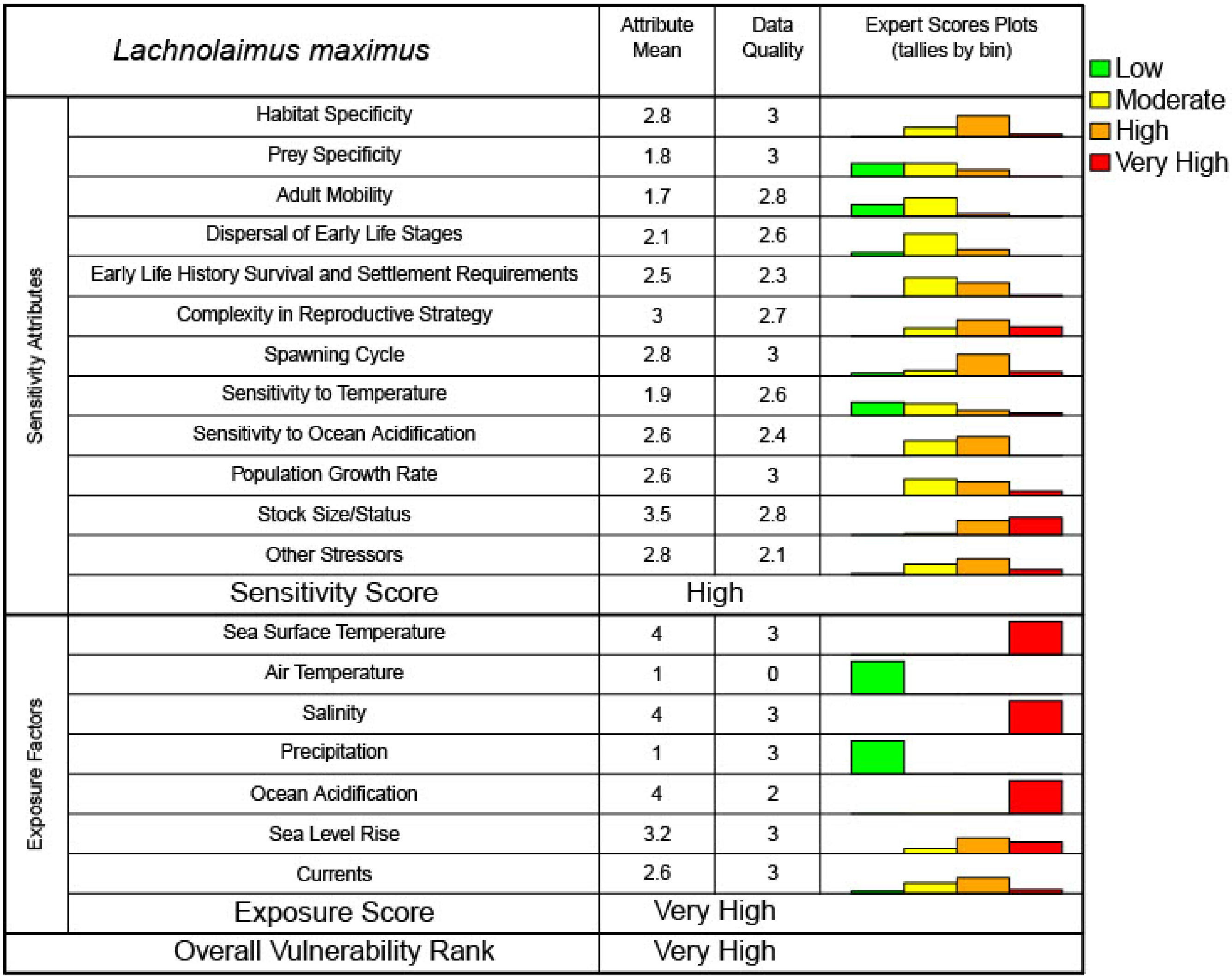
Hogfish − *Lachnolaimus maximus*

Overall Vulnerability Rank = Very High 🟥

Biological Sensitivity = High 🟧
Climate Exposure = Very High 🟥

Data Quality = 100% of scores≥ 2



	Lachnolaimus maximus	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.8	3	
	Prey Specificity	1.8	3	
	Adult Mobility	1.7	2.8	
	Dispersal of Early Life Stages	2.1	2.6	
	Early Life History Survival and Settlement Requirements	2.5	2.3	
	Complexity in Reproductive Strategy	3	2.7	
	Spawning Cycle	2.8	3	
	Sensitivity to Temperature	1.9	2.6	
	Sensitivity to Ocean Acidification	2.6	2.4	
	Population Growth Rate	2.6	3	
	Stock Size/Status	3.5	2.8	
	Other Stressors	2.8	2.1	
	Sensitivity Score	High		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	4	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	3.2	3	
	Currents	2.6	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		Very High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Hogfish (*Lachnolaimus maximus*)

Overall Climate Vulnerability Rank: Very High. (26% bootstrap results in High, 74% bootstrap results in Very High).

Climate Exposure: Very High. Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Salinity (4.0). Hogfish are found in coastal oceanic waters, on reefs and rock hardbottom.

Biological Sensitivity: High. Two sensitivity attributes scored ≥ 3.0: Complexity in Reproductive Strategy (3.0) and Stock Size/Status (3.5). Hogfish are a popular target of spearfishers and have been identified as likely to be overfished. The species is a protogynous haremic spawner, and a study from the Florida Keys reef tract found populations of Hogfish in fished areas exhibited virtually no reproductive activity compared to populations within a nearby marine protected area, highlighting the breakdown of normal social structure and processes due to fishing activity (Munoz et al. 2010).

Distributional Vulnerability Rank: Moderate. Two attributes indicated moderate potential for distribution shift: high adult mobility, and widely dispersive early life stages (broadcast spawning in the upper water column).

Directional Effect in the Southeast U.S. Shelf: The directional effect of climate change on Hogfish on the Southeast U.S. Shelf is projected to be neutral. There is little information available on directional effects of climate change on Hogfish, although there may be some effect of Ocean Acidification given the reliance on molluscs and crustaceans in their diet.

Data Quality: 100% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution: Hogfish diet consists primarily of molluscs and crustaceans (Randall and Warmke 1967) and are likely to be affected by increasing ocean acidification, which could also negatively impact the coral reef habitat they utilize (Andrews et al. 2004). They enjoy a temperate to tropical distribution and could conceivably expand their distribution north of North Carolina if sea surface temperatures warm, but it is not clear if they would find preferable habitat.

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. 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 haremic mating systems are common, both pair and group spawning occurs throughout the year, usually in late afternoon (Thresher 1984, Warner & 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, Holt and Riley 2001, Jones 1993). The pelagic larval stage lasts several weeks (mean PLD in the Atlantic ranges from 21 — 104 days (Jones 1993, Schultz & Cowen 1994, Sponaugle & Cowen 1997, Victor 1986), 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 13 years, and a moderate value for natural mortality rate (0.4; McBride and Richardson 2007). Hogfish in Florida were determined to be overfished and undergoing overfishing by a 2003 stock assessment (Ault et al. 2003), in which a 60 % decline in numbers of Hogfish harvested from 1987-2001 was reported. The bulk of fishing pressure comes from the recreational sector. 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). Other potential stressors for Hogfish include possible anthropocentric pollution and alteration of seagrass bed nursery habitat, coral bleaching, temperate reef degradation, and lionfish predation.

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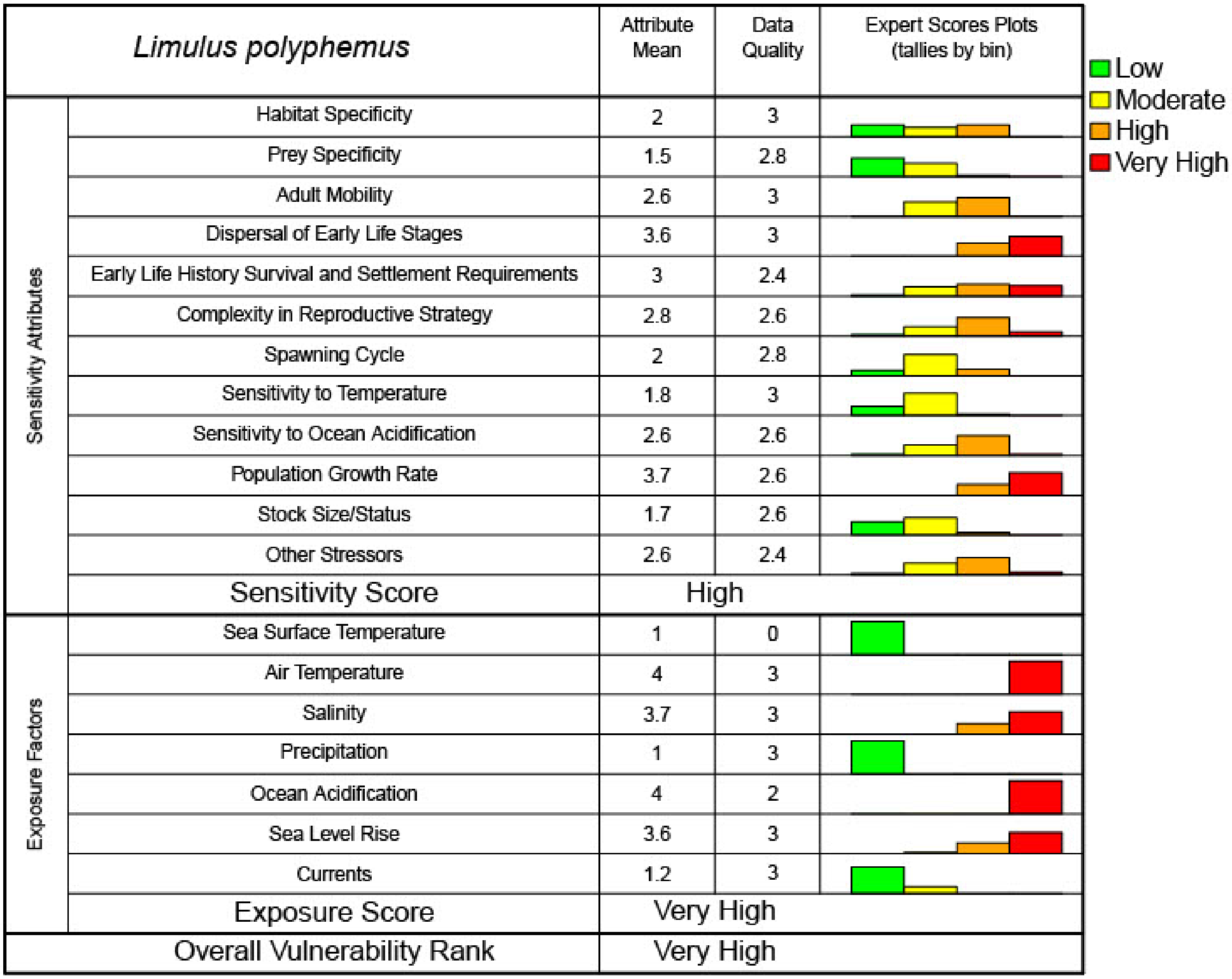
Horseshoe Crab – *Limulus polyphemus*

Overall Vulnerability Rank = Very High 🟥

Biological Sensitivity = High 🟧
Climate Exposure = Very High 🟥

Data Quality = 100% of scores≥ 2



	Limulus polyphemus	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2	3	
	Prey Specificity	1.5	2.8	
	Adult Mobility	2.6	3	
	Dispersal of Early Life Stages	3.6	3	
	Early Life History Survival and Settlement Requirements	3	2.4	
	Complexity in Reproductive Strategy	2.8	2.6	
	Spawning Cycle	2	2.8	
	Sensitivity to Temperature	1.8	3	
	Sensitivity to Ocean Acidification	2.6	2.6	
	Population Growth Rate	3.7	2.6	
	Stock Size/Status	1.7	2.6	
	Other Stressors	2.6	2.4	
	Sensitivity Score	High		
Exposure Factors	Sea Surface Temperature	1	0	
	Air Temperature	4	3	
	Salinity	3.7	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	3.6	3	
	Currents	1.2	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		Very High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Atlantic Horseshoe Crab (*Limulus polyphemus*)

Overall Climate Vulnerability Rank: Very High. (1% bootstrap results in High, 99% bootstrap results in Very High.

Climate Exposure: Very High. Four exposure factors contributed to this score: Air Temperature (4.0), Ocean Acidification (4.0) , Salinity (4.0) and Sea Level Rise (3.6). Adult Horseshoe Crab migrate annually from the ocean or deep bay waters to spawn on estuarine beaches (Baptist et al. 1957, Botton and Loveland 2003). Evidence from Delaware Bay and New England waters suggest some adults overwinter in local embayments (Botton et al. 1992).

Biological Sensitivity: High. Three sensitivity attributes scored above 3.0: Population Growth Rate (3.3), Early Life History Survival and Settlement Requirements (3.0), and Dispersal of Early Life Stages (3.6). Horseshoe Crab are a long-lived, late-maturing species (ASMFC 2010) and dispersal of larval stages is limited, with larvae settling close to spawning beaches (Botton and Loveland 2003).

Distributional Vulnerability Rank: Low. Three attributes indicated limited potential for distribution shift: limited adult mobility, limited early life stage dispersal, and sensitivity to temperature.

Directional Effect in the Southeast U.S. Shelf: The effect of climate change on Horseshoe Crab is likely to be negative. Sea level rise may reduce available spawning habitat. Increasing Sea Surface Temperature will negatively impact egg and larval survival and reduce productivity. Increasing Ocean Acidification will have an effect on primary prey items of Horseshoe Crab (ASMFC 2010), thereby reducing productivity, and there is some evidence from the literature that the quality of their chitin shell may be negatively impacted by an increasingly acidic ocean (Mustafa et al. 2015).

Data Quality: 100% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution: Horseshoe Crab are already widely distributed along the east coast. The species is capable of surviving extreme environmental regimes but development is slowed at temperatures below 20°C. They may be affected by increasing ocean acidification by virtue of their reliance on shellfish that form calcium carbonate shells (ASMFC 2010). Increases in water temperature could speed up onset of spawning season (Shuster 1982). While most Horseshoe Crab spawn in close proximity to beaches, those that do not would rely on tidal stream transport for larvae to reach suitable nursery habitat.

Life History Synopsis**:** Horseshoe Crab are distributed geographically along the east coast of North America from Maine through south Florida and the Gulf of Mexico, including the Florida Keys and Marquesas (but not the Dry Tortugas) to the Yucatan peninsula, with peak abundance in Delaware Bay (Botton and Ropes 1987). Juvenile Horseshoe Crab are habitat specialists in that they utilize intertidal flats, usually near breeding beaches (Smith et al. 2016). These habitats are flat, open, sandy, low energy beaches along bays and estuaries. Though not rare per se, these habitats are not abundant along portions of the Atlantic coast. Older individuals move out of these intertidal areas to deeper waters (Botton and Ropes 1987), migrating annually from ocean or deep bay waters to spawn on estuarine beaches (Baptist et al. 1957; Botton and Ropes 1987; Botton and Loveland 2003; Shuster 1979; Shuster and Botton 1985; Smith et al. 2009a). Evidence from Delaware Bay and New England waters suggest some adults overwinter in local embayments. This offshore/shelf/coastal habitat appears general and is likely abundant. Horseshoe Crab are restricted to salinities that exceed 7 parts per thousand. *Limulus* has been described as an ecological generalist (Shuster and Sekiguchi 2009) able to tolerate a wide range of environmental parameters throughout its distribution. Horseshoe crabs are capable of surviving physical extremes in temperature, salinity, pH, dissolved oxygen, and anoxic sediments (Shuster 1982). However, extremes in temperature or salinity may slow or stop development down until environmental conditions improve. Juvenile Horseshoe Crab diet is varied and includes particulate organic matter (POM) from algal and animal sources (Carmichael et al. 2009). Young crabs are supported by high quantities of benthic and suspended POM, shifting between marine and salt marsh based food webs. These food types are common. The diet composition of mature crabs shifts to larger prey, primarily bivalves (Botton 2009). Primary prey for adult Horseshoe Crab are blue mussels (*Mytilus edulis*) and surf clams (*Spisula solidissima*) (Botton and Haskin 1984; Botton and Ropes 1989). There is speculation that declines in surf clams in the mid-Atlantic are attributable to climate-change induced increases in water temperature. Adults are mobile but not highly mobile; they are mobility-limited in that they are slow crawlers/swimmers. Horseshoe Crab spawning season varies latitudinally, with peak spawning occurring on east Florida beaches in April, May, and August (Ehlinger and Tankersly 2007), while in South Carolina spawning occurs from March-July, with a peak in May (Thompson 1998). Horseshoe Crab form large spawning aggregations on sandy beaches, with timing of aggregation formation cued by rising seawater temperatures and increasing daylight hours (Shuster 1982). Moon phase (new and full moons) and tides are stimuli as well (Wenner and Thompson 2000). Males attach themselves to a female's posterior spines via their own claw-like pedipalps. Females will dig a pit 5-20 cm deep on the sandy beach and deposit her eggs, while the male externally fertilizes the eggs as they are deposited (Leschen et al. 2006; Rudloe 1979). Eggs incubate for 2-4 weeks after fertilization (Botton 1995) and upon hatching, the larvae swim for approximately six days (time to consume yolk sac) before settling in the estuary (Shuster 1982). Larvae are not strong swimmers and any that hatch outside the nursery area would be dependent upon tidal stream transport to get back to the estuary. Adults are usually benthic, and thus do not utilize much of the water column. While horseshoe crabs have a chitinous shell and are not directly affected by ocean acidification, they do include a number of bivalves as primary prey items and could be impacted by the effects of ocean acidification on their prey (ASMFC 2010). Horseshoe Crab likely have a slow population growth rate, as indicated by a very high age at maturity (10 years), a moderately high maximum age (20 years), moderate maximum size (60 cm) and a natural mortality rate M=0.15 (ASMFC 2010). These life history characteristics indicate that the population would be slow to respond to disturbances or population depletions. An assessment of population trends indicated population growth in the Southeast region, but assessment of trends in the Florida Atlantic region was highly uncertain with a decreasing population index in the Jacksonville area being somewhat offset by an increasing population index in the Indian River area (ASMFC 2010). This assessment estimated that B-current/B-MSY for sexes combined was 1.44, indicating the stock was not overfished.While the entire Atlantic is considered a single stock of Horseshoe Crab for management purposes, genetic analysis points to the possibility of four regional stocks within the United States: Northeast (Gulf of Maine), mid-Atlantic, Florida-Atlantic, and Florida-Gulf (ASMFC 2010). Numerous studies suggest that populations are localized, population decreases in small areas may not be capable of swift recovery. Literature does not note variations in reproductive success or local extinctions. Other potential stressors for Horseshoe Crab in the southeast include general coastal development leading to degraded habitat (e.g., dredging, shoreline armoring), as well as storm increases and intensity, hypoxia, and harmful algal blooms due to excessive nutrient inputs.

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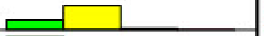
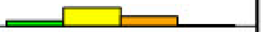
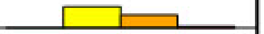
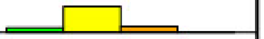
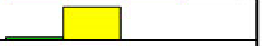
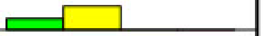
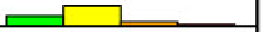
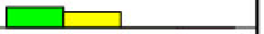
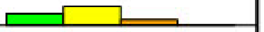
King Mackerel − *Scomberomorus cavalla*

Overall Vulnerability Rank = Moderate 🟨

Biological Sensitivity = Low 🟩
Climate Exposure = Very High 🟥

Data Quality = 100% of scores≥ 2

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

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

King Mackerel (*Scomberomorus cavalla*)

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

Climate Exposure: Very High. Four exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0), Salinity (4.0) and Currents (3.5). King Mackerel is an oceanadromous species and exposure to all factors occur during all life stages.

Biological Sensitivity: Low. No sensitivity attributes scored ≥ 2.5:

Distributional Vulnerability Rank: High. King Mackerel are highly mobile habitat generalists with highly dispersive early life stages.

Directional Effect in the Southeast U.S. Shelf: The effect of climate change on King Mackerel is estimated to be neutral. King Mackerel larvae require temperatures between 22°C-28°C for optimum growth and survival. Abundance should remain stable on the southeast U. S. shelf but projected warming of northern waters could lead to a northward distribution shift. The effect of ocean acidification is likely to be negligible as King Mackerel are primarily piscivores.

Data Quality: 100% of the data quality scores were 2 or greater. Early Life History Survival and Settlement Requirements had the lowest data quality score, 2.0, likely because of the uncertainty surrounding the development of larval and juvenile King Mackerel (it is thought that larval King Mackerel do not settle out, but instead complete development in the water column).

Climate Effects on Abundance and Distribution: King Mackerel preferred temperature and salinity ranges of 23-29.8°C and 29.6-37.4 ppt (McEachran et al. 1980) indicate the species may respond favorably to a changing climate regime. While they currently inhabit the northern extreme of their range (Gulf of Maine) only during the summer months (Collette and Nauen 1983), warming sea surface temperatures could allow King Mackerel to utilize that area during a wider temporal window. The species feeds predominantly on fishes and should be minimally affected by ocean acidification.

Life History Synopsis**:** King Mackerel is a large reef-associated fish species found in coastal waters from the Gulf of Maine south to Brazil, including the Gulf of Mexico and the Caribbean (Briggs 1958; Godcharles and Murphy 1986). However, the coastal area between Maine and northern Florida is utilized only during the warmest summer months (Collette and Nauen 1983). Large groups of King Mackerel aggregate along the coast of North and South Carolina throughout the spring, summer, and fall of the year (Godcharles and Murphy 1986). Larvae remain in high salinity waters throughout development. Larvae may be present across the continental shelf, but are often most abundant in middle to outer shelf waters. McEachran et al. (1980) found larvae over a temperature range of 19.6-29.8°C (preferred range 23-29.8°C) and salinity range of 27.3-37.4 ppt (preferred range 29.6-37.4 ppt). Adults are found in open coastal waters of the continental shelf, often near outer reefs, and are also sometimes found near inlets.

Diet of larval King Mackerel consists exclusively of fishes, while juveniles prey on herring, anchovies, jacks, and menhaden, as well as lesser amounts of squid and shrimp. Adults prey primarily on fishes, including herrings, jacks, menhaden, anchovies, and lesser quantities of penaeid shrimp and squid. King Mackerel are highly mobile: large schools have been found to migrate over considerable distances along the U.S. Atlantic coast, water temperature permitting. Both Atlantic and Gulf of Mexico stocks undertake migrations to a south Florida mixing zone. King Mackerel are gonochoristic, spawning in the open ocean. King Mackerel occur in small schools normally, confounding the ability to call a group of fish a 'spawning aggregation'. They likely occur in small aggregations to spawn and spawning condition fish are exploited by the fishery and caught in large numbers (Burton personal observation). Temperature is likely a trigger for spawning. There is no information in the literature on planktonic larval duration. Off the SEUS coast, large concentrations of larvae were found to occur in the vicinity of the Charleston Bump, a deflection in the Gulf Stream off South Carolina. This suggests that the area of upwelling associated with the Charleston Bump is an important spawning/nursery area. While there is no information in literature on this topic, phenological changes in emergence of larval food (primarily fishes) could result in a prey mismatch and reduced survival of King Mackerel larvae. There is also no information on settlement, as the species uses the water column for the majority of its life cycle. Adults are found in temperatures from 19-30°C (mean preferred temperature 27°C). King Mackerel utilize the water column from 5-140 m. King mackerel should not be greatly affected by increased ocean acidification as their diet consists primarily of schooling fishes, and they are enough of a diet generalist to offset any effect of acidification on an individual prey. However, if any of those prey species are reliant upon diet items affected by a changing ocean chemistry, there could be some indirect or cascading effects. King Mackerel have a slow population growth rate, including an extended longevity (32 years), large maximum body size, low growth coefficient, and moderate age-at-maturity. This indicates the species is vulnerable to slow recovery from population disturbances. King Mackerel were not considered overfished based on a 2009 stock assessment (SEDAR 2009). A study of mtDNA variation found that King Mackerel from southeast US Atlantic waters were weakly genetically differentiated from King Mackerel from the Gulf of Mexico (Gold et al. 2002). King Mackerel are not estuarine users and are not subject to associated anthropogenic impacts felt by many other species. Excessive fishing pressure could impact the overall stock health if proper management is not employed.

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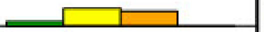
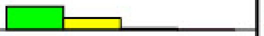
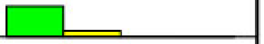
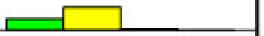
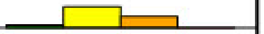
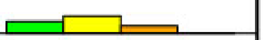
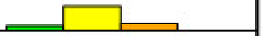
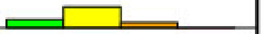
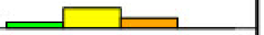
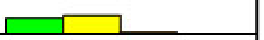
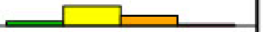
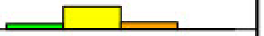
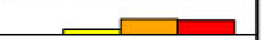
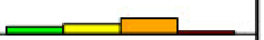
Lane Snapper – *Lutjanus synagris*

Overall Vulnerability Rank = Moderate 🟨

Biological Sensitivity = Low 🟩
Climate Exposure = Very High 🟥

Data Quality = 83% of scores ≥ 2

	Lutjanus synagris	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.3	2.8	
	Prey Specificity	1.4	3	
	Adult Mobility	1.2	2.6	
	Dispersal of Early Life Stages	1.7	2	
	Early Life History Survival and Settlement Requirements	2.2	1.8	
	Complexity in Reproductive Strategy	1.9	2.2	
	Spawning Cycle	2.1	3	
	Sensitivity to Temperature	1.9	2.8	
	Sensitivity to Ocean Acidification	2.1	2.6	
	Population Growth Rate	1.6	2.8	
	Stock Size/Status	2.2	1.2	
	Other Stressors	2	2.4	
	Sensitivity Score	Low		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	4	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	3.2	3	
	Currents	2.4	2.8	
	Exposure Score	Very High		
Overall Vulnerability Rank		Moderate		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Common Name (*Species Name*) - Lane Snapper - *Lutjanus synagris*

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

Climate Exposure: Very High. Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0), and Salinity (4.0). Exposure to all three factors occurs during the life stages. Lane Snapper are coastal offshore reef fish inhabiting coral reefs and rocky hard bottom areas, as well as sandy areas and seagrass beds close to shore.

Biological Sensitivity: Low. No sensitivity attributes scored above 2.5.

Distributional Vulnerability Rank: High. Three attributes indicated high potential for distribution shift: high adult mobility, widely dispersing early life stages, and moderately generalist habitat preferences.

Directional Effect on the Southeast U.S. Shelf: The directional effect of climate change on Lane Snapper on the Southeast U.S. Shelf is estimated to be positive. Increased warming of mid-Atlantic waters could lead to a northward shift in distribution, as posited for the congener gray snapper (Hare et al. 2012). Moderate effects of ocean acidification are expected due to a substantial inclusion of crustaceans in their diet. Lane Snapper tolerate a fairly wide salinity range, and juveniles utilize estuaries and mangrove areas where there is a tidal fluctuation of salinity.

Data Quality: 83% of the data quality scores were 2 or greater. Stock size/Status was identified as a data gap, likely because the species has not been assessed. Early Life History Survival and Settlement Requirements was also identified as data deficient.

Climate Effects on Abundance and Distribution: No studies have been conducted on climate effects on Lane Snapper. Currently rare north of North Carolina due to thermal tolerances, warming temperatures might allow for a minor range expansion northward. The species has a moderate reliance on crustaceans in their diets and may be affected by increasing ocean acidification, which might also affect coral reef habitat they use.

Life History Synopsis**:** Lane Snapper is a coastal and estuarine species widely distributed from North Carolina to Brazil, including Bermuda and the Bahamas, throughout the Gulf of Mexico and Caribbean (Lindeman et al. 2016). Juveniles are found in seagrasses and nearshore hardbottom habitats, while adults are common in seagrass areas, reefs, hardbottom and rubble areas (Lindeman and Snyder 1999). Lane Snapper have been found to depths up to 400 m (Anderson 2002), but are usually found in depths of 30-120 m in continental and insular shelf areas (Rivas 1970). Lane Snapper are commonly found in salinities ranging from 19-35 ppt (Springer and Woodburn 1960). The lower values in this range are due to their usage of inshore estuarine nursery areas. The species is common in temperatures ranging from 16-29°C (Rivas 1970). Lane Snapper are not limited in their mobility, although Bortone and Williams (1986) observed that adults tended to remain in an area once they reached maturity. The species is known to form large spawning aggregations in different locations (south Florida, Wicklund 1969; Jamaica, Thompson and Munro 1974; Cuba, Claro et al., 2001), although little is known of if or how far they migrate to these aggregations. Timing of peak spawning off Florida occurs June-August (Manooch and Mason 1984; Rodriguez-Pino 1962, while Erdman (1976) found peak spawning of Lane Snapper occurred in May off Puerto Rico. Eggs and pelagic and rely on tidal currents for transport into estuaries where they utilize seagrass beds as nursery habitat. Juveniles are found in seagrass beds as well as nearshore hardbottom. Lane Snapper are a diet generalist, with juveniles feeding primarily on crustaceans (Reid 1964). Adults feed on benthic crustaceans (portunid crabs, penaeid and mantis shrimp), annelid worms, gastropods, and small fishes (Dancel and Paramo 2010). Franks and Vanderkooy (2015) found the most abundant diet items for adults were amphipods, decapod crustaceans, and fishes. There could be indirect impacts of ocean acidification on Lane Snapper due to their reliance on shell forming crustaceans in their diets. The species have a moderate longevity, attaining a maximum age of 19 years from Bermuda (Luckhurst et al. 2000) and 17 years from the Gulf of Mexico (Johnson et al. 1995). Studies from the southeast U. S. Atlantic coast found the maximum age to be either 10 years (Mason and Manooch 1984) or 12 years (Brennan 2004). Males and females both reached maturity at 2 years of age. Growth is moderately fast, as exhibited by a von Bertalanffy growth coefficient of 0.33 for north Florida fish and 0.63 for fish from south Florida/Florida Keys (Brennan 2004). Lane Snapper have not been assessed from the southeastern U. S. Atlantic coast. Attempts to perform a data-limited stock assessment on the species from the Gulf of Mexico were unsuccessful and stock status could not be determined (SEDAR 49, 2016). A lone study of genetic variation in populations of Lane Snapper found genetic heterogeneity between populations and the northern Gulf of Mexico and fish from the southern Gulf/south Florida/east coast Florida (Karlsson et al. 2009). Other stressors that could impact Lane Snapper include environmental alterations of their nursery habitat due to development, lionfish predation on juveniles and subadults on nearshore reefs, and possibly increasing temperatures.

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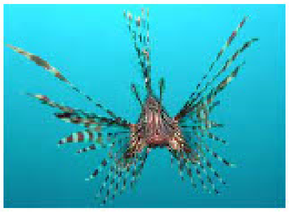
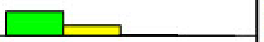
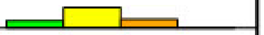
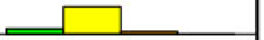
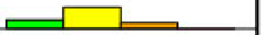
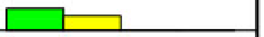
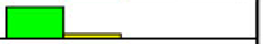
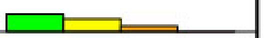
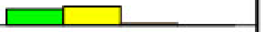
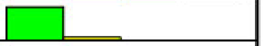
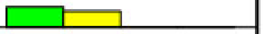
Lionfish – *Pterois volitans*



Overall Vulnerability Rank = Moderate 🟨

Biological Sensitivity = Low 🟩
Climate Exposure = Very High 🟥

Data Quality = 75% of scores ≥ 2

Pterois volitans		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.4	3	
	Prey Specificity	1.1	2.9	
	Adult Mobility	2	3	
	Dispersal of Early Life Stages	1.9	2	
	Early Life History Survival and Settlement Requirements	1.9	1.3	
	Complexity in Reproductive Strategy	1.4	2.2	
	Spawning Cycle	1.1	2.8	
	Sensitivity to Temperature	1.7	3	
	Sensitivity to Ocean Acidification	1.6	3	
	Population Growth Rate	1.1	2.7	
	Stock Size/Status	1.2	0.9	
	Other Stressors	1.4	1.7	
	Sensitivity Score	Low		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	3.9	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	1	0	
	Currents	2.3	2.8	
	Exposure Score	Very High		
Overall Vulnerability Rank		Moderate		

- 🟩 Low
- 🟨 Moderate
- 🟧 High
- 🟥 Very High

Lionfish (*Pterois volitans* and *P. miles*)

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

Climate Exposure: Very High. Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Salinity (3.9). Exposure to all three factors occur during the life stages. Lionfish are a habitat generalist found in estuarine and mangrove areas inshore as well as on reefs and rocky hardbottom habitat offshore.

Biological Sensitivity: Low. No sensitivity attributes scored ≥ 2.5.

Distributional Vulnerability Rank: High. Lionfish, while tending to be site-attached, are capable of significant movements (Tamburello and Cote 2015). Lionfish are habitat generalists with widely dispersive early life stages.

Directional Effect in the Southeast U.S. Shelf: The directional effect of climate change on Lionfish on the Southeast U.S. Shelf is estimated to be positive. Effects of ocean acidification are expected to be minimal despite substantial inclusion of crustaceans in their diet, as Lionfish are opportunistic carnivores able to switch to fishes. Lionfish are tropical, with an average lethal low temperature of 10.0°C and a low temperature at which feeding ceases of 16.0°C (Kimball et al. 2004). These tolerances indicate it is unlikely that Lionfish can currently overwinter north of Cape Hatteras, NC, but future warming of mid-Atlantic waters could lead to a northward shift in distribution. Lionfish should thrive on the southeastern U. S. shelf under current warming scenarios.

Data Quality: 75% of the data quality scores were 2 or greater. Attributes identified as data-deficient include Stock Size/Status (likely because the species is not a SEDAR-assessed species), Early Life History Settlement and Survival Requirements (paucity of information in literature on settlement stages), and Other Stressors (thought to be an area of concern for the species but little specific information in the literature).

Climate Effects on Abundance and Distribution: A very successful invasive species, Lionfish will likely benefit from a changing climate. There may be some minor effects of increasing Ocean Acidification, as Lionfish do consume crustaceans but are able to switch to consuming fishes; in an environment where teleost fishes are limited there may be some negative effects of Ocean Acidification. While Lionfish juveniles (likely larval exports) have been found in the mid-Atlantic, they have a preferred temperature range which limits their distribution to North Carolina, but warming ocean temperatures could allow them to expand their range.

Life History Synopsis**:** Native to the subtropical and tropical regions of the South Pacific, Indian Ocean, and the Red Sea, Red Lionfish (*Pterois volitans*) and Devil Firefish (*P. miles*) are now established throughout the warm-temperate and tropical western Atlantic, Gulf of Mexico, and Caribbean, and have continued to expand their range to the south-eastern coast of Brazil, (Fishbase; Ferreira et al. 2015, Côté & Smith 2018; Schofield et al. 2020). These two species are nearly morphologically identical and 93% of specimens sampled from the Atlantic as well as North Carolina were *P. volitans* (Hamner et al. 2007), so hereafter we refer to invasive specimens collectively as Lionfish or *P. volitans*. Lionfish are a medium-sized predatory species in the family Scorpaenidae. In the invaded range, specimens have been observed from Rhode

Island to Arraial do Cabo, Brazil, and have also been recorded in the Mediterranean Sea (Schofield et al. 2020). Lionfish are habitat generalists. Juveniles and adults have been found in a wide variety of low relief and high relief natural and artificial habitats, including temperate hard bottom reefs, algal sand plains, coral reefs, mangroves, seagrass beds, and estuaries, as well as shipwrecks and other human-made artificial structures such as discarded fishing gear (Muñoz et al. 2011; Côté et al. 2013; Côté & Smith 2018). They have been found in estuarine rivers up to 6.5 km from the ocean in nearly fresh water and can occupy depths from the surface (e.g., mangroves) to more than 300 m (Côté et al. 2013; Côté & Smith 2018). In the Bahamas, Anton et al. (2014) found Lionfish to occur at greater density and biomass at sites that were sheltered from wave exposure. In mesophotic depths at Bermuda, higher Lionfish densities were observed at sites with lower seafloor temperatures, suggested by Goodbody-Gringley (2019) to reflect the higher densities of prey hypothesized to result from upwelling in these locations. In Honduras, aggregations of Lionfish were associated with high habitat complexity that contained larger refuge sizes, high live biotic cover, and a greater variety of growth forms (Hunt et al. 2019). Adult Lionfish reach a maximum length of 48.8 cm total length (TL), and a maximum age of 9 years, although specimens have been reported to reach 30 years in captivity (Eddy et al. 2019; Harrell 2019; Potts et al. unpubl.). Lionfish are opportunistic generalist carnivores that consume at least 167 vertebrate and invertebrate prey species (Peake et al. 2018, and references therein). They display an ontogenetic shift from a diet dominated by invertebrates (mostly shrimps, along with crabs, and mollusks) to a diet dominated by fish (Muñoz et al. 2011; Peake et al. 2018). Initial studies of both juvenile and adult Lionfish in estuarine and hard bottom habitats revealed site fidelity to particular areas, with most individuals moving less than 10 or 150 m from their release locations, respectively (Jud & Layman 2012; Bacheler et al. 2015). However, additional studies of adults from coral and hard bottom reefs have revealed that extensive movements are possible, with regular movements over 200 m and occasional movements up to 10 km (Côté et al. 2013; Tamburello & Côté 2015; Kletou et al. 2016). In particular, Tamburello & Côté (2015) showed that seascape structure (continuous versus patchy habitats, as well as distance between patches) influenced Lionfish movements, with Lionfish on continuous reefs moving faster and more often than those on patch reefs. Lionfish do not form spawning aggregations and are typically found solitary or in small groups. These groups can be large in the invaded range, where densities can far exceed (390 fish per ha) those in the native range (80 fish per ha) (Green & Côté 2009; Albins & Hixon 2013). As dusk approaches, gregariousness increases, while males search for females amid aggressive confrontations with other males. Distinct courtship behavior includes the male circling around a ripe female, characterized by a swollen abdomen with a distinct silvery coloration. When ready to spawn, a single male leads the female upward into the water column for gamete release (Fishelson 1975). Regarding the spawning season, at lower latitudes spawning appears to take place year round on a daily basis with females capable of spawning approximately every three days (Eddy et al. 2019; Thresher 1984), although a spawning season from June-November was apparent at the higher latitude of Bermuda (Eddy et al. 2019). The average planktonic larval duration of Lionfish was estimated at 26.2 days with a range between 20-35 days (Ahrenholz & Morris 2010). Early life history (larval) requirements of Lionfish are unknown. Claydon et al. (2012) found that Lionfish preferentially, but not exclusively, settled to shallow habitats such as mangrove, seagrass, and sheltered reef <5 m deep. García-Rivas et al. (2018) found the smallest (<15 cm) lionfish in shallow mixed habitats such as mangroves, sand patches, docks, and lagoons with sheltered conditions. Similarly, Anton et al. (2014) found Lionfish to occur at greater density and biomass at sites that were sheltered from wave exposure. In the invaded range, Lionfish appear to be limited by winter seafloor temperatures that fall below 9.5°C (Barker et al. 2018), which at present day tend to be north of Cape Hatteras, North Carolina (Grieve et al. 2016). They occur from 22.4-29°C (preferred temperature, Kaschner et al. 2016) and in the invaded range can be found distributed across five zoogeographic provinces. They occupy habitats from mangroves located in very shallow water (1 m) to depths of greater than 300 m. As ocean temperatures warm with global climate change, their range is expected to expand, as for native tropical and subtropical species with similar thermal minima (Barker et al. 2018). Lionfish may serve as indicator species for community change from rising seafloor temperatures when they persist in locations poleward and inshore of their current distribution (Whitfield et al. 2014; Grieve et al. 2016). Lionfish may be indirectly affected by ocean acidification, as juveniles in particular are known to consume prey (e.g., shrimps, crabs; Peake et al. 2018) that may be negatively affected by lower pH conditions (Kurihara et al. 2008; Bhadury 2015; Long et al. 2015). Evidence suggests that Lionfish have a relatively rapid population growth rate. Lionfish reach maturity in the first or second year, have a maximum life span in the wild of nine years, reach a small-to-medium maximum length of 48 cm TL, and have a Von Bertalanffy growth coefficient (K) estimated to range from 0.32-0.77 (Eddy et al. 2019; Harrell 2019; Potts et al. unpubl.). Although the stock has never been assessed, in the invaded range it is productive, abundant, and has rapidly increased, so the workshop scorers thought the population would be at or above B_{MSY}. In the invaded range, lionfish have rapidly expanded their distribution across five zoogeographic provinces. There are no known major threats, therefore, it is classified as Least Concern (IUCN Red List, Motomura et al. 2016). Other potential stressors for Lionfish are not readily apparent.

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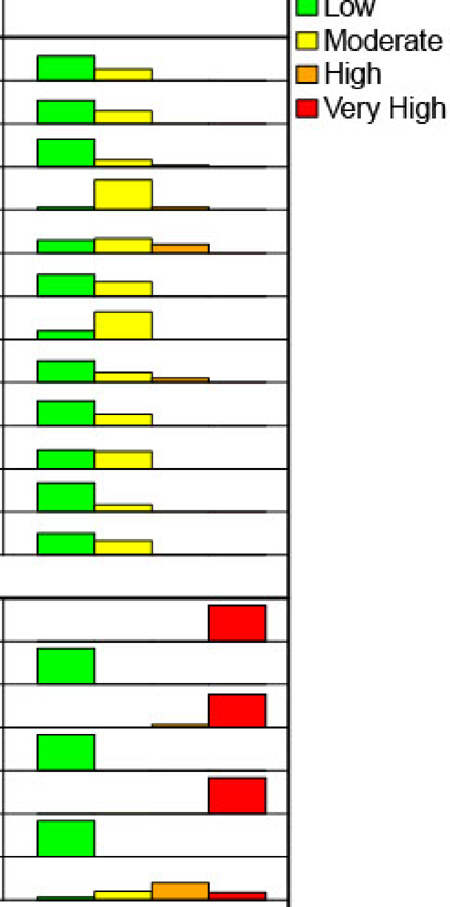
Little Tunny − *Euthynnus alletteratus*

Overall Vulnerability Rank = Moderate 🟨

Biological Sensitivity = Low 🟩
Climate Exposure = Very High 🟥

Data Quality = 75% of scores ≥ 2



Euthynnus alletteratus		Attribute Mean	Data Quality
Sensitivity Attributes	Habitat Specificity	1.3	3
	Prey Specificity	1.4	2.6
	Adult Mobility	1.3	3
	Dispersal of Early Life Stages	2	2
	Early Life History Survival and Settlement Requirements	1.9	1
	Complexity in Reproductive Strategy	1.4	1.8
	Spawning Cycle	1.8	3
	Sensitivity to Temperature	1.5	2.8
	Sensitivity to Ocean Acidification	1.3	2.4
	Population Growth Rate	1.5	2.4
	Stock Size/Status	1.2	1.4
	Other Stressors	1.4	2
	Sensitivity Score	Low	
Exposure Factors	Sea Surface Temperature	4	3
	Air Temperature	1	0
	Salinity	3.9	3
	Precipitation	1	0
	Ocean Acidification	4	2
	Sea Level Rise	1	0
	Currents	2.8	2.8
	Exposure Score	Very High	
Overall Vulnerability Rank		Moderate	

Little Tunny (*Euthynnus alletteratus*)

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

Climate Exposure: Very High. Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Salinity (4.0). Little Tunny are a pelagic oceanadromous species and exposure to all three factors occur during the life stages.

Biological Sensitivity: Low. No sensitivity attributes scored above 2.5:

Distributional Vulnerability Rank: High. Three attributes indicated high potential for distribution shift: high adult mobility, widely dispersing early life stages, and generalist habit use (open water).

Directional Effect on the Southeast U.S. Shelf: The effect of climate change on Little Tunny on the Southeast U.S. Shelf is estimated to be neutral. The effect of ocean acidification is expected to be minimal, as the species is primarily piscivorous. There is little evidence for either a positive or negative directional effect of climate change.

Data Quality: 75% of the data quality scores were 2 or greater. Attributes identified as data-deficient include Complexity in Reproductive Strategy, Early Life History Settlement and Survival Requirements, and Other Stressors. Little is known specifically from the literature about reproduction and the fate of propagules.

Climate Effects on Abundance and Distribution: Little Tunny are widely distributed along the eastern seaboard from Massachusetts to Florida. The species might conceivably expand its range further north if temperatures warmed (preferred temperature range 11.5 - 27.8°C, mean 23.3°C. The species may be minimally affected by Ocean Acidification, as they are opportunistic predators feeding primarily on clupeoid fishes, but they also feed occasionally on crustaceans, squids, hyperiid amphipods, pteropods, heteropods and tunicates (Bahou *et al*. 2007, Falautano *et al*. 2007).

Life History Synopsis**:** Little Tunny is a reef-associated and oceanodromous species found in nearshore neritic waters (Cervigón 1994). In the western Atlantic the species is found from Massachusetts through Brazil, including throughout the Gulf of Mexico. In the Gulf of Mexico most juveniles and pre-adults are commonly found in deeper waters, beyond the edge of the continental shelf (Collette et al. 2011). De Sylva and Rathjen (1961) also found younger fish in open oceanic waters. Most catches of adults occur in inshore turbid or green water (deSylva and Rathjen 1961). Adult Little Tunny are opportunistic predators, eating mainly clupeoid fishes, but also crustaceans, squid, amphipods, pteropods and tunicates. Juveniles likely eat smaller planktonic sized items included in adult diet (Bahou et al. 2007; Falautano et al. 2007). Adults are highly mobile, and are considered a highly migratory species. They are thought to make migrations along the east coast from south to north as the seasons warm (Chilton 1949). Little Tunny spawn outside the continental shelf region throughout its range (Schaefer 2001), in waters of at least 25°C. Spawning season off the east coast of Florida is from March -November (deSylva and Rathjen 1961). Eggs are shed in several batches, up to 1.75 million eggs per female in a season. Spawning aggregations are not documented, although since the species is known to be schooling it may be hard to confirm the function of an aggregation as spawning-related. Fertilized eggs are pelagic, spherical, and buoyant, 0.8-1.1 mm in diameter. Larvae, approximately 3 mm in size, hatch 24 hours after fertilization. Larvae grow rapidly (1.07 mm/day while remaining in the water column from mid-depth to surface (Allman and Grimes 1998). Little Tunny have a reported temperature range of 11-28°C, but Cruz-Castan et al. (2019) report an optimal temperature of 24-28°C from the southwestern Gulf of Mexico. Little Tunny may be affected by increasing ocean acidification because they include some crustaceans and pteropods in their diet, but they may compensate at older ages switching to a more fish-based diet. Population growth rate of Little Tunny is high, based on a maximum age of 10 years, high growth coefficient estimates ranging from 0.39-0.69, an age at maturity of 2 years. Little Tunny have not been assessed, but are not considered to be overfished, having a rapid growth and maturity habit and being fairly short-lived. IUCN lists them as a Species of Least Concern. The species is not estuarine dependent at all, and its oceanic/midwater habit as well as fast growth habit makes it unlikely to be subject to lionfish predation.

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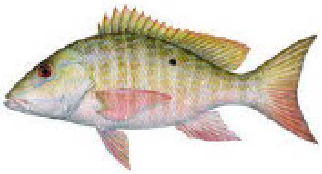
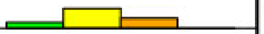
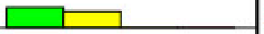
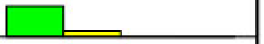
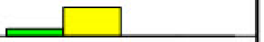
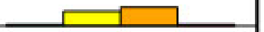
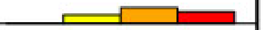
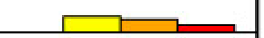
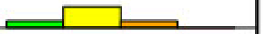
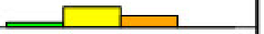
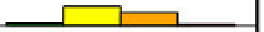
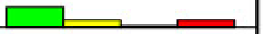
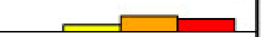
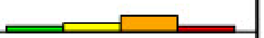
Mutton Snapper – *Lutjanus analis*



Overall Vulnerability Rank = High 🟧

Biological Sensitivity = Moderate 🟨
Climate Exposure = Very High 🟥

Data Quality = 100% of scores≥ 2

	Lutjanus analis	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.1	2.8	
	Prey Specificity	1.4	3	
	Adult Mobility	1.2	2.8	
	Dispersal of Early Life Stages	1.8	2.8	
	Early Life History Survival and Settlement Requirements	2.6	2	
	Complexity in Reproductive Strategy	3.1	2.6	
	Spawning Cycle	2.8	3	
	Sensitivity to Temperature	2	3	
	Sensitivity to Ocean Acidification	2.2	2.8	
	Population Growth Rate	2.7	2.4	
	Stock Size/Status	2.4	2.6	
	Other Stressors	1.9	2.4	
	Sensitivity Score	Moderate		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	4	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	3.2	3	
	Currents	2.6	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Common Name (*Species Name*) - Mutton Snapper - *Lutjanus analis*

Overall Climate Vulnerability Rank: High. (93% bootstrap results in High, 7% bootstrap results in Very High).

Climate Exposure: Very High. Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Salinity (4.0). Mutton Snapper is a marine reef dweller also found in seagrass beds and mangrove habitats, and exposure to all three factors occurs during all life stages.

Biological Sensitivity: Moderate. Four sensitivity attributes scored ≥ 2.5: Complexity in Reproductive Strategy (3.1), Spawning Cycle (2.8), Early Life History Settlement and Survival Requirements (2.6), and Population Growth Rate (2.7). Mutton Snapper are a long-lived, late maturing fish known for forming spawning aggregations which have historically been highly exploited (Burton et al. 2005).

Distributional Vulnerability Rank: High. Three attributes indicated high potential for distribution shift: high adult mobility (Feeley et al. 2018), widespread dispersal of early life stages (Domeier 2004), and low habitat specialization.

Directional Effect on the Southeast U.S. Shelf: The effect of climate change on Mutton Snapper on the Southeast U.S. Shelf is estimated to be positive, although uncertainty is reflected in the expert scores (45% positive, 45% neutral, 10% negative). Effects of ocean acidification will likely be moderate because of both diet and habitat preference (coral reef habitat). Warming temperatures could create suitable thermal profiles for Mutton Snapper in northern areas, but it is unlikely that suitable habitats (seagrass beds, mangroves, coral reefs) would be available in northern areas. There is no evidence to suggest a positive directional effect of climate change on Mutton Snapper, thus the uncertainty reflected in the division of expert scores.

Data Quality: 100% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution: Mutton Snapper are likely to be affected by an increasingly acidic ocean, as they consume crustaceans, molluscs and echinoderms, and adults rely on structurally complex coral reef habitat, which may be degraded by Ocean Acidification. Increasing Ocean Surface Temperature may allow the species to expand its range northward beyond Florida, although the availability of suitable preferred nursery habitat (shallow water high salinity seagrass beds and/or mangroves) may limit their ability to successfully expand their range.

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°N - 28 °S. Preferred temperatures range from 19-28°C, with a mean of 24.8°C. Mutton snapper are found in depths of 1-95 m. This species inhabits reefs, 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. Main prey items are bony fishes, crustaceans, molluscs, and echinoderms (Allen 1985). Mutton Snapper are commonly found in salinities ranging from 20-35 ppt, values indicative of habitats ranging from seagrass beds and mangrove creeks to offshore reefs. 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 Kjerve 2008). 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 - 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 2.2-2.5 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 included deep-water commercially caught fish found a maximum age of 40 years (Faunce et al. 2007). Maturity is not achieved until age-5 or age-6. Natural mortality was estimated at M = 0.29, and the von Bertalanffy growth coefficient was estimated as K = 0.16. Mutton Snapper in the southeastern U. S. is considered a single stock, with little genetic variation throughout the area and the Caribbean. Mutton Snapper have not been assessed from the southeastern U. S. Atlantic coast. A stock assessment from the Gulf of Mexico, which included Florida Keys/Dry Tortugas fish, found $SSB_{2013}/SSB_{MSY} = 1.13$, indicating the species was not overfished. 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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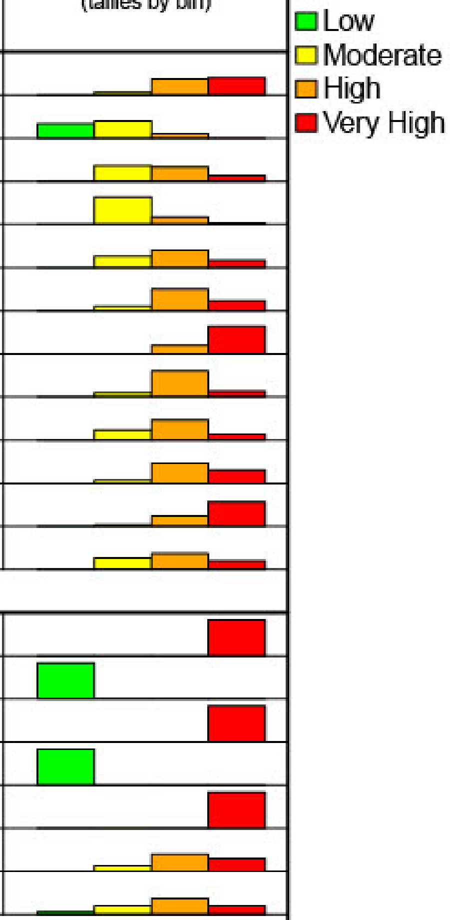
Nassau Grouper − *Epinephelus striatus*

Overall Vulnerability Rank = Very High 🟥

Biological Sensitivity = High 🟧
Climate Exposure = Very High 🟥

Data Quality = 92% of scores ≥ 2

	Epinephelus striatus	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	3.4	3	
	Prey Specificity	1.7	3	
	Adult Mobility	2.7	2.4	
	Dispersal of Early Life Stages	2.3	2.8	
	Early Life History Survival and Settlement Requirements	2.9	1.7	
	Complexity in Reproductive Strategy	3.2	2.9	
	Spawning Cycle	3.8	3	
	Sensitivity to Temperature	3	2.6	
	Sensitivity to Ocean Acidification	2.9	2.4	
	Population Growth Rate	3.3	2.5	
	Stock Size/Status	3.6	2.3	
	Other Stressors	2.9	2.4	
	Sensitivity Score	High		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	4	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	3.2	2.8	
	Currents	2.8	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		Very High		



🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Nassau Grouper (*Epinephelus striatus*)

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

Climate Exposure: Very High Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Salinity (4.0). Nassau grouper is a marine reef fish also found in seagrass beds, thus exposure to all three factors occurs during the life stages.

Biological Sensitivity: High. Six sensitivity attributes scored ≥ 3.0: Habitat Specificity (3.4), Complexity in Reproductive Strategy (3.2), Spawning Cycle (3.8), Population Growth Rate (3.3), Sensitivity to Temperature (3.0) and Stock Size/Status (3.6). Nassau Grouper have historically formed large spawning aggregations at predictable times and locations, leading to near extirpation. In 1992 the species was protected from all harvest in U.S. waters with an Endangered Species Act listing of Threatened.

Distributional Vulnerability Rank: Moderate. Three attributes indicated moderate potential for distribution shift: moderate habitat specialization, potential for widespread early life stage dispersal, and high adult mobility (Nassau Grouper are capable of long migrations to spawning sites; Bolden 2002) .

Directional Effect on the Southeast U.S. Shelf: The directional effect of climate change on Nassau Grouper on the Southeast U.S. Shelf is estimated to be negative (50% of scores were negative while 40% were neutral and 10% positive). Rising seawater temperatures may negatively affect productivity by delaying timing of spawning (Tucker et al. 1993). Nassau Grouper rely on high-relief coral reefs as a primary habitat, and damages to or losses of this ecosystem type due to climate change (increasing temperatures) cannot likely be offset by their use of other rocky ledge type habitat. Nassau Grouper consume a large quantity of crustaceans and are likely to be affected by Ocean Acidification.

Data Quality: 92% of the data quality scores were 2 or greater. Early Life History Settlement and Survival Requirements, scored as of moderate to high sensitivity, was identified as a data-deficient attribute.

Climate Effects on Abundance and Distribution: Increasing Ocean Acidification could impact Nassau Grouper because of the inclusion of significant amounts of crustaceans (crabs, lobster, shrimp) in the diet (Carter et al. 1994), and lesser amounts of shelled mollusks. Ocean Acidification may also impact Nassau Grouper habitat. Although this species also inhabits rocky reefs, these are unlikely to be able to compensate for the loss of quality coral reef habitat. Between 1970-2011 (41 years), an overall 59% decline in coral cover was observed in the Caribbean, which was caused by anthropogenic stressors, *Diadema antillarum* decline, and coral disease (Jackson et al. 2014). Ocean temperatures of 25-26°C are the trigger for development and spawning (Colin 1992; Tucker et al. 1993), and climate-driven increases in water temperature could alter reproductive seasons.

Life History Synopsis**:** Nassau Grouper is a large grouper that is found in Bermuda and the Bahamas and South Florida, and through the Caribbean to Venezuela, where it is associated with tropical and subtropical coral and rocky reefs (Carter et al. 1994, Stevens et al. 2019). In the Atlantic waters of the southeastern U.S. the range of Nassau Grouper is generally 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). Nassau Grouper form large spawning aggregations in winter in the Caribbean. Spawning cues include lunar and diurnal cycles, water temperatures and local current conditions, and spawning occurs on the outer reef slope or shelf break (Chérubin et al. 2020). Spawning, and females in spawning condition, have been observed at many locations in the Caribbean and Bahamas, but no spawning has been documented off the southeast Atlantic U.S. states. In other parts of its range, Nassau Grouper form spawning aggregations at highly predictable times and locations, making them vulnerable to overfishing. 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). The fertilized eggs hatch after ~24 h and remain pelagic for 35 to 45 d. 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 y to reach reproductive maturity and may live 29 or more years (Waterhouse et al, 2020). Nassau Grouper eat mostly fish, but crustaceans and cephalopods are a significant part of the diet. Shelled mollusks are infrequently consumed. Crustaceans include crabs, lobster, shrimp and others (Carter et al. 1994). The fishery for Nassau Grouper in U.S. Atlantic waters (state and federal) has been closed since 1992.

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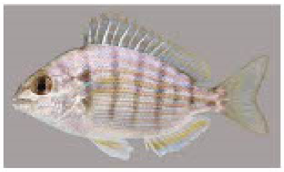
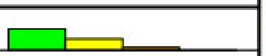
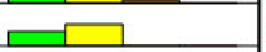
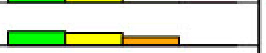
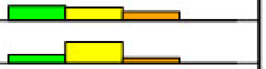
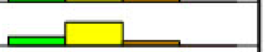
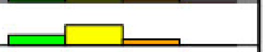
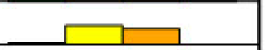
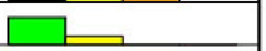
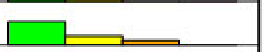
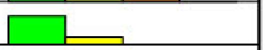
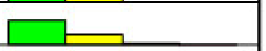
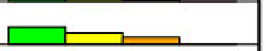
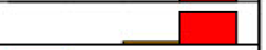
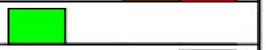
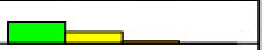
Pinfish – *Lagodon rhomboides*



Overall Vulnerability Rank = Moderate 🟨

Biological Sensitivity = Low 🟩
Climate Exposure = Very High 🟥

Data Quality = 92% of scores ≥ 2

	Lagodon rhomboides	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.5	3	
	Prey Specificity	1.6	2.6	
	Adult Mobility	1.8	3	
	Dispersal of Early Life Stages	1.9	2.4	
	Early Life History Survival and Settlement Requirements	1.9	2	
	Complexity in Reproductive Strategy	1.9	2.6	
	Spawning Cycle	2.4	2.8	
	Sensitivity to Temperature	1.2	2.6	
	Sensitivity to Ocean Acidification	1.5	2.6	
	Population Growth Rate	1.2	2.6	
	Stock Size/Status	1.4	1.6	
	Other Stressors	1.7	2.2	
	Sensitivity Score	Low		
Exposure Factors	Sea Surface Temperature	1	0	
	Air Temperature	4	3	
	Salinity	3.9	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	3.6	3	
	Currents	1.5	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		Moderate		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Pinfish (*Lagodon rhomboides*)

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

Climate Exposure: Very High. Four exposure factors contributed to this score: Air Temperature (4.0), Ocean Acidification (4.0), Sea Level Rise (3.6), and Salinity (4.0). Juvenile Pinfish reside in shallow estuarine areas while adults occupy a variety of coastal and nearshore habitats.

Biological Sensitivity: Low. No sensitivity attributes scored ≥ 2.5.

Distributional Vulnerability Rank: High. Three attributes indicated high potential for distribution shift: Pinfish are habitat generalists, adults are mobile, and the species has widely dispersive early life stages.

Directional Effect on the Southeast U.S. Shelf: The effect of climate change on Pinfish on the southeast U.S. shelf is projected to be positive. Pinfish are eurythermal and euryhaline, although studies have found feeding ceases at temperatures above 35℃ and below 6℃, indicating a possible effect on fitness in the southern end of the distribution as well as limits to northward movement. The effect of ocean acidification on Pinfish over the next 30 years is expected to be minimal to moderate.

Data Quality: 92% of the data quality scores were 2 or greater. Only Stock Size/Status (1.6) was data deficient, likely due to the fact that pinfish are not a managed species and have had no stock assessment performed.

Climate Effects on Abundance and Distribution: An occasional resident of waters north of Virginia, Pinfish may respond positively to climate-induced warming by increasing their abundance and distributional range north. Excessive warming in the southern end of the range (above 32℃) will cause Pinfish to leave the estuaries for deeper, cooler water (Cameron 1969) or cease feeding (Peters et al. 1973). Juvenile Pinfish diets include a diversity of invertebrates including polychaetes, amphipods, copepods, and bryozoans (Barbosa and Taylor 2020), while larger Pinfish feed on mollusks, polychaetes and other invertebrates (Binion-Rock et al. 2019), thereby indicating that Pinfish may be affected by Ocean Acidification.

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 Mid-Atlantic 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; 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 movement patterns of adult fish or if any stock structure exists. 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). 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). 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. 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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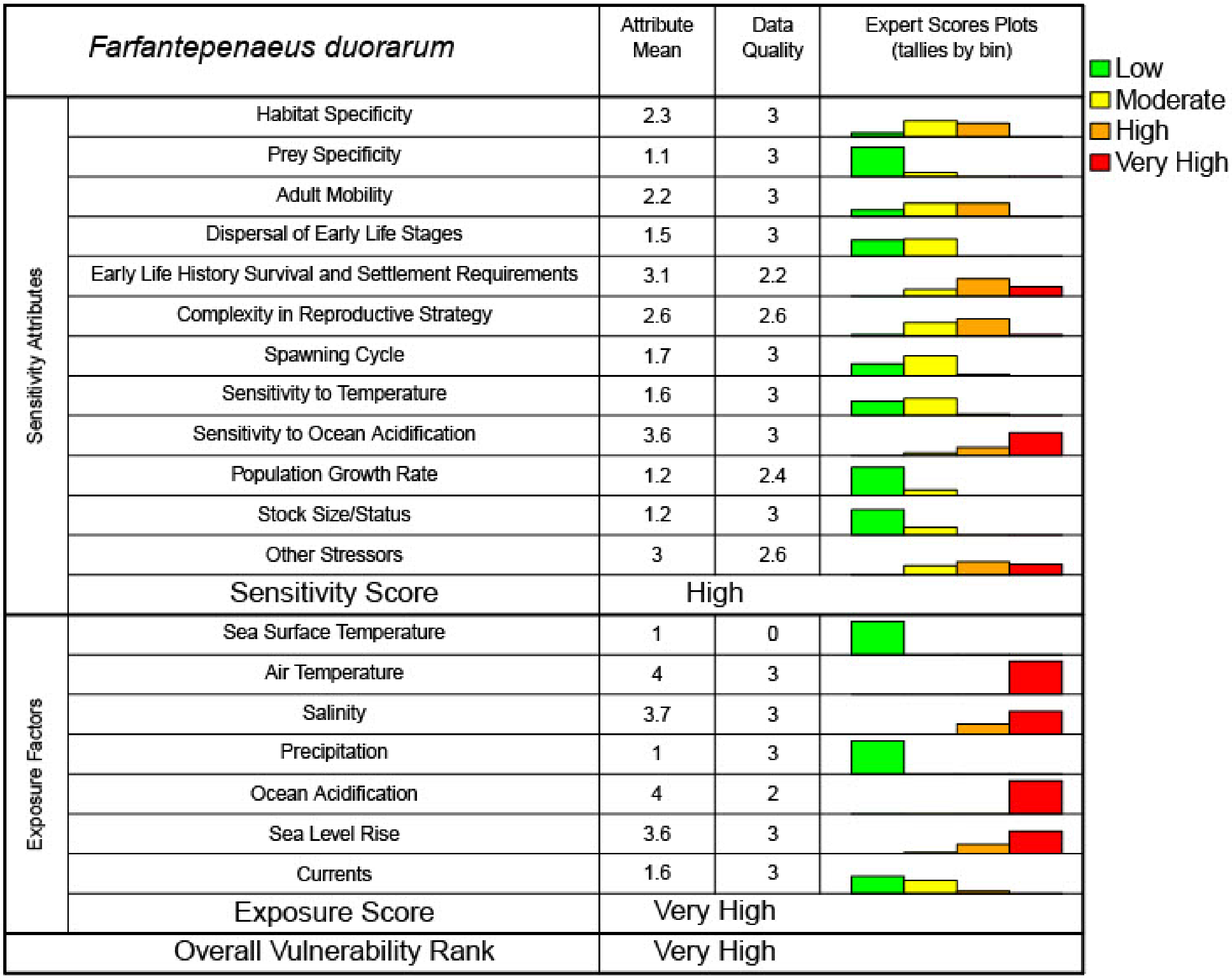
Pink Shrimp – *Farfantepenaeus duorarum*

Overall Vulnerability Rank = Very High 🟥

Biological Sensitivity = High 🟧
Climate Exposure = Very High 🟥

Data Quality = 100% of scores≥ 2



Farfantepenaeus duorarum		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.3	3	
	Prey Specificity	1.1	3	
	Adult Mobility	2.2	3	
	Dispersal of Early Life Stages	1.5	3	
	Early Life History Survival and Settlement Requirements	3.1	2.2	
	Complexity in Reproductive Strategy	2.6	2.6	
	Spawning Cycle	1.7	3	
	Sensitivity to Temperature	1.6	3	
	Sensitivity to Ocean Acidification	3.6	3	
	Population Growth Rate	1.2	2.4	
	Stock Size/Status	1.2	3	
	Other Stressors	3	2.6	
	Sensitivity Score	High		
Exposure Factors	Sea Surface Temperature	1	0	
	Air Temperature	4	3	
	Salinity	3.7	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	3.6	3	
	Currents	1.6	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		Very High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Pink Shrimp (*Farfantepenaeus duorarum*)

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

Climate Exposure: Very High. Four exposure factors scored ≥ 3.5: Salinity (3.7), Ocean Acidification (4.0), Air Temperature (4.0), and Sea Level Rise (3.6). Early life stages of Pink Shrimp use shallow estuarine areas, while adults are found in relatively shallow coastal habitats.

Biological Sensitivity: High. Three sensitivity attributes scored ≥ 3.0: Early Life History Settlement and Survival Requirements (3.1), Sensitivity to Ocean Acidification (3.6), and Other Stressors (3.0). Pink Shrimp are obligate estuarine residents during their early life stages and are thus subject to anthropogenic disturbances. Increasing acidification could have both direct (shell formation) and indirect (prey) effects on their productivity.

Distributional Vulnerability Rank: Moderate. Three attributes indicated moderate potential for distribution shift: mobile adults that may be behaviorally limited from extensive migration, preferring specific habitat types; early life stages that may disperse hundreds of kilometers to suitable nursery areas; and relatively selective habitat preferences (specific sediment types) that may limit distribution expansion.

Directional Effect on the Southeast U.S. Shelf: The effect of climate change on Pink Shrimp is projected to be neutral. As Pink Shrimp are more tolerant of thermal and salinity extremes, increasing temperatures could lead to changes in abundance and distribution (northward movement in search of suitable habitat), but increasing ocean acidification could affect fitness and survival (Mustafa et al. 2015).

Data Quality: 100% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution: Post larval and juvenile stages of Pink Shrimp prefer less saline areas of seagrass beds as nursery grounds and so could be affected by increasing salinity, although adults are more tolerant of a wide salinity range. Changes in freshwater inputs to nursery areas (through changes in precipitation brought on by warmer, drier overall climate) could also affect salinity and therefore fitness and survival of Pink Shrimp. Increasing ocean acidification could have consequences both directly (shell formation) as well as indirectly (molluscs and copepods in diet). Pink Shrimp rely on larval transport from offshore spawning areas to suitable nursery habitat, and climate-driven changes to currents could affect survival. Larval duration is known to be temperature dependent and increases in estuarine temperatures could affect timing of development.

Life History Synopsis**:** Pink Shrimp are a commercially important penaeid shrimp distributed from the Chesapeake Bay south along the eastern seaboard and throughout the Gulf of Mexico, including the Yucatan Peninsula, Mexico (Perez-Farfante, 1969). Postlarval Pink Shrimp settle in shallow, less saline areas of seagrass beds in estuarine nursery habitats, and juveniles use seagrass beds as nursery grounds until they reach about 18 mm carapace length when they migrate offshore as subadults (Murphey and Fonseca 1995). Adults inhabit the inner littoral zone of nearshore coastal waters. Primary habitat is sand, sand-shell or coral-mud bottoms from intertidal zone out to 50 meters in depth (Rulifson 1981; Kennedy and Barber 1986). Pink shrimp are opportunistic omnivores that consume caridean and other penaeid shrimps, copepods, isopods, amphipods, ostracods, small mollusks, polychaetes, seagrasss, benthic diatoms, algae, green algae, detritus, bacterial films, slime molds and yeast (Eldred et al. 1961; Odum and Heald 1972; Sastrakusumah 1971; Schwamborn and Criales 2000). Pink Shrimp are highly mobile (Gitschlag 1986; Sheridan et al. 1987), but tend to stay in waters shallower than 50 m preferring specific sediment types; they prefer sandy-mud, carbonate sands, or shell hash and not hard bottom or organic muds (Grady 1971; Rulifson 1981). Pink Shrimp likely spawn once in the northern part of their spawning range (North Carolina; Williams 1955) but spawn multiple times during a year in Florida (Cummings 1961). Spawning occurs over a temperature range of 19-30℃, with spawning occurring more frequently in higher temperatures. When temperatures drop in the fall, spawning shifts to deeper, cooler waters (Jones et al. 1970). Spawning occurs offshore and eggs hatch after 1-5 hr. Larvae utilize currents, daily vertical migrations, and selective tidal stream transport to migrate across the inner shelf towards inshore nursery habitats. Hundreds of kilometers may separate offshore spawning and inshore nursery grounds (Sheridan et al. 1987; Criales et al. 2007, 2011). Duration of planktonic stages is temperature dependent, usually lasting 3-4 weeks, and is dependent on currents for larval transport to nearshore seagrass beds (Munro et al. 1968). Pink Shrimp are the most tolerant of the three species of commercially important penaeid shrimp to colder temperatures, and the only species able to successfully overwinter in estuaries in the northern portion of the range (North Carolina and South Carolina). They can survive temperatures as low as 3℃ but likely will have reduced growth rates in cooler temperatures. They may burrow into sediments during extreme cold weather to enhance survival. Pink Shrimp activity is highest at temperatures above 26℃ (Fuss and Ogren 1966). As shell forming invertebrates, Pink Shrimp are likely to be affected by ocean acidification (Dall et al. 1990). Additionally, they rely on copepods and molluscs in their diet (Odum and Heald 1972), species prone to the effects of an increasingly acidic environment. Pink Shrimp are fast-growing and short-lived (maximum age 2 years; Hart 2016), a small maximum body size (170 mm), an early age-at maturity (Phares 1981) and fairly high natural mortality rate. Pink Shrimp are not considered overfished in either the Gulf of Mexico or South Atlantic. Gulf and Atlantic stocks appear to be genetically similar (McMillen-Jackson and Bert 2004). Pink Shrimp are likely to be affected by other stressors such as pollution (pesticides: Coppage and Matthews 1974; mercury pollution; Evans and Crumley 2005), harmful algal blooms, anthropogenic alteration of seagrass habitats (dredging, development), and changes in available nursery habitat due to sea level rise and potential changing salinity regimes (although Pink Shrimp are more tolerant of a wide salinity range than other penaeid shrimp).

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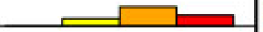
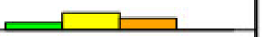
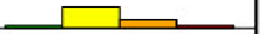
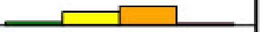
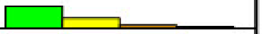
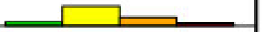
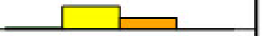
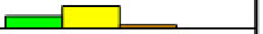
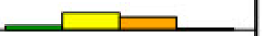
Redband Parrotfish − *Sparisoma aurofrenatum*

Overall Vulnerability Rank = High 🟧

Biological Sensitivity = Moderate 🟨
Climate Exposure = Very High 🟥

Data Quality = 58% of scores ≥ 2

	Sparisoma aurofrenatum	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	3.1	3	
	Prey Specificity	1.8	3	
	Adult Mobility	2.1	1.9	
	Dispersal of Early Life Stages	2.3	2.1	
	Early Life History Survival and Settlement Requirements	2.7	1.8	
	Complexity in Reproductive Strategy	2.5	2.3	
	Spawning Cycle	1.6	2.8	
	Sensitivity to Temperature	2.3	2.8	
	Sensitivity to Ocean Acidification	2.3	2	
	Population Growth Rate	1.8	1.8	
	Stock Size/Status	1.8	1.4	
	Other Stressors	2.5	1.7	
	Sensitivity Score	Moderate		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	4	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	2.9	3	
	Currents	2.3	2.8	
	Exposure Score	Very High		
Overall Vulnerability Rank		High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Redband Parrotfish (*Sparisoma aurofrenatum*)

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

Climate Exposure: Very High. Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Salinity (4.0). Exposure to all three factors occurs during the life stages.

Biological Sensitivity: Moderate. Four sensitivity attributes scored ≥ 2.5: Habitat Specificity (3.1), Complexity in Reproductive Strategy (2.5), Early Life History Settlement and Survival Requirements (2.7), and Other Stressors (2.5). Redband Parrotfish prefer shallow algal-rich coral reefs (McEachran and Fechhelm 2005). Little information exists on early life history requirements or reproductive strategy, but they are thought to be pair spawners (Robertson and Warner 1978). Preferred shallow coral reef habitat could be affected by nearshore runoff.

Distributional Vulnerability Rank: Moderate. Three attributes indicated moderate potential for distribution shift: a preference for a specific habitat type, limited adult mobility due to a behavioral preference to stay close to this habitat type, and moderately dispersive early life stages.

Directional Effect on the Southeast U.S. Shelf: The effect of climate change on Redband Parrotfish on the Southeast U.S. Shelf is estimated to be neutral. There is little information available to assess the directional effect of climate change on Redband Parrotfish.

Data Quality: 58% of the data quality scores were 2 or greater. Early Life History Settlement and Survival Requirements, an attribute of moderate sensitivity and importance, was scored by experts as data deficient.

Climate Effects on Abundance and Distribution: The species prefers seagrass beds, mangroves, and clear-water coral reefs, the latter a habitat increasingly threatened by warming-induced coral bleaching and increasing acidification. Additionally, adults feed on coral polyps.

Life History Synopsis**:** Redband Parrotfish is a small reef-associated fish species distributed in the western Atlantic from southern Florida (and Bermuda) through Brazil, including the Gulf of Mexico and throughout the Caribbean Sea. This species utilizes reef and seagrass habitats from 2-20 m depth. It inhabits clear coral and algal-rich reefs. It is solitary or in small groups and feeds on algae. Juveniles are often found in seagrass beds (McEachran and Fechhelm 2005). Juvenile redband parrotfish are herbivores, feeding on benthic algae and seagrasses. Adult diets are very similar, but adult Redband Parrotfish have been known to eat coral polyps (McEachran and Fechhelm 2005). There is limited information in the literature regarding mobility of Redband Parrotfish. They probably remain close to their home territory, especially during the spawning season. Boschung (1983) states that they stay between 2-20 m depth because of their lack of ability to swim in strong currents. Redband Parrotfish are protogynous hermaphrodites. They are thought to be pair spawners but also form harems with one dominant male and several smaller females (Robertson and Warner 1978; Allsop and West 2003). Breeding may occur year round, usually in the morning hours. Fertilization is external into the water column, with eggs and sperm released in an upward rush. Eggs are approximately 1mm in diameter and buoyant. Larvae hatch after 25 hours. There is very limited information available about early life history or settlement. It is likely that larvae rely on passive tidal transport to drift into the inshore seagrass areas utilized as nursery areas. Redband Parrotfish are a subtropical/tropical species, occurring in temperatures of 26-28°C (Fishbase). While their herbivory makes it unlikely that the species will suffer indirect effects from prey being affected by increasing ocean acidification, Redband Parrotfish could be impacted by ocean acidification effects on their coral reef habitat. There is no information available about the rate of population growth or stock productivity of Redband Parrotfish. Redband Parrotfish are not assessed, nor is there any information available about population structure. While they are included in artisanal fisheries, they are not a major target and are considered a species of least concern by the IUCN. Potential stressors for Redband Parrotfish include possible ocean acidification and coral bleaching and predation by lionfish on juveniles.

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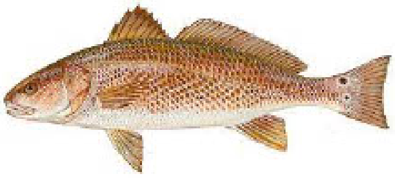
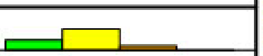
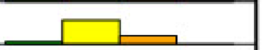
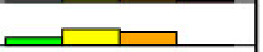
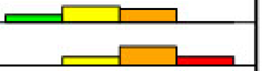
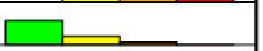
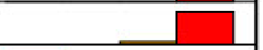
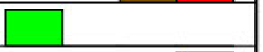
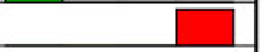
Red Drum − *Sciaenops ocellatus*



Overall Vulnerability Rank = High 🟧

Biological Sensitivity = Moderate 🟨
Climate Exposure = Very High 🟥

Data Quality = 100% of scores≥ 2

	Sciaenops ocellatus	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.8	2.8	
	Prey Specificity	1.2	3	
	Adult Mobility	1.6	3	
	Dispersal of Early Life Stages	2.2	3	
	Early Life History Survival and Settlement Requirements	2.6	2.6	
	Complexity in Reproductive Strategy	2.2	2.8	
	Spawning Cycle	3	3	
	Sensitivity to Temperature	1.4	3	
	Sensitivity to Ocean Acidification	2	3	
	Population Growth Rate	3	2.8	
	Stock Size/Status	2.3	2.6	
	Other Stressors	2.1	2.8	
	Sensitivity Score	Moderate		
Exposure Factors	Sea Surface Temperature	1	0	
	Air Temperature	4	3	
	Salinity	3.9	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	3.6	3	
	Currents	1.4	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Red Drum (*Sciaenops ocellatus*)

Overall Climate Vulnerability Rank: High. (73% bootstrap results in High, 27% bootstrap results in Very High).

Climate Exposure: Very High. Four exposure factors contributed to this score: Salinity (3.9), Ocean Acidification (4.0), Air Temperature (4.0), and Sea Level Rise (3.6). Exposure to all factors occurs during the life stages. Red Drum are estuarine dependent marine fish usually found in nearshore coastal waters. Adults tend to aggregate in large schools that tend to stay close to the surface (Powers et al. 2012).

Biological Sensitivity: Moderate. Three sensitivity attributes scored ≥ 2.5: Spawning Cycle (3.0), Population Growth Rate (3.0), and Early Life History Settlement and Survival Requirements (2.6). Red Drum are a long-lived, relatively late maturing fish (Wenner 2000) with a discrete spawning period (Ross et al. 1995).

Distributional Vulnerability Rank: High. Three attributes indicated a high potential for distribution shift: Red Drum are highly mobile adults with a habitat generalist habit, and moderately to highly widespread dispersal of early life stages.

Directional Effect on the Southeast U.S. Shelf: The effect of climate change on Red Drum on the Southeast U.S. Shelf is estimated to be positive. Warming temperatures would reduce overwinter mortality and potentially increase recruitment, as well as allow more habitat to become thermally available to Red Drum in northern areas. Increasing Ocean Acidification will likely have an effect on Red Drum.

Data Quality: 100% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution: There have been limited studies of potential climate effects on Red Drum distribution. Productivity is likely related to climate. Severe winters may cause high mortality of young-of-year Red Drum independent of body size (Anderson and Scharf 2012), whereas smaller young-of-the-year are more susceptible to mortality during moderate winters. Rooker et al. (1998) found that predation on young-of-the-year Red Drum was lower in vegetated compared to non-vegetated habitats suggesting potential susceptibility to sea-level rise and loss of vegetated habitats in estuaries and coastal areas. Red Drum diet consists largely of blue crabs and penaeid shrimp in addition to menhaden (Scharf and Schlict 2000), thus the species will likely be affected by Ocean Acidification.

Life History Synopsis**:** Red Drum is a large coastal and estuarine-associated fish distributed in the western Atlantic from Delaware south along the U.S. coast, throughout the entire Gulf of Mexico from Florida Bay to Veracruz, Mexico (R. Robertson pers. comm. 2014). Juveniles are dependent on estuarine nursery habitats and inlets up until about age five, and are vulnerable to pollution and other environmental disturbances during the estuarine phase (Peters and

McMichael 1987). Adults are habitat generalists, utilizing nearshore coastal waters, inlets near barrier islands, and estuaries for spawning in both the Gulf of Mexico and North Carolina waters. This species occurs over sand and sandy mud bottoms and is abundant in the surf zones off Cape Hatteras (North Carolina) and Texas during seasonal migrations. It aggregates in large schools that tend to stay close to the surface (Powers et al. 2012). Adults tagged off North Carolina moved through inlets into Pamlico Sound in spring/summer months and moved out of inlets into coastal waters in the fall. Adults utilize these nearshore or estuarine areas, often with seagrass beds, for foraging, but tend to move out into preferred deeper water for spawning. Juveniles feed on zooplankton and invertebrates such as small crabs and shrimp (Chao 2002). With growth, the diet expands to include fish and larger invertebrates. Adults preferentially utilize deeper water at night and gradually move into adjacent shallow seagrass habitats after sunrise, likely for foraging. It is an aggressive, opportunistic ambush predator with a diet consisting mostly of blue crabs (*Callinectes sapidus*) as well as penaeid shrimp and some benthic fishes. Red Drum are highly mobile, performing age-dependent migrations with a high rate of (primarily southward) movement by age 1 during fall months within the Pamlico Sound estuary of North Carolina. Most age 3 individuals move from the estuaries to offshore areas (Brogan 2010), and North Carolina is the most significant northern overwintering grounds for subadults on the Atlantic coast (Bacheler et al. 2009). Spawning adults return to natal estuaries between mid August through late November and form aggregations near bay mouths or inlets and over nearshore continental shelf waters (Bacheler et al. 2009, Flaherty and Landsberg 2011). Red Drum are gonochoristic and spawn in coastal waters near inlets and passes, allowing the eggs to be transported on currents into estuarine nursery areas.Tidal flows and nonlocal forcing mechanisms were responsible for movement of sciaenid larvae through tidal inlets and channels in North Carolina, USA (Pietrafesa & Janowitz 1988). Ross et al. (1995) found that Red Drum spawning occurred in both nearshore coastal waters close to inlets as well as in Pamlico Sound. Timing of peak spawning was August-October. Spawning appears to be temperature dependent, with spawning occurring between 22-30°C, with 22-25°C the optimal range, and a South Carolina study confirmed that spawning occurred as temperature dropped below 30°C in August (Renkas 2010). Eggs and larvae are pelagic, postlarvae spend 20 days in the water column before becoming demersal. Settlement of larvae into seagrass habitat begins between 15-20 mm total length (Rooker and Holt 1997). Red Drum have a temperate to tropical distribution, preferring a fairly discrete and warm temperature regime. Fishbase lists its preferred range as from 15.5-27°C, with a mean occurrence of 24°C. Red Drum are very likely to be affected by increased ocean acidification because invertebrates such as blue crab comprise a large part of the diet of adults, and juveniles prey on penaeid shrimp and other species of crabs as well. Population growth rate is moderately slow based on a high maximum age (i.e., 62 years; SEDAR 2015), large maximum body size (>1.5m), high age at maturity (4-5 years, Wenner 2000), a low vulnerability growth coefficient value of 0.25-0.29 (SEDAR 2015), and a moderate to very high level of vulnerability imparted by the natural mortality rate of 0.47 for fish < age-6 and 0.18 for fish > age-6. The sum of these characteristics could make populations of Red Drum slower to rebound from deleterious effects of a changing climate. A recent Atlantic red drum stock assessment concluded that B_{curr}/MSST = 0.25, indicating that Red Drum in the Atlantic are overfished (SEDAR 2015). The genetic variation doesn't appear to be compromised based on large variations in reproductive success. While earlier studies showed little to no structure in Atlantic populations of Red Drum, more recent studies show genetic differentiation does exist between NC and locations south of NC during spawning season, but mixing of adults does occur outside of the temporal spawning period (Chapman et al. 2002; Seyoum et al 2000; Cushman et al. 2014). Red Drum are highly estuary dependent and thus very susceptible to anthropocentric changes to this habitat, either directly (habitat alteration) or indirectly (climate induced). Most estuaries suffer from development-related pollution issues. There is no evidence of effects of red tide on Atlantic Red Drum, but recent red tides in the Gulf of Mexico have affected red drum populations. There is also no reporting of lionfish predation on red drum juveniles, but lionfish have shown a broad tolerance for salinity and temperature fluctuations often seen in estuaries, and have in fact successfully invaded some Florida estuaries (Jud et al. 2011, 2015), so lionfish predation on early life stages of Red Drum is likely just a matter of time.

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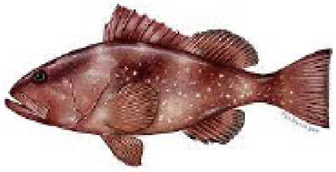
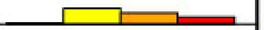
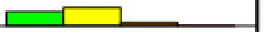
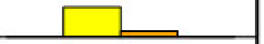
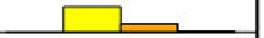
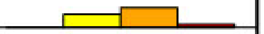
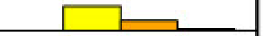
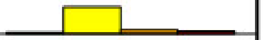
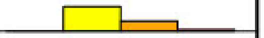
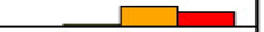
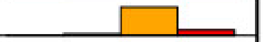
Red Grouper − *Epinephelus morio*



Overall Vulnerability Rank = Very High 🟥

Biological Sensitivity = High 🟧
Climate Exposure = Very High 🟥

Data Quality = 83% of scores ≥ 2

	Epinephelus morio	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.7	3	
	Prey Specificity	1.7	3	
	Adult Mobility	2.2	2.4	
	Dispersal of Early Life Stages	2.3	2.6	
	Early Life History Survival and Settlement Requirements	2.7	1.8	
	Complexity in Reproductive Strategy	2.7	2.7	
	Spawning Cycle	2.4	3	
	Sensitivity to Temperature	2.2	2.8	
	Sensitivity to Ocean Acidification	2.4	2.2	
	Population Growth Rate	3.4	2.6	
	Stock Size/Status	4	2.8	
	Other Stressors	3.1	1.7	
	Sensitivity Score	High		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	3.9	3	
	Precipitation	1	0	
	Ocean Acidification	4	2	
	Sea Level Rise	1	0	
	Currents	2.7	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		Very High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Red grouper (*Epinephelus morio*)

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

Climate Exposure: Very High. Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Salinity (3.9). Red Grouper is an offshore marine species that is also found in seagrass beds and on inshore reefs as juveniles.

Biological Sensitivity: High. Three sensitivity attributes scored ≥ 3.0: Population Growth Rate (3.4). Stock Size/Status (4.0), and Other Stressors (3.1). Red Grouper is a slow growing, long-lives species considered overfished in a recent stock assessment, and the species may be impacted by coastal development and harmful algal blooms.

Distributional Vulnerability Rank: Moderate. Two attributes indicated moderate potential for distribution shift: adult mobility and early life stage dispersal. Red Grouper, while found in seagrass beds as juveniles, tend to prefer more rocky or hard substrate habitat as adults (Moe 1969).

Directional Effect on the Southeast U.S. Shelf: The effect of climate change on Red Grouper on the Southeast U.S. Shelf is estimated to be neutral (with the expert scores equally distributed between the three categories). Warming seawater temperatures in the southeast may make nursery habitats less productive, although Red Grouper are not estuarine obligate. Adults in deeper water habitats are not expected to be greatly impacted by increasing temperatures . While Red Grouper do prey upon some crustaceans, they are opportunistic feeders and the effect of ocean acidification is expected to be minimal.

Data Quality: 83% of the data quality scores were 2 or greater. Other Stressors and Early Life History Settlement and Survival Requirements were identified as attributes with low data quality.

Climate Effects on Abundance and Distribution: There are few references to effects of climate change on abundance and distribution of Red Grouper in the scientific literature. Given their preferred temperature range, occurrence north of North Carolina is likely due to larval escapement via the Gulf Stream rather than from immigration of adults (Thompson and Munro 1978), but future warming scenarios might lead to increasingly successful establishment in northern areas. Ocean Acidification may have substantial effects due to their reliance on crustaceans in juvenile diets (Moe 1969).

Life History Synopsis**:** Red Grouper is a large-bodied grouper species distributed from North Carolina through southern Brazil, including Bermuda, throughout the Gulf of Mexico and Caribbean (FishBase.org). Small juveniles are occasionally found in shallow seagrass beds and inshore reefs, while larger juveniles are commonly found occupying ledges on rocky reef bottoms (Harter et al. 2008; Coleman and Koenig 2010). Adults prefer rocky bottom with ledges as well as artificial hard bottom like shipwrecks and are therefore generally considered to be reef-associated (Moe 1969). 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). According to one tagging study, adult Red Grouper were capable of moving as far as 30km (Moe 1969), though information on this topic is scarce. Red Grouper spawn in relatively small polygynous groups and do not appear to aggregate (Coleman et al. 1996). Sadovy et al. (1994) reported that Red Grouper aggregating behavior is similar to that of red hind (i.e., patchily distributed short term aggregations comprised primarily of older larger fish, with pair spawning in single male/multi female clusters. Spawning activity of red grouper has peaks in March and May in waters 19-21°C (Moe 1969; Johnson et al. 1998). Red Grouper are protogynous hermaphrodites, developing first as males and transitioning to females later (age at 50% maturity: 7.2 years; Johnson et al. 1998; Burgos et al. 2007). Red Grouper eggs are pelagic, hatching approximately 30h after spawning. Fertilized eggs require high salinity (32ppt or higher) to maintain buoyancy. Larvae are pelagic for 30-40 days prior to settlement (University of Florida red grouper webpage). Red Grouper populations have maximum reported age of 29 years and an associated natural mortality estimate of 0.14 (SEDAR 2017). Estimated intrinsic rate of population increase for Red Grouper is 0.05-0.15 and the von Bertalanffy K is estimated as 0.213. Most of these values categorize red grouper as High or Very High Vulnerability.

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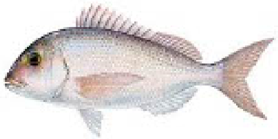


Red Porgy – *Pagrus pagrus*

Overall Vulnerability Rank = High 🟧

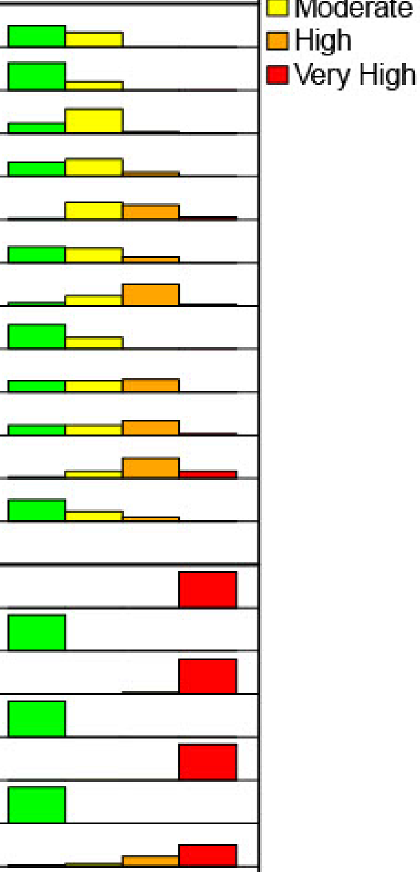
Biological Sensitivity = Moderate 🟨

Climate Exposure = Very High 🟥

Data Quality = 100% of scores≥ 2

	Pagrus pagrus	Attribute Mean	Data Quality
Sensitivity Attributes	Habitat Specificity	1.4	3
	Prey Specificity	1.2	3
	Adult Mobility	1.8	2.8
	Dispersal of Early Life Stages	1.7	2.8
	Early Life History Survival and Settlement Requirements	2.5	2.1
	Complexity in Reproductive Strategy	1.7	2.9
	Spawning Cycle	2.6	3
	Sensitivity to Temperature	1.3	3
	Sensitivity to Ocean Acidification	2	3
	Population Growth Rate	2.2	2.9
	Stock Size/Status	2.9	3
	Other Stressors	1.5	2.3
	Sensitivity Score	Moderate	
Exposure Factors	Sea Surface Temperature	4	3
	Air Temperature	1	0
	Salinity	4	3
	Precipitation	1	0
	Ocean Acidification	4	2
	Sea Level Rise	1	0
	Currents	3.4	3
	Exposure Score	Very High	
Overall Vulnerability Rank		High	

Expert Scores Plots (tallies by bin)



Red Porgy (*Pagrus pagrus*)

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

Climate Exposure: Very High. Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Salinity (4.0). Red Porgy is a marine offshore species exposed to all three of these factors during their life stages.

Biological Sensitivity: Moderate. Three sensitivity attributes scored ≥ 2.5: Spawning Cycle (2.6), Stock Size/Status (2.9) and Early Life History Settlement and Survival Requirements (2.5). Red Porgy have a short, discrete spawning season (Manooch 1976b, Roumillat and Waltz 1993), and there is a paucity of information on larval/juvenile requirements. The species is overfished and appears to suffer from poor recruitment, hindering stock rebuilding (SEDAR 2012).

Distributional Vulnerability Rank. High. Three attributes indicated high potential for distribution shift: adult mobility, widespread dispersal of early life stages, and low habitat specialization. Additionally, the species has a low sensitivity to temperature change, which could allow a shift into areas with new thermal regimes.

Directional Effect on the Southeast U.S. Shelf: The effect of climate change on Red Porgy on the Southeast U.S. Shelf is estimated to be neutral (the expert scores were equally split between the three categories). The species has a wide thermal tolerance and occupies a broad depth distribution and is not likely to be affected by rising sea surface temperatures initially. The effect of ocean acidification could be substantial, as Red Porgy predominantly consumes crustaceans and molluscs.

Data Quality: 100% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution: Both juvenile and adult Red Porgy are likely to be negatively impacted by increasing ocean acidification as their diets consist of a large amount of invertebrates (Manooch 1976a).

Life History Synopsis**:** Red Porgy is a medium-sized (historically capable of attaining lengths to 70 cm) reef-associated fish species widely distributed in the western Atlantic from the United States to Argentina, including the Gulf of Mexico but not the eastern Caribbean Sea (Hoese and Moore 1998). The species is also found in the eastern Atlantic and the Mediterranean Sea (Ball et al. 2007). Juvenile Red Porgy inhabit low-profile rock, gravel or sand substrate, as well as seagrass beds. One study from Greece found few to no larger adult Red Porgy found on trawlable habitat, indicating as they grow and mature they move off to deeper, more structured habitat (Labroupoulou et al. 1999). Adults are commonly found over irregular and low-profile live hard bottoms at depths between about 20 and 250 m (most commonly <100 m), often associated with rock, rubble or sand substrata, over the continental shelf (Manooch and Hassler 1978; Fischer et al. 1987). Small juveniles (46-64 mm) eat amphipods, copepods, stomatopods and annelid worms. Larger juveniles (130-162 mm) feed on foods similar to adult diets, predominantly crabs, but also mollusks, and echinoderms, with teleost fishes making up 15% of food volume in Red Porgy stomachs (Manooch 1976a). Adults are highly mobile yet exhibit high site fidelity once they recruit to a patch of habitat. Tagging studies have shown very little movement of adult Red Porgy (Manooch and Hassler 1978). Red porgy eggs and larvae are pelagic for a number of days, thus their distribution is influenced by currents and winds. Larvae complete yolk absorption 4 days post-hatch, and complete digestion of the oil globule after 7 days. Transformation from larvae to juvenile occurs between days 23-32 post hatch, at a mean size of 12.7 mm TL. Ranzi (1969) referred to vertical migration of larval and postlarval phases of Red Porgy: "All of these stages [<10 mm] can be fished in the deep plankton but at 10 mm *Pagrus* comes to the surface." He noted a shift from planktonic to benthic existence at lengths above 20 mm. It is highly probable that young Red Porgy are distributed inshore of adult populations. Manooch (1975) reported young-of-year trawled from 9 m off Charleston, S.C. Even though they may occur inshore as juveniles, adverse conditions of low water temperature, competitive exclusion, and unsuitable substrate reduce the longevity of this inshore distribution. Not only are eggs and larvae transported inshore by Ekman transport, but they are probably transported for relatively long distances. Limited information is available on early life history and settlement requirements. Egg quality is dependent on a narrow temperature range (temperatures >14.5℃ affected egg diameter), and this is likely true for larvae/juveniles as well (larvae usually found inshore of adult fish, but these fish likely move farther offshore as soon as they are able) (Mihelakakis et al. 2001; Manooch and Hassler 1978). There is no information about potential mismatches of spawning time and availability of larval food. The species' high fecundity might potentially offset predation on early life stages (for example, juvenile Red Porgy are likely susceptible to lionfish predation in co-occurring habitats). Red Porgy are a protogynous hermaphrodite. Female Red Porgy in the South Atlantic Bight mature at sizes 50 mm larger than those found in the Gulf of Mexico (Harris and McGovern 1997, DeVries 2005). Females mature at age-1 or age-2, at approximately 300 mm TL. Red Porgy off the Carolinas were found to spawn January-April, with peak GSI occurring in January and highest proportion of ripe fish found January-March (Manooch 1976b). This agrees well with a South Carolina study that found peak number of hydrated oocytes in January-February (Roumillat and Waltz 1993). There is no evidence of large, predictable spawning aggregations. Histological evidence shows that Red Porgy spawn wherever mature individuals occur (Devries 2005). Bottom temperatures during the spawning period for fish from North and South Carolina ranged from 16.4℃ to 21.5℃ (winter-early spring temperatures) (Manooch 1976b). Fishbase reports a preferred temperature range for Red Porgy of 15.8 - 27.8℃, mean 24.1℃. The species is found from 0-250 m, and most frequently utilizes depths from 10-80 m (Carpenter 2002). Red Porgy are likely to be impacted by increasing ocean acidification, in large part due to reliance on obligate benthic animals such as crabs (majids, portunids, calappids), mollusks, and echinoderms in their diet. Juveniles between 130-160 mm had diets similar to adults (Manooch 1976a). Red Porgy have a moderate population growth rate, including a longevity of 18 years (Potts and Manooch 2002), a natural mortality rate of 0.22 (SEDAR 2012), a von Bertalanffy growth coefficient of 0.28 (Harris and McGovern 1997), and a maximum body size of 700+ mm, although most fish currently landed are <550 mm. A 2012 SEDAR stock assessment update found $SSB_{curr}/SSB_{MSY} = 0.47$, indicating the stock was overfished, while $F_{curr}/F_{MSY} = 0.64$, indicating the stock was not undergoing overfishing (SEDAR 2012). This assessment concluded that rebuilding is not occurring as expected due to poor recruitment; a new updated assessment is due to be released in the spring of 2020. Other stressors affecting Red Porgy include lionfish predation on juveniles/subadults (Peake et al. 2018).

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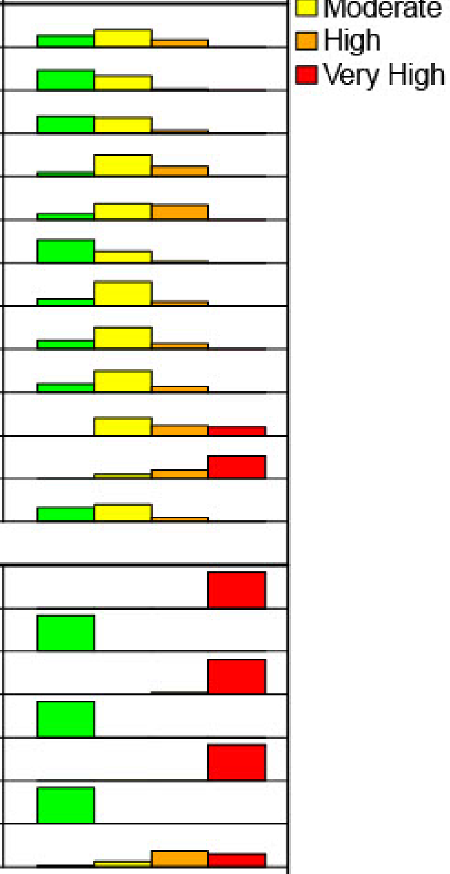
Red Snapper – *Lutjanus campechanus*

Overall Vulnerability Rank = High 🟧

Biological Sensitivity = Moderate 🟨
Climate Exposure = Very High 🟥

Data Quality = 83% of scores ≥ 2

Lutjanus campechanus		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.9	2.8	
	Prey Specificity	1.5	3	
	Adult Mobility	1.6	2.8	
	Dispersal of Early Life Stages	2.2	2.4	
	Early Life History Survival and Settlement Requirements	2.2	1.8	
	Complexity in Reproductive Strategy	1.4	2.6	
	Spawning Cycle	1.9	3	
	Sensitivity to Temperature	1.9	3	
	Sensitivity to Ocean Acidification	1.9	2.8	
	Population Growth Rate	2.8	2.8	
	Stock Size/Status	3.5	2.8	
	Other Stressors	1.7	1.8	
	Sensitivity Score	Moderate		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	3.9	3	
	Precipitation	1	0	
	Ocean Acidification	4	2	
	Sea Level Rise	1	0	
	Currents	3.1	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		High		



Red Snapper (*Lutjanus campechanus*)

Overall Climate Vulnerability Rank: High. (3% bootstrap results in Moderate, 87% bootstrap results in High, 10% bootstrap results in Very High.

Climate Exposure: Very High**.** Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Salinity (3.9). Exposure to all three factors occurs during the life stages. Red Snapper are found in continental shelf habitats during all life stages.

Biological Sensitivity: Moderate. Two sensitivity attributes scored above 2.5: Stock Size/Status (3.5) and Population Growth Rate (2.8). Red Snapper are long-lived, have a slow population growth rate and are currently overfished and undergoing overfishing.

Distributional Vulnerability Rank: High. Three attributes indicated high potential for distribution shift: high adult mobility, widespread dispersal of early life stages, and to a lesser degree, relatively low habitat specialization. While smaller, post-juvenile fish are structure-oriented, larger and older adults may become independent of this structure association and occur over the open continental shelf, as is reported for Red Snapper in the Gulf of Mexico (Galloway et al. 2009).

Directional Effect on the Southeast U.S. Shelf: The effect of climate change on Red Snapper on the Southeast U.S. Shelf is estimated to be positive. Red Snapper have fairly robust thermal tolerances and will likely not be affected by near-term warming. Ocean acidification may have some minor effects on juveniles but Red Snapper quickly become more piscivorous as they grow. There is little evidence to suggest an overall negative directional effect of climate change on Red Snapper.

Data Quality: 83% of the data quality scores were 2 or greater. The sensitivity attribute Other Stressors was scored as data-deficient but was not scored as highly sensitive, despite a lack of information about the effect of other stressors on the species.

Climate Effects on Abundance and Distribution: Effects of changing climate on Red Snapper are likely to be minimal. The species has 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 occuring in 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 and artificial reefs 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 (Wells et al. 2008). Adults can be highly mobile yet show high site fidelity in some places (Galloway et al. 2009; Williams-Grove 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 (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 – September (White and Palmer 2004). Eggs hatch approximately one 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). Gulf Stream currents presumably aid larval Red Snapper transport along the southeast US Atlantic coast, but settlement locations are poorly known, as are the locations of small juveniles in the region (Rindone et al. 2015). 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 that may themselves be sensitive to ocean acidification. Red Snapper have a slow population growth rate, including an old maximum age (51 years; Anderson et al. 2015), low natural mortality rate, and large maximum body size (SEDAR 2017). Red Snapper are overfished in the South Atlantic region, with spawning stock biomass values of ~0.2 compared to historical values, and overfishing appears to be ongoing ($F/F_{30\%} = 2.7$; SEDAR 2017). 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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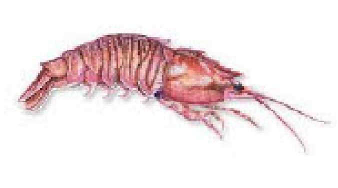
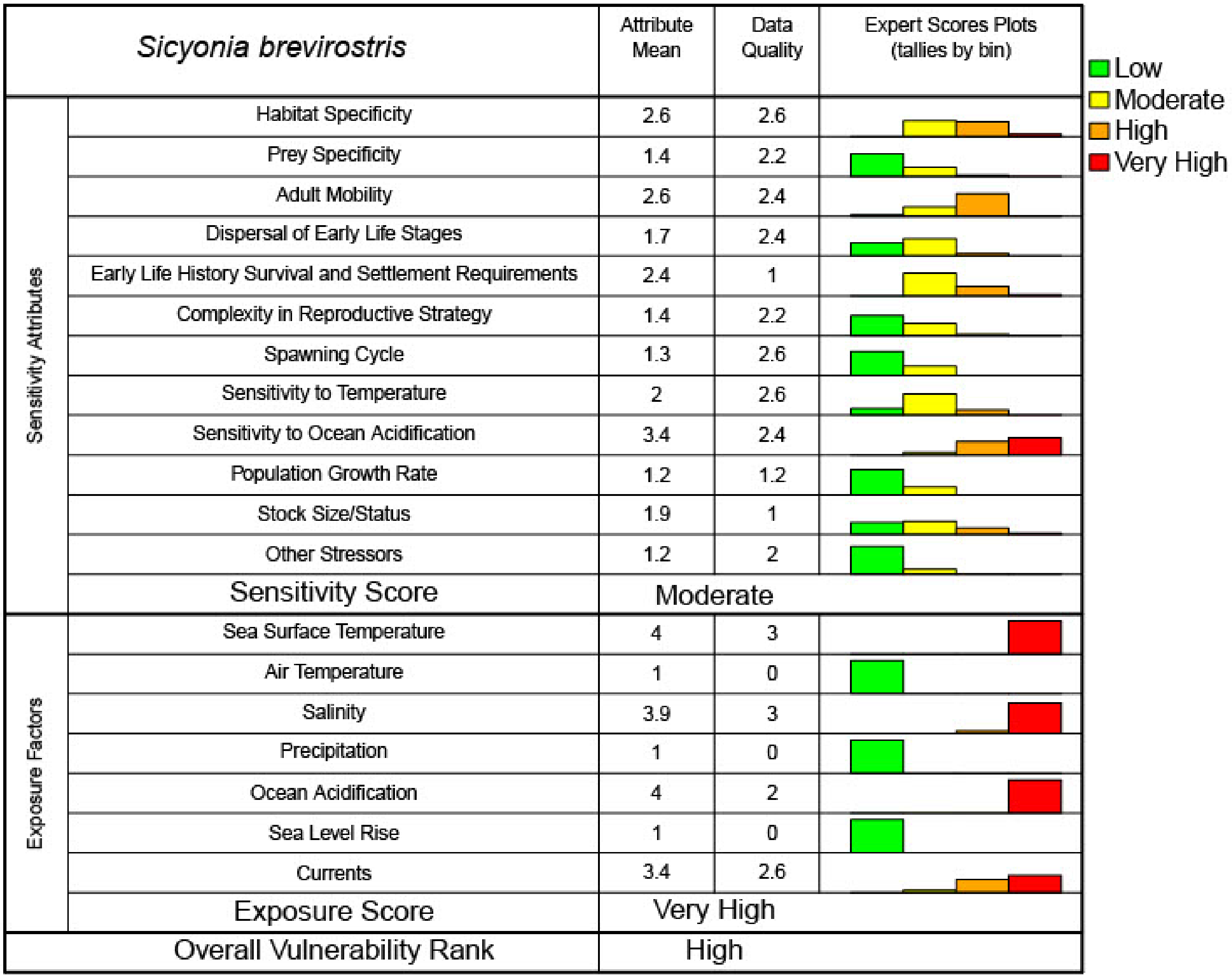
Rock Shrimp – *Sicyonia brevirostris*



Overall Vulnerability Rank = High 🟧

Biological Sensitivity = Moderate 🟨
Climate Exposure = Very High 🟥

Data Quality = 75% of scores ≥ 2



	Sicyonia brevirostris	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.6	2.6	
	Prey Specificity	1.4	2.2	
	Adult Mobility	2.6	2.4	
	Dispersal of Early Life Stages	1.7	2.4	
	Early Life History Survival and Settlement Requirements	2.4	1	
	Complexity in Reproductive Strategy	1.4	2.2	
	Spawning Cycle	1.3	2.6	
	Sensitivity to Temperature	2	2.6	
	Sensitivity to Ocean Acidification	3.4	2.4	
	Population Growth Rate	1.2	1.2	
	Stock Size/Status	1.9	1	
	Other Stressors	1.2	2	
	Sensitivity Score	Moderate		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	3.9	3	
	Precipitation	1	0	
	Ocean Acidification	4	2	
	Sea Level Rise	1	0	
	Currents	3.4	2.6	
	Exposure Score	Very High		
Overall Vulnerability Rank		High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Rock Shrimp (*Sicyonia brevirostris*)

Overall Climate Vulnerability Rank: High. (2% bootstrap results in Moderate, 98% bootstrap results in High).

Climate Exposure: Very High. Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Salinity (3.9). Exposure to all three factors occurs during the life stages.

Biological Sensitivity: Moderate. Three sensitivity attributes scored ≥ 2.5: Adult Mobility (2.6), Habitat Specificity (2.6) and Sensitivity to Ocean Acidification (3.4). Rock Shrimp inhabit a very specific type of offshore shelf habitat and, while mobile, remain close to this substrate, often burrowing into it during daylight hours (Cobb et al. 1973).

Distributional Vulnerability Rank: Low. Three attributes indicated low potential for distribution shift: limited adult mobility (behaviorally-mediated), limited early life stage dispersal (Kennedy et al. 1977 reported that shelf currents retained larvae on the shelf), and high habitat specialization (Taylor 1979).

Directional Effect on the Southeast U.S. Shelf: The effect of climate change on Rock Shrimp is estimated to be negative. Cook and Murphy (1965) reported that larvae raised under laboratory conditions were killed at salinities above 35 ppt. Increasing ocean acidification could affect fitness and survival both directly through shell formation (Mustafa et al. 2015) as well as indirectly through diet (reliance on crustaceans and molluscs). Changes to existing oceanic currents could impact successful recruitment of Rock Shrimp to suitable nursery habitat.

Data Quality: 75% of the data quality scores were 2 or greater. Early Life History Settlement and Survival Requirements was identified as a data-deficient attribute that also scored as moderately sensitive.

Climate Effects on Abundance and Distribution: There have been no directed studies on climate effects on abundance and distribution of Rock Shrimp. Potential impacts could include negative effects of Ocean Acidification on both shell formation as well as indirect effects on the invertebrates they consume (molluscs, crustaceans). They are found to occur in a fairly narrow temperature range (Kennedy et al. 1977), and Cook and Murphy (1965), in laboratory studies, found that larvae were killed at salinities above 35 ppt, or below 27 ppt.

Life History Synopsis**:** Rock Shrimp occurs in the Western Atlantic from Virginia south along the Atlantic coast to Florida, including the Bahamas and Cuba, and the Gulf of Mexico to the Yucatán. Centers of abundance include the waters off Cape Lookout, North Carolina and Cape Canaveral, Florida. Rock Shrimp preferred habitat is quartz and shell sand substrate of fine to medium grain, usually found between 18-73 m, with highest densities found between 34-55 m (Hill 2005). Trawl surveys in North Carolina have found them in depths to 181 m, in similar habitat to that described above (Taylor 1979). Diet of Rock Shrimp consists mainly of mollusks, crustaceans and polychaete worms, with nematodes and foraminiferans comprising a smaller portion. Gut content analysis found ostracods, amphipods and decapods as primary components, with tanaidaceans, isopods, cumaceans, gastropods and other bivalves present (Kennedy et al. 1977). There is no distinction made in the literature between juvenile and adult diet. Rock Shrimp tend to stay close to substrate and are nocturnally active, tending to burrow into substrate during daylight hours (Cobb et al. 1973). Spawning occurs year-round with peaks in November and January (Kennedy et al. 1977). There is no indication the species uses spawning aggregations; copulation occurs between individuals, with external fertilization (Kennedy et al. 1977). Spawning habitat is on the continental shelf, in mid- to deepwater shell hash habitat. While temperature was not found to be an important cue for initiating spawning, it was found to trigger ovarian development to more mature stages. Kennedy et al. (1977) found that a water temperature increase off Cape Canaveral FL between August and October led to an increase in the percentage of mature females in the population, and that high lunar light intensity stimulated spawning, with a higher percentage of spawning females found on the full moon. Eggs hatch within 24 hours. Lab rearing experiments found a development time of 29 days from nauplius to post-larva, and an additional 30-60 days to the juvenile stage (Cook and Murphy 1965). Kennedy et al (1977) report that shelf currents near Cape Canaveral retained larvae and recruits on the Florida shelf and might transport them inshore in springtime, although the species is not an obligate estuarine user. Kennedy et al. (1977) found Rock Shrimp in temperatures from 18-27°C off the east coast of Florida. Taylor (1979), in an exploratory trawling survey off North Carolina, found Rock Shrimp in temperatures from 21-24°C. They are a benthic animal and do not generally utilize the water column. Rock Shrimp will likely be impacted by ocean acidification as they utilize molluscs and crustaceans as primary diet items, and they are not known as diet generalists, able to switch to other items. There is little information in the literature with which to estimate the population growth rate of Rock Shrimp. They are highly productive, with population sizes varying annually based on environmental conditions, and they have a small maximum size, a rapid maturation life history characteristic, and a short longevity. Based on these characteristics the species likely has a fairly rapid population growth rate and would respond quickly to population disturbances. Rock Shrimp are not currently undergoing overfishing (NMFS 2017), but there was not enough information available to estimate B/B_{MSY}. No information was found in the literature on genetic stock structure. Rock Shrimp have an entirely oceanic (non-estuarine) life history, living offshore beyond the range of most immediate anthropogenic impacts. The primary stressor on rock shrimp populations is likely fishing pressure, although lionfish predation cannot be ruled out as impacting rock shrimp populations.

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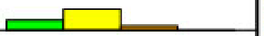
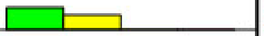
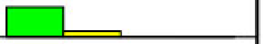
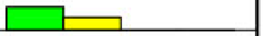
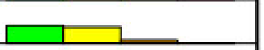
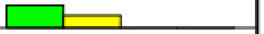
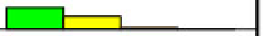
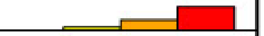
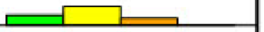
Sandbar Shark − *Carcharhinus plumbeus*

Overall Vulnerability Rank = High 🟧

Biological Sensitivity = Moderate 🟨
Climate Exposure = Very High 🟥

Data Quality = 100% of scores≥ 2

	Carcharhinus plumbeus	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.8	3	
	Prey Specificity	1.4	3	
	Adult Mobility	1.2	2.8	
	Dispersal of Early Life Stages	1.4	2.6	
	Early Life History Survival and Settlement Requirements	1.2	3	
	Complexity in Reproductive Strategy	1.6	2.1	
	Spawning Cycle	2.4	2.6	
	Sensitivity to Temperature	1.4	3	
	Sensitivity to Ocean Acidification	1.4	2.8	
	Population Growth Rate	3.6	2.8	
	Stock Size/Status	2.8	2.4	
	Other Stressors	1.9	2.3	
	Sensitivity Score	Moderate		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	3.9	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	2.4	3	
	Currents	2.5	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

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Sandbar Shark (*Carcharinus plumbeus*)

Overall Climate Vulnerability Rank: High. (1% bootstrap results in Moderate, 89% bootstrap results in High, 10% bootstrap results in Very High.

Climate Exposure: Very High. Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Salinity (3.9). Exposure to all three factors occurs during the life stages. Sandbar Sharks occupy both coastal and offshore waters of the western Atlantic, where they are exposed to these factors.

Biological Sensitivity: Moderate. Two sensitivity attributes scored ≥ 2.5: Population Growth Rate (3.6) and Stock Size/Status (2.8). Sandbar Sharks are a long-lived elasmobranch (31 years) with a delayed age at maturity (13-16 years: Lawler 1976). The annual intrinsic rate of population increase can vary from 2.5% to 11.9% (Sminkey 1994, Sminkey and Musick 1995b); McAuley et al. (2005) estimated a rate of increase of 2.5% for Western Australian Sandbar Sharks in the absence of fishing. The species was determined to be overfished in the southeast United States by a recent stock assessment (SEDAR 2017).

Distributional Vulnerability Rank: High. Sandbar Sharks are habitat generalists that are highly mobile, have free swimming, dispersive early life stages, and enjoy a relatively wide temperature tolerance (Musick et al. 2009).

Directional Effect on the Southeast U.S. Shelf: The directional effect of climate change on Sandbar Shark is estimated to be neutral. The species enjoys a tropical-warm temperate distribution. There is very little information suggesting either negative or positive effects of climate change.

Data Quality: 100% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution: While fishing pressure is the greatest threat to Sandbar Shark populations, climate stressors will likely make it more difficult for recovery from population disturbances caused by overfishing. Some effects of increasing Ocean Acidification are possible, as juvenile Sandbar Shark include a variety of crustaceans in their diets.

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 to Argentina. The species occurs in coastal areas (associated with sandy/muddy flats, bays, estuaries, and harbors), as well as offshore areas near topographic features (e.g. banks, near islands, flat reefs). Juveniles tend to occur in offshore waters as well as in bays and shallow coastal areas (potential nurseries). Sandbar Sharks are diet generalists, with neonates feeding on crabs and other large crustaceans; teleost fishes make up an increasing proportion of diet with increasing age (Ellis and Musick 2007; Medved et al. 1985)). Adults feed on a diverse array of teleosts, rajiids, and cephalopods (Stevens and McLoughlin 1991; Stillwell and Kohler 1993). Sandbar Sharks are highly mobile, with a tagging study finding one individual moving 3000 km (Kohler and Turner 2001). 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 (Springer 1960, Colvocoresses and Musick 1989), with an average litter size of 9 pups per female. Sandbar shark females only give birth every 2.5 years, and pupping is thought to occur in summer months. Sandbar Sharks are found in a range of temperatures, from 16-30°C, with a mean preferred temperature of 27°C (Fishbase.org). Juveniles tend to occur in offshore temperate waters, while larger sharks mainly occur in tropical waters (McAuley et al. 2005). Increasing ocean acidification may potentially affect young Sandbar Sharks, which feed on crabs and other crustaceans, but they likely are able to switch to other diet items if necessary. Sandbar Sharks exhibit a slow population growth rate (2-12%, Sminkey 1994), and life history characteristics of a moderately old maximum age 31 years (Andrews et al. 2011), a large maximum length, an age at maturity of 13-16 years (Sminkey and Musick 1995b), a low fecundity and a low growth coefficient (k = 0.03-0.09: Hale and Barramore 2013, Sminkey and Musick 1995a). 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. IUCN lists the species as vulnerable to overfishing. There was no evidence that genetic variation has been compromised (Musick et al. 2009). Fishing pressure remains the most concerning stressor. Temperature does not appear to impact post-release mortality (e.g. in bycatch scenarios). 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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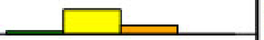
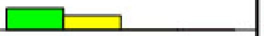
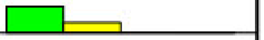
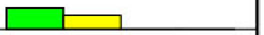
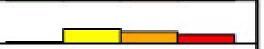
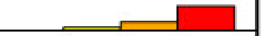
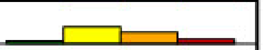
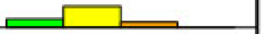
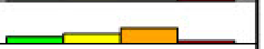
Sand Tiger Shark – *Carcharias taurus*

Overall Vulnerability Rank = High 🟧

Biological Sensitivity = Moderate 🟨
Climate Exposure = Very High 🟥

Data Quality = 92% of scores ≥ 2

Carcharias taurus		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.2	3	
	Prey Specificity	1.4	3	
	Adult Mobility	1.3	2.8	
	Dispersal of Early Life Stages	1.4	2.4	
	Early Life History Survival and Settlement Requirements	1.3	3	
	Complexity in Reproductive Strategy	2.1	2.3	
	Spawning Cycle	2.8	2.6	
	Sensitivity to Temperature	1.1	3	
	Sensitivity to Ocean Acidification	1	3	
	Population Growth Rate	3.6	2.4	
	Stock Size/Status	2.5	1.7	
	Other Stressors	1.9	2.1	
	Sensitivity Score	Moderate		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	3.9	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	2.4	3	
	Currents	2	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

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Sand Tiger Shark (*Carcharius taurus*)

Overall Climate Vulnerability Rank: High. (3% bootstrap results in Moderate, 87% bootstrap results in High, 10% bootstrap results in Very High).

Climate Exposure: Very High. Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Salinity (3.9). Exposure to all three factors occurs during the life stages. Sand Tiger Sharks are found in coastal waters and estuaries.

Biological Sensitivity: Moderate. Three sensitivity attributes scored ≥ 2.5: Spawning Cycle (2.8), Population Growth Rate (3.6), and Stock Size/Status (2.5). Sand Tiger Sharks are a long-lived, slow-growing and late-maturing (age-6 for males, age-9 for females; Carlson et al. 2008) elasmobranch with a limited spawning season (once a year, for 3-4 months) (Castro 2011).

Distributional Vulnerability Rank: High. Three attributes indicated high potential for distribution shift: high adult mobility and widespread dispersal of early life stages, and a low degree of habitat specialization within preferred temperature preferences (McCandless et al. 2007).

Directional Effect on the Southeast U.S. Shelf: The directional effect of climate change on Sand Tiger Shark is estimated to be neutral. Sand Tigers are mobile sharks with a subtropical-warm temperate distribution. There is very little information available that suggests either negative or positive effects of climate change.

Data Quality: 92% of the data quality scores were 2 or greater. Stock Size/Status, an attribute scored as moderate sensitivity, was judged to be data-deficient. This is likely due to lack of biomass estimates, as the species has not been assessed by the SEDAR process.

Climate Effects on Abundance and Distribution: There are no studies on the effects of climate change on Sand Tiger Shark. They consume shelled invertebrates, but are likely able to switch prey types opportunistically, so there would likely be a minimal effect of Ocean Acidification. Estuarine areas used as nursery habitat will possibly be affected by Sea Level Rise as well as rising Sea Surface Temperature.

Life History Synopsis**:** The Sand Tiger Shark is a large coastal shark species found in continental shelf waters of the U. S. Atlantic Ocean from Maine to Florida and throughout the northern Gulf of Mexico (Compagno 1984). Juvenile Sand Tigers use shallow (<15 m) estuarine nursery areas during summer months. Within estuaries the species are habitat generalists, with preferred temperatures ranging from 19-27°C, and salinity values >22 ppt (McCandless et al. 2007). Adult Sand Tiger Sharks inhabit coastal, demersal waters, usually <25 m, and are often found near deep sandy-bottomed low areas or rocky caves, usually in the vicinity of inshore rocky reefs and islands, as well as shipwrecks. They are less frequently found in deeper depths, out to 200 m, on the continental shelf. They usually live near the bottom, but may also move throughout the water column (Compagno 1984). Juvenile Sand Tiger Sharks are opportunistic omnivores, feeding on Summer Flounder, skates, clupeids, Goosefish, sea robin, Scup, Bluefish, Butterfish, eels, and some invertebrates - lobsters, crabs, and squids. Adults have a similar diet, but size classes of prey increase with shark size, and adults are less reliant on estuarine prey species (Collette and Klein-MacPhee 2002; Castro 2011). Adult Sand Tiger Sharks can be highly mobile. Bigelow and Schroeder (1953) reported northward movements along the Atlantic coast as far as the Gulf of Maine, with a return south in the fall. Kohler et al. (1998) reported one individual moving a distance of 641 nautical miles, and also observed seasonal movements up and down the Atlantic coast from tagging data. Sand Tiger Sharks are ovoviviparous, with intrauterine cannibalism (adelphophagy followed by oophagy), so that eventually a single embryo develops per pregnant female (Carlson et al. 2008). Sand Tigers mature late, with females maturing at age-9 and males at age-6. Recent data and observations indicate a reproductive periodicity of every two years. The gestation period is 9-12 months. Sand Tiger Sharks have an estimated size at birth of 95-100 cm. Sand Tiger Sharks are found in temperatures from 12-29°C but prefer temperate/subtropical waters, with the mean observed occurrence at 24.5°C (Fishbase). They begin to return from the northernmost point of their migrations in the fall when seawater temperature begins to decrease. Sand Tiger Sharks may be slightly affected by increased ocean acidification because they prey upon some invertebrate species that may themselves be sensitive to ocean acidification. As they increase in size, however, they likely can switch to a more teleost-dominated diet. Sand Tiger Sharks have a slow maximum intrinsic rate of increase, based on an old maximum age, low natural mortality rate, a low growth coefficient, a low intrinsic rate of population increase, a very large maximum body size, and a late age-at-maturity (Carlson et al. 2008). These life history characteristics would make it difficult for the species to recover successfully from population depletion. Sand Tiger Sharks have not been officially assessed via the SEDAR assessment process. However, they have been prohibited in commercial and recreational catches since 2001. Cortes et al. (2008) observed that even though the stock productivity was low, the species exhibited low susceptibility to longline fisheries, and Carlson et al. (2008) stated after examining trends in size that Sand Tigers were not heavily exploited, and that average size has remained stable over a long time series. They concluded based on these data that a listing of species of concern was unwarranted. There is no information available on stock structure in Sand Tiger Sharks. Other potential stressors for Sand Tiger Sharks include human impacts to estuarine areas used as nursery areas.

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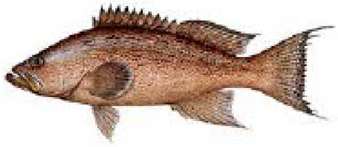
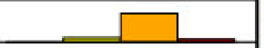
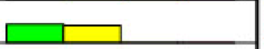
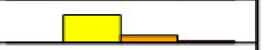
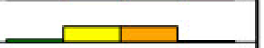
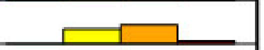
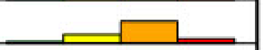
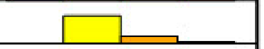
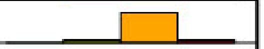
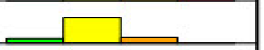
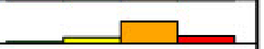
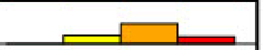
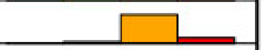
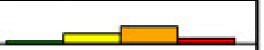


Scamp Grouper – *Mycteroperca phenax*

Overall Vulnerability Rank = Very High 🟥

Biological Sensitivity = High 🟧
Climate Exposure = Very High 🟥

Data Quality = 67% of scores ≥ 2

	Mycteroperca phenax	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	3	3	
	Prey Specificity	1.5	3	
	Adult Mobility	2.3	2.4	
	Dispersal of Early Life Stages	2.4	1.4	
	Early Life History Survival and Settlement Requirements	2.7	1	
	Complexity in Reproductive Strategy	2.8	2.4	
	Spawning Cycle	2.3	3	
	Sensitivity to Temperature	3	2.6	
	Sensitivity to Ocean Acidification	2	2.2	
	Population Growth Rate	3	2.2	
	Stock Size/Status	3	1	
	Other Stressors	3.1	1.5	
	Sensitivity Score	High		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	3.9	3	
	Precipitation	1	0	
	Ocean Acidification	4	2	
	Sea Level Rise	1	0	
	Currents	2.7	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		Very High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Scamp (*Mycteroperca phenax*)

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

Climate Exposure: Very High. Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Salinity (3.9). Exposure to all three factors occurs during the life stages.

Biological Sensitivity: High. Five sensitivity attributes scored ≥ 3.0: Habitat Specificity (3.0), Population Growth Rate (3.0), Sensitivity to Temperature (3.0), Stock Size/Status (3.0) and Other Stressors (3.1). Scamp prefer specific habitat types and could be moderately affected by Ocean Acidification due to inclusion of crustaceans in their diet. The species has a slow Population Growth Rate, and even though scamp matured by age-3, transition from female to male did not occur until between age-7 and age-11 (Lombardi-Carlson et al. 2012).

Distributional Vulnerability Rank: Moderate. Scamp have a moderate potential for distribution shift based on high adult mobility (tagging studies, Wilson and Burns 1996) and widespread dispersal of early life stages, but tempered by specific habitat preferences (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).

Directional Effect on the Southeast U.S. Shelf: The effect of climate change on Scamp on the Southeast U.S. Shelf is estimated to be neutral (with uncertainty reflected in the fact that 40% of scores were negative and 25% were positive). Critical habitats (mangroves and *Oculina* coral reefs) are both likely to be impacted by habitat destruction, but Scamp do occupy a variety of other habitats (low-relief hardbottom and ledges). A primarily piscivorous habit should minimize the effects of ocean acidification.

Data Quality: 67% of the data quality scores were 2 or greater. 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: Scamp may be affected by Ocean Acidification through both diet (some consumption of crustaceans) and their known preference for *Oculina* coral habitat, which has also been degraded by damage from fishing gear. Little is known of salinity tolerances, but Scamp reside in oceanic reef habitat as well as nearshore areas such as jetties and mangrove areas.

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 110 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. The five most frequently occuring food items 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 (Gilmore and Jones 1992, Coleman et al. 2011). Spawning occurs from February through July in the South Atlantic Bight with a peak in March to mid-May (Matheson et al. 1986, Coleman et al. 1996, Lombardi-Carlson et al. 2012). 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 location 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 20-30℃ (Gracia-Lopez 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 (30 years; Harris et al. 2002), moderate natural mortality rate of 0.15, low growth coefficient of 0.09-0.17, a large maximum body size of almost 900 mm (Harris et al. 2002). Age of maturity of females is 1-3 years, but the mean age of transition from female to male ranges from 7.5-11 years (Lombardi-Carlson et al. 2012, Potts unpubl. data). A SEDAR stock assessment for Scamp has not been completed, although one is currently (2021) underway. However, a recent publication (Bacheler and Ballenger 2018) described a decline in mean relative abundance of scamp tof 92% from 1994 to 2016, suggesting the stock has experienced recruitment failure. 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 on juveniles, and exposure to red tide events.

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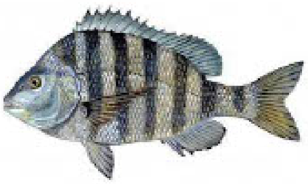
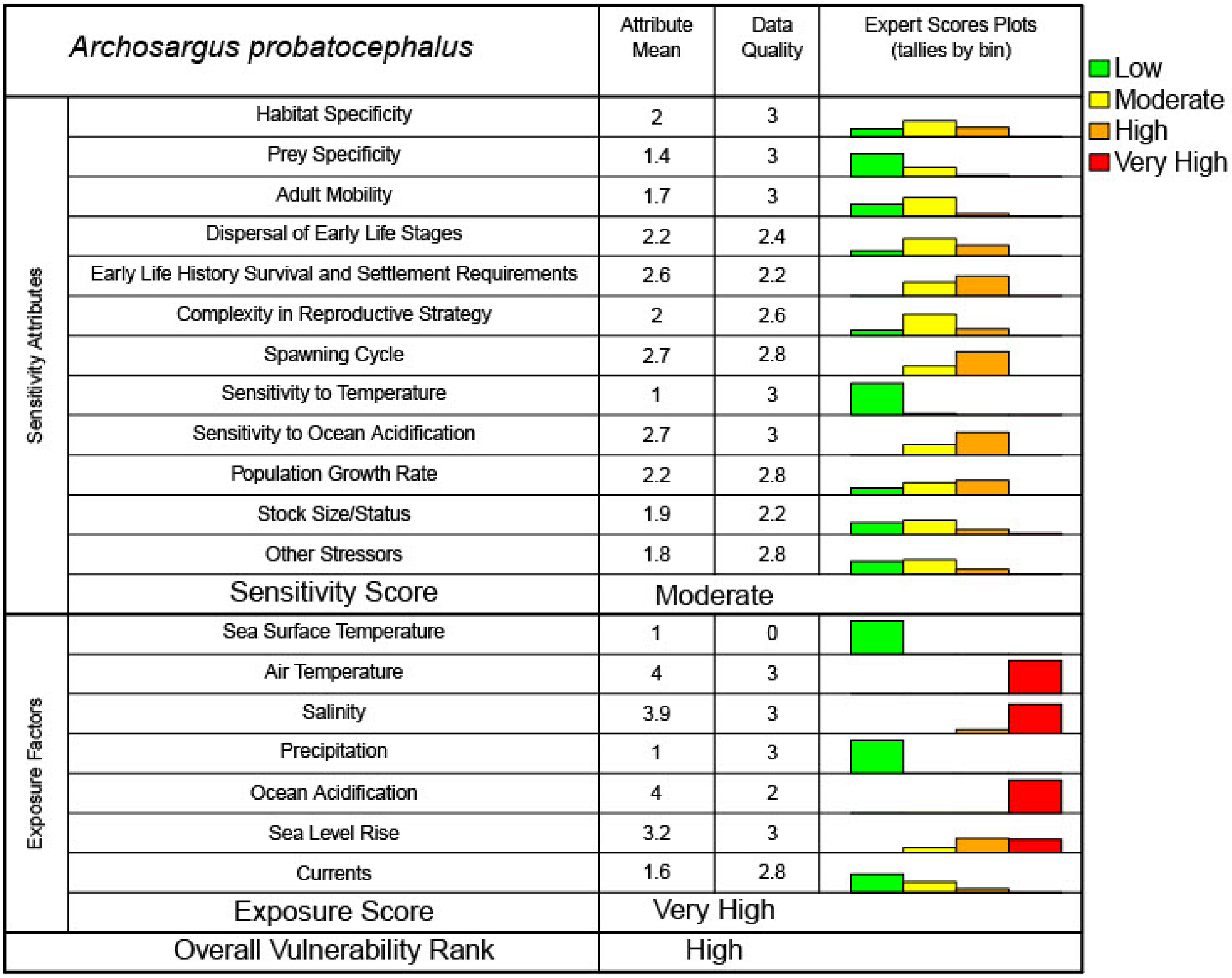


Sheepshead − *Archosargus probatocephalus*

Overall Vulnerability Rank = High 🟧

Biological Sensitivity = Moderate 🟨
Climate Exposure = Very High 🟥

Data Quality = 100% of scores≥ 2



	Archosargus probatocephalus	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2	3	
	Prey Specificity	1.4	3	
	Adult Mobility	1.7	3	
	Dispersal of Early Life Stages	2.2	2.4	
	Early Life History Survival and Settlement Requirements	2.6	2.2	
	Complexity in Reproductive Strategy	2	2.6	
	Spawning Cycle	2.7	2.8	
	Sensitivity to Temperature	1	3	
	Sensitivity to Ocean Acidification	2.7	3	
	Population Growth Rate	2.2	2.8	
	Stock Size/Status	1.9	2.2	
	Other Stressors	1.8	2.8	
	Sensitivity Score	Moderate		
Exposure Factors	Sea Surface Temperature	1	0	
	Air Temperature	4	3	
	Salinity	3.9	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	3.2	3	
	Currents	1.6	2.8	
	Exposure Score	Very High		
Overall Vulnerability Rank		High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Sheepshead (*Archosargus probatocephalus*)

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

Climate Exposure: Very High. Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Salinity (3.9). Sea Level Rise (3.2) was also scored as High exposure for this species known to use seagrass beds and coastal river habitats.

Biological Sensitivity: Moderate. Two sensitivity attributes scored ≥ 2.5: Early Life History Settlement and Survival Requirements (2.6), and Ocean Acidification (2.7). Sheepshead consume many types of hard shelled organisms (bivalve molluscs, brachyurans, barnacles; Carpenter et al. 2014).

Distributional Vulnerability Rank: Moderate. Four sensitivity attributes indicated moderate potential for distribution shift: Sheepshead are habitat generalists that are mobile, have dispersive early life stages, and have low sensitivity to temperature (Carpenter et al. 2014).

Directional Effect on the Southeast U.S. Shelf: The effect of climate change on Sheepshead on the Southeast U.S. Shelf is estimated to be positive. Sheepshead have wide thermal and salinity tolerances and should not be affected by increases in these environmental parameters in the near term. Increasing Ocean Acidification will likely have an effect on Sheepshead as they consume a variety of molluscs and echinoderms, although seagrasses and algae may make up a more significant portion of their diet and they will likely be able to adapt. Increases in sea level may open up additional suitable habitat, although they would be subject to stressors such as pollution, harmful algal blooms, etc., in these areas that might reduce productivity.

Data Quality: 100% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution: Sheepshead have a wide thermal and salinity tolerance, and their preferred habitat is not uncommon, so they likely will respond positively to future climate changes. The species does include a high diversity of invertebrates in its diet, and thus Ocean Acidification could have moderate impact, although they seem capable of adapting by consuming small fish or even algae. Sea Level Rise could have an impact on their preferred habitat, seagrass and coastal rivers.

Life History Synopsis**:** Sheepshead is a structure-oriented fish that occurs throughout the southeast U.S., including the entire Gulf of Mexico and the Atlantic coast as far north as New York (Seyoum et al. 2017; Adams et al. 2018). The Atlantic population is genetically distinct from the two populations occurring in the Gulf of Mexico (Seyoum et al. 2017). Further, age and growth characteristics follow a latitudinal trend in the Atlantic, suggesting that this species may exhibit some level of stock structure at a finer geographic scale (Adams et al. 2018). This latitudinal cline in growth traits also suggests that climate change might impact the population dynamics of regional stocks. Presently, limited data exist on the coastal movements of adult Sheepshead, which makes drawing conclusions about the impact of climate on regional population traits more difficult. Sheepshead is a relatively long-lived species, and individuals greater than 30 years of age have been observed (McDonough et al. 2011; Adams et al. 2018; NCDMF 2019). Larger fish may exceed 500 mm in length and 5 kg in weight. Adults are highly mobile and occupy a wide variety of structured estuarine habitats during the warmer months, including oyster reefs, seagrass, and artificial structures (Lehnert and Allen 2002). They also occur over hard-bottom or artificial structures on the continental shelf throughout the year (Reeves et al. 2018). According to a study in South Carolina, a majority of Sheepshead reach maturity by age-2 (McDonough et al. 2011). Adult Sheepshead develop gonads during the overwintering period and spawning takes place between February and early May, most likely in nearshore habitats (McDonough et al. 2011; Heyman et al. 2019). Individual females spawn throughout a protracted season at a frequency that may range from a few days to several weeks (Render and Wilson, 1992; McDonough *et al*. 2011). Sheepshead are highly fecund, and total annual fecundity might exceed 10 million eggs in a season (McDonough *et al*. 2011). Planktonic eggs were shown to hatch within 28 hours at 23°C (Tucker and Alshuth 1997). The planktonic larval phase lasts between 30 and 40 days (Parsons and Peters 1989; Tucker and Alshuth 1997). Juvenile Sheepshead are thought to primarily inhabit shallow estuarine areas, particularly structured habitats such as seagrass and oyster reefs (Lehnert and Allen 2002; Baillie *et al*. 2015). Upon the onset of cooler temperatures, adult Sheepshead—and presumably juveniles—migrate offshore to overwinter. Due to the presumed temperature dependence of spawning and also nursery habitat use, changing ocean temperatures may have important impacts on the phenology of this species. Further, the reliance of estuarine biogenic habitat, especially at the juvenile stage, might indicate an important source of vulnerability to climate change for Sheepshead. Diet of Sheepshead consists of a wide diversity of invertebrates including barnacles, hydroids, polychaetes, and crabs (Sedberry 1987). Further, evidence suggests that this species is omnivorous and feeds on seagrass and algae to some extent (Cutwa and Turingan 2000). While little is known about the trophic ecology of juveniles, the high prey diversity of adult fish suggests that the diet of sheepshead would be relatively robust to changes in climate. There are aspects of Sheepshead life history that require further research to assess climate sensitivity of this species. For example, the early age at maturity and high fecundity of Sheepshead suggests that potential population growth rate might be robust to climate variation. However, very little is known about interannual variation in recruitment for this species. Further, the nature of Sheepshead spawning aggregations, and how vulnerable they are to fishing activities, is largely unknown.

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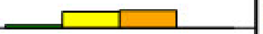
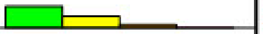
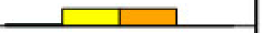
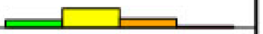
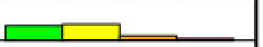
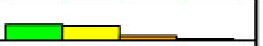
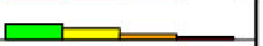
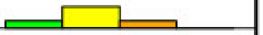
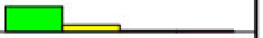
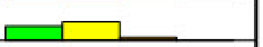
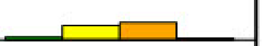
Slippery Dick – *Halichoeres bivittatus*

Overall Vulnerability Rank = Moderate 🟨

Biological Sensitivity = Low 🟩
Climate Exposure = Very High 🟥

Data Quality = 67% of scores ≥ 2

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

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Slippery Dick (*Halichoeres bivittatus*)

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

Climate Exposure: Very High. Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Salinity (4.0).

Biological Sensitivity: Low. No sensitivity attributes scored ≥ 2.5.

Distributional Vulnerability Rank: Moderate. Three attributes indicated limited to moderate potential for distribution shift: behaviorally-limited adult mobility (Slippery Dick are capable of movement but tend to occupy discrete ranges of habitat and remain close to those areas) , moderate early life stage dispersal (planktonic larval duration of 18-27 days, after which the settler buries into the sediment for 3-5 days to complete metamorphosis into the juvenile stage; Sponaugle and Cowen 1997), and relatively moderate to high habitat specialization.

Directional Effect on the Southeast U.S. Shelf: The effect of climate change on Slippery Dick on the Southeast U.S. Shelf is estimated to be positive. There is little information available to assess the directional effect of climate change on Slippery Dick. While North Carolina is the recognized northern extent of their geographic distribution, warming temperatures could make more habitat along the mid-Atlantic or northeast thermally available.

Data Quality: 67% of the data quality scores were 2 or greater. Population Growth Rate and Stock Size/Status were scored as data-deficient, likely because the species is a common reef-dweller and not the subject of fisheries management or any directed fishery.

Climate Effects on Abundance and Distribution: There have been no directed studies of climate effects on abundance and distribution of Slippery Dick. The species may be affected by increasing Ocean Acidification, as their diets consist of a large amount of benthic crustaceans. Their narrow preferred temperature range could lead to decreases in productivity or survival in the face of increasing Ocean Surface Temperature, or cause them to expand their distribution further north in order to find a more habitable temperature.

Life History Synopsis**:** Slippery Dick are a small reef-associated fish species distributed from North Carolina, USA and Bermuda to Rio de Janeiro (Menezes et al. 2003) Brazil, including the Gulf of Mexico and throughout the Caribbean. Juvenile Slippery Dick are most often found on shallow rock reef/ledge habitat to 30 m depth. In St. Croix they were the most abundant species utilizing the back-reef/lagoonal embayment habitat, but were also associated with algal plains and seagrass beds (Mateo and Tobias 2001). Adults utilize similar habitats. Randall (1968) observed Slippery Dick on coral reef, rubble, seagrass habitats and rock jetties and vegetated temperate hardbottom ledge reefs as are common off the Carolinas. Levin and Hay (2002) found Slippery Dick to prefer *Sargassum* over Zonaria seagrass in manipulative experiments. Adult and juvenile diets did not differ significantly, with diets consisting of benthic invertebrates, including gastropods, bivalves and crabs, polychaetes, stomatopod and decapod shrimps, amphipods, echinoderms, and small amounts of larval fishes (Clifton and Motta 1998). Slippery Dick are not limited in mobility physically, but behaviorally they tend to occupy discrete ranges of habitat and do not undergo extensive moves away from these centers. The species is a protogynous hermaphrodite. They spawn almost daily in the more tropical portion of the range (Warner and Robertson 1978), while in North Carolina peak spawning season was determined to be May-June. Spawning is pelagic, and eggs and larvae are planktonic and thus are likely transported to some degree by currents to preferred backreef habitats of lagoonal embayments (Mateo and Tobias 2001). Planktonic larval duration from a study in Barbados was found to be 18-27 days (Sponaugle and Cowen 1997), while Victor (1986) found an average larval duration of 24 days. Settlement occurs proximal to the new moon (maximum amplitude tide). The settler then buries itself into the sand for 3-5 days to complete metamorphosis into a juvenile. After emergence the juvenile can be found swimming close to the substrate. Preferred temperature range is 24.4-28.2°C, with a mean of 27.3°C. Slippery Dick could be affected by ocean acidification given their reliance on shell-forming invertebrates (benthic crustaceans) in their diets. No specific information is available on the productivity of Slippery Dick. However, the life history characteristics of a small maximum size, low maximum age, and a low age-at-maturity, suggest the species' vulnerability to population depletions would be low and the species would be able to recover fairly quickly. Slippery Dick have not been the focus of a stock assessment, nor are they likely to be. Rocha et al. (2005) found the populations throughout the range appear to be well connected except for ones in North Florida and the Gulf of Mexico, which are genetically distinct and may actually represent a different species. Other potential stressors for Slippery Dick include possible coral bleaching, temperate reef degradation, anthropocentric alteration of lagoonal embayment habitat, and lionfish predation.

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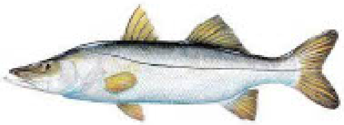
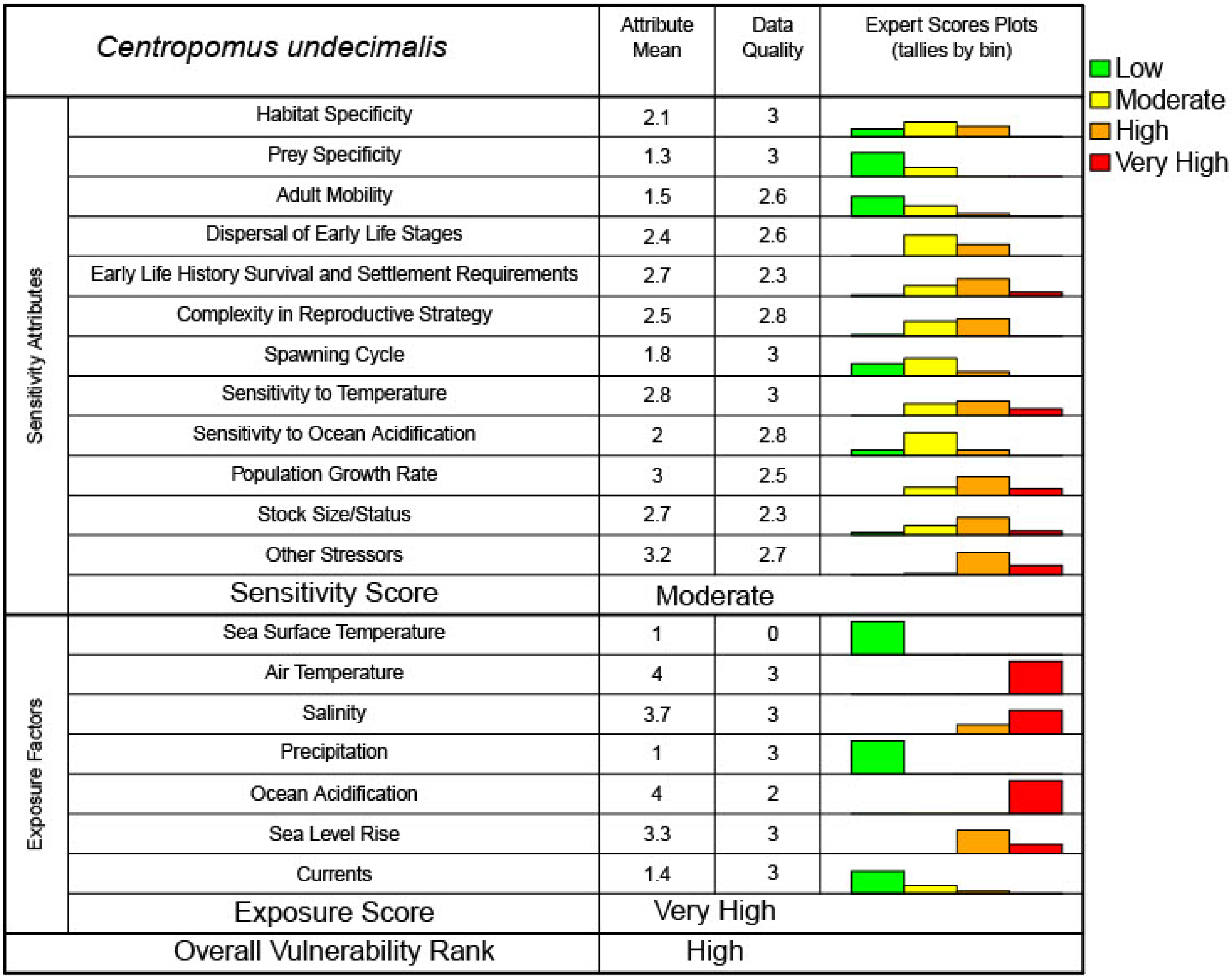
Snook – *Centropomus undecimalis*



Overall Vulnerability Rank = High 🟧

Biological Sensitivity = Moderate 🟨
Climate Exposure = Very High 🟥

Data Quality = 100% of scores≥ 2



	Centropomus undecimalis	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.1	3	
	Prey Specificity	1.3	3	
	Adult Mobility	1.5	2.6	
	Dispersal of Early Life Stages	2.4	2.6	
	Early Life History Survival and Settlement Requirements	2.7	2.3	
	Complexity in Reproductive Strategy	2.5	2.8	
	Spawning Cycle	1.8	3	
	Sensitivity to Temperature	2.8	3	
	Sensitivity to Ocean Acidification	2	2.8	
	Population Growth Rate	3	2.5	
	Stock Size/Status	2.7	2.3	
	Other Stressors	3.2	2.7	
	Sensitivity Score	Moderate		
Exposure Factors	Sea Surface Temperature	1	0	
	Air Temperature	4	3	
	Salinity	3.7	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	3.3	3	
	Currents	1.4	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Snook (*Centropomus undecimalis*)

Overall Climate Vulnerability Rank: High. (44% bootstrap results in High, 56% bootstrap results in Very High).

Climate Exposure: Very High. Three exposure factors scored ≥ 3.5: Air Temperature (4.0), Ocean Acidification (4.0) and Salinity (3.7). Additionally, Sea Level Rise was considered highly sensitive with a score of 3.3. Snook utilize shallow coastal habitats, including mangroves, seagrass beds, and the lower portions of coastal rivers. While they enjoy a wide salinity tolerance, they are sensitive to extremely cold temperatures and have historically suffered cold-stun mortality events.

Biological Sensitivity: Moderate. Six sensitivity attributes scored ≥ 2.5: Other Stressors (3.2), Population Growth Rate (3.0), Early Life History Settlement and Survival Requirements (2.7), Sensitivity to Temperature (2.8), Stock Size/Status (2.7) and Complexity in Reproductive Strategy (2.5). Snook are a relatively late-maturing fish that are a popular target of recreational anglers in Florida. Its use of coastal wetlands makes it vulnerable to anthropogenic habitat alterations and degradations as well as climate impacts such as sea level rise, storm surge, and extreme storms.

Distributional Vulnerability Rank: Moderate. Snook are highly mobile fish with moderately dispersive early life stages, but they have specific preferred habitats and minimum thermal tolerances which might limit range expansion.

Directional Effect on the Southeast U.S. Shelf: The effect of climate change on Snook on the Southeast U.S. Shelf is estimated to be positive with high agreement (90%) among expert scorers. While Snook abundance is concentrated in south Florida, in recent years they have expanded their range as far north as St. Augustine Florida. A euryhaline habit allows them to utilize a wide variety of habitat (riverine, estuarine, marine) and warming seawater temperatures could allow more fish to shift distribution northward, an expansion currently limited by lethal thermal minima (Shafland and Foote 1983). Productivity in the southern portion of their current range is expected to remain stable or increase, as the species has a thermal maximum of 40°C.

Data Quality: 100% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution: Snook are expected to be impacted by increasing ocean acidification through impacts to diet (copepods, crustaceans). Temperature is an environmental variable that will likely have much influence on Snook distribution, as warming could lead to a northward expansion of their range, but cold stun mortality events could occur if sudden cold fronts cause water temperatures to drop below 10°C. Reliance on nursery habitat such as mangroves and riverine areas make Snook more susceptible to anthropogenic habitat alteration as well as sea level rise, storm surge, and extreme storms.

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., including Bermuda, and in the Gulf of Mexico from the Florida Keys north to the Suwannee 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 included pinfish, anchovies, and pink shrimp, whereas diet in rivers was composed 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 was dominated by sunfishes. Adults capitalize on "prey pulses" such as when prey are 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 prey pulses 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-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 Snook on the east coast of Florida extended to Cape Canaveral, whereas fisheries-independent monitoring has shown that in recent years the species range has expanded to at least New Smyrna, possibly St Augustine, but has not yet reached Jacksonville. While Snook normally utilizes coastal shallow habitat (<3 m), they are known to move into warmer (~2°C) sheltered waters at southerly latitudes. At the species range limit, movements into warm spring-fed 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 microcustraceans and larger snook eat shrimp, crayfish and crabs. Snook have a slow population growth rate, as indicated by a large maximum body size (140 cm), a moderately slow growth coefficient (K=0.24), an extended longevity (21 years), a low natural mortality rate (M=0.20) and age at full maturity for females of 7 years (males mature at age-1, but Snook may be transitional from age-1 to age-7) (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 Atlantic coast of Florida, transitional spawning potential ratio (tSPR) = 39%, spawning biomass = 345 mt, SSB was 60% of 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 and Snook are negatively impacted by mosquito control efforts throughout Florida. High freshwater flows in rivers are needed to inundate floodplains to produce prey pulses but these are being diverted to reservoirs. Microplastics could be an issue and harmful algal blooms could negatively impact Snook populations as well.

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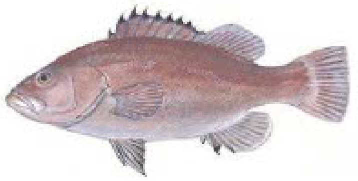
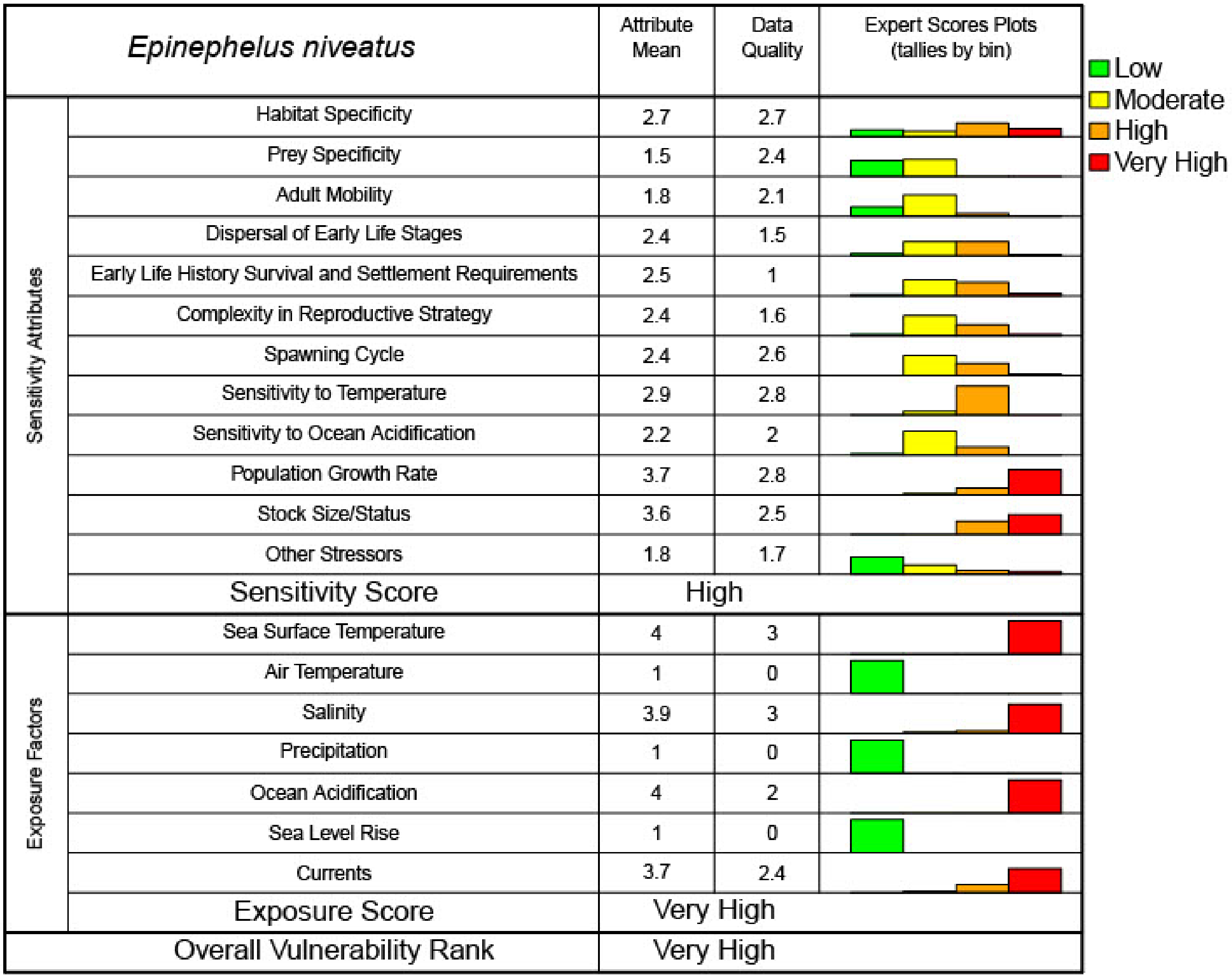
Snowy Grouper − *Epinephelus niveatus*



Overall Vulnerability Rank = Very High 🟥

Biological Sensitivity = High 🟧
Climate Exposure = Very High 🟥

Data Quality = 67% of scores ≥ 2



	Epinephelus niveatus	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.7	2.7	
	Prey Specificity	1.5	2.4	
	Adult Mobility	1.8	2.1	
	Dispersal of Early Life Stages	2.4	1.5	
	Early Life History Survival and Settlement Requirements	2.5	1	
	Complexity in Reproductive Strategy	2.4	1.6	
	Spawning Cycle	2.4	2.6	
	Sensitivity to Temperature	2.9	2.8	
	Sensitivity to Ocean Acidification	2.2	2	
	Population Growth Rate	3.7	2.8	
	Stock Size/Status	3.6	2.5	
	Other Stressors	1.8	1.7	
	Sensitivity Score	High		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	3.9	3	
	Precipitation	1	0	
	Ocean Acidification	4	2	
	Sea Level Rise	1	0	
	Currents	3.7	2.4	
	Exposure Score	Very High		
Overall Vulnerability Rank		Very High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Snowy Grouper (*Hyporthodus niveatus*)

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

Climate Exposure: Very High. Four exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0), Salinity (3.9) and Currents (3.7). Adult Snowy Grouper are a resident of the continental shelf, while juveniles are often seen in shallower inshore areas. Exposure to all these exposure factors occurs during all life stages.

Biological Sensitivity: High. Two sensitivity attributes scored ≥ 3.0: Population Growth Rate (3.7) and Stock Size/Status (3.6). Snowy Grouper have a slow population rate of increase, with fish being long-lived and slow-growing (Matheson and Huntsman 1984), and relatively late-maturing (Wyanski et al. 2000; Kowal 2010, Kolmos et al. 2019). Recent stock assessments have found snowy grouper are overfished (SEDAR 2013).

Distributional Vulnerability Rank: Moderate. Attributes indicating a moderate potential for distribution shift include: adult mobility, potentially widespread early life stage dispersal (larvae in the open ocean for 40-60 days; and a fairly specific preferred habitat type (rocky ledge and cliffs, and areas of eroded limestone, with vertical relief up to 10 m and high currents (Matheson and Huntsman 1984).

Directional Effect on the Southeast U.S. Shelf: The directional effect of climate change on Snowy Grouper on the Southeast U.S. Shelf is estimated to be negative. There may be negative impacts from Ocean Acidification due to inclusion of crustaceans in their diet. Changes in oceanic circulation patterns could impact successful recruitment as well as the delivery of nutrients to their deepwater habitat, affecting productivity.

Data Quality: 67% of the data quality scores were 2 or greater. Sensitivity attributes identified as data-deficient and moderately sensitive were Dispersal of Early Life Stages and Early Life History Settlement and Survival Requirements. Little is known for Snowy Grouper for these attributes beyond the presence of pelagic larvae.

Climate Effects on Abundance and Distribution: There are no directed studies on the impacts of climate on abundance and distribution of Snowy Grouper. The species may be impacted by Ocean Acidification since they include gastropods and crustaceans in their diet. As a continental shelf resident they may be dependent on current oceanic circulation patterns to transport larvae to suitable nursery habitat as well as deliver nutrients to their adult shelf habitat, and potential climate-forced changes to these currents might have negative effects on productivity or survival.

Life History Synopsis**:** Snowy Grouper is a long-lived demersal species ranging in the Atlantic from Canada to southern Brazil, including the Gulf of Mexico and Caribbean (Matheson and Huntsman 1984; Scott and Scott 1988). Snowy Grouper are protogynous hermaphrodites, with the majority maturing first as females at age 4-8 and transitioning to males at age 5-12 (Kolmos et al. 2019). Maximum ages of Snowy Grouper have been reported as high as 56 years (Sanchez et al. 2019). The species is a summer spawner on the outer continental shelf, with post-spawn ovaries found in female fish from March-October (Kolmos et al. 2019). Snowy Grouper prefer hardbottom (natural and artificial), usually in waters 100-400 m deep. Preferred prey include teleost fishes and cephalopods, and juveniles are thought to have the same diet as adults (Bielsa and Labisky 1997). It is unknown whether Snowy Grouper form spawning aggregations, but they are typically found in dense schools, so aggregations are thought to be likely. Pelagic larvae are believed to remain in the open ocean for 40-60 days prior to settlement. While no information is available about settlement requirements, Snowy Grouper larvae may use auditory or chemical cues to find habitat. Stevens et al. (2019) reported maximum length (L_∞) as 1178 mm total length, the von Bertalanffy *K* as 0.09, and the theoretical age at length zero as -2.88 years. SEDAR (2013) concluded that with reported values of $SSB_{2012}/SSB_{MSY} = 0.49$, and $SSB_{2012}/MSST = 0.65$, the Snowy Grouper stock in the South Atlantic is overfished. Trawls operating in inshore reef habitats may pose a threat to juveniles. Given the depth in which adult Snowy Grouper live, they are unlikely to be affected by many human-induced ecological impacts.

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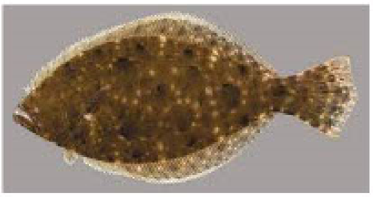
Southern Flounder – *Paralichthys lethostigma*



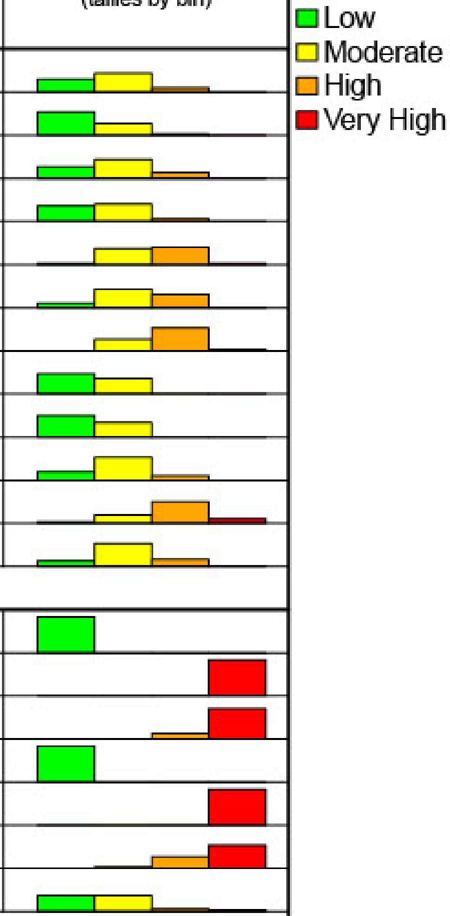
Overall Vulnerability Rank = High 🟧

Biological Sensitivity = Moderate 🟨

Climate Exposure = Very High 🟥

Data Quality = 100% of scores≥ 2

Paralichthys lethostigma		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.8	3	
	Prey Specificity	1.4	3	
	Adult Mobility	1.8	2.8	
	Dispersal of Early Life Stages	1.6	2.8	
	Early Life History Survival and Settlement Requirements	2.5	2.6	
	Complexity in Reproductive Strategy	2.2	2.4	
	Spawning Cycle	2.7	2.6	
	Sensitivity to Temperature	1.4	3	
	Sensitivity to Ocean Acidification	1.4	2.8	
	Population Growth Rate	1.9	2.6	
	Stock Size/Status	2.8	2.2	
	Other Stressors	2	2.4	
	Sensitivity Score	Moderate		
Exposure Factors	Sea Surface Temperature	1	0	
	Air Temperature	4	3	
	Salinity	3.8	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	3.6	3	
	Currents	1.7	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		High		



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Southern Flounder (*Paralichthys lethostigma*)

Overall Climate Vulnerability Rank: High. (2% bootstrap results in Moderate, 98% bootstrap results in High).

Climate Exposure: Very High. Four exposure factors contributed to this score: Salinity (3.8), Ocean Acidification (4.0), Sea Level Rise (3.6) and Air Temperature (4.0). Exposure to all four factors occurs during the life stages. Southern flounder are estuarine-obligate for their first two years, after which they move to shallow coastal, inner shelf habitats. Juveniles consume shrimp and crabs and could be affected indirectly by increasing ocean acidification.

Biological Sensitivity: Moderate. Three sensitivity attributes scored above 2.5: Early Life History Settlement and Survival Requirements (2.5), Complexity in Reproductive Strategy (2.7) and Stock Size/Status (2.8). Southern Flounder depend on a drop in water temperatures to cue their seaward spawning movements, so increasing temperatures could affect timing. The stock is overfished and undergoing overfishing (NCDMF 2012).

Distributional Vulnerability Rank: High. Southern flounder are habitat generalists that are mobile, and have dispersive early life stages.

Directional Effect on the Southeast U.S. Shelf: The effect of climate change on Southern Flounder on the Southeast U.S. Shelf is estimated to be positive with the majority of expert scores in the positive or neutral classification. Adults are distributed from North Carolina southward but broad thermal and salinity tolerances do not rule out either continued productivity in the Southeast U. S. or a more northward range extension. Once Southern Flounder reach 20 mm in size they switch from consuming invertebrates to a primarily piscivorous diet, so the impact of ocean acidification on diet is expected to be lower than for a strict invertivore.

Data Quality: 100% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution: Southern Flounder may be impacted by Ocean Acidification both indirectly (inclusion of invertebrates in diets, primarily in juveniles) and directly (survival of eggs and larvae found to decrease with increasing CO_2 concentrations; Chambers et al. 2014). Changes in Ocean Surface Temperature may affect temperature-dependent timing of offshore spawning movements. Wood and Austin (2009), in a study from the Chesapeake Bay, suggest large-scale climate forcing is responsible for changes in recruitment patterns of Summer Flounder and two other species, indicating that productivity may change with changing climate. Bell et al. (2014) presented evidence that changes in Summer Flounder distribution were attributable to reduced fishing pressure and expanding population rather than changes in temperature.

Life History Synopsis: Southern Flounder are a benthic flatfish species (Paralichthyidae) distributed in the western Atlantic Ocean from the Chesapeake Bay south to the Loxahatchee River, Florida. While absent from the southern Florida peninsula, the species ranges in the Gulf of Mexico from the Caloosahatchee River estuary along the entire U.S. Gulf coast to Mexico (Gilbert 1986, Munroe 2002). Juvenile Southern Flounder remain in estuaries until reaching sexual maturation (~2 years) when they migrate to join adults on the inner continental shelf. Adults can be found on the inner continental shelf as well as riverine, estuarine coastal waters. Preferred substrate is mud or silt (Reagan and Wingo 1985; Munroe 2015). Juvenile Southern Flounder consume a wide variety of invertebrates, primarily amphipods and mysid shrimp, copepods, and blue crab; once reaching 20 mm they prey primarily on small fishes (Reagan and Wingo 1985). Adult diets consist primarily of fishes (fat sleepers, anchovies, menhaden, mullet, sciaenids) but also crustaceans depending on regional location (Burke 1995). Tagging studies indicate large-scale (>50 km) movements of relatively large fish in the fall, presumably associated with offshore winter spawning migrations. Nearly all Southern Flounder that demonstrated large-scale movement were recovered to the south of the system in which they were tagged, suggesting that the spawning activity of fish using North Carolina estuaries may be concentrated mostly off the southeastern U.S. continental shelf. Tagging data suggest limited movement (<1 km) during estuarine residency (Craig et al. 2015, Wenner et al. 1990, Monoghan 1992). Adult Southern Flounder undertake moderate offshore migrations from estuarine and nearshore waters in the fall. These movements are usually triggered by a drop in water temperature of 4-5 °C. Spawning occurs in the southeastern U. S. from November to March on the continental shelf. Laboratory work has shown that eggs hatch after 3 days at 18°C and 30 ppt salinity (Denson and Smith 1997). Pelagic larval duration is 30-60 days, and larvae return to estuarine habitats by passive transport on nearshore/tidal currents from November through April, with peak recruitment in February (Burke et al. 1991). Metamorphosing larvae migrate towards low-salinity headwaters to settle. By day 16 larvae begin settling out of the water column and onto the bottom (Burke et al. 1991). Southern Flounder have a wide temperature tolerance (~5-35°C). The species is also highly euryhaline, withstanding fluctuations in salinities ranging from 0- 35 ppt or more. Southern Flounder may be impacted by increasing acidification of the oceans because juveniles rely on invertebrate species (shrimp, crabs) in their diet. Additionally, survival of eggs and larvae were found to decrease with increasing CO_2 concentrations (Chambers et al. 2014). Population growth rate of Southern Flounder should be moderately fast, making them resilient to population disturbances. This is based on a low maximum age (9, (Takade-Heumacher and Batsavage 2009), a moderate maximum body size (80 cm), a fairly young age at maturity (76% of age-2 fish mature (Midway and Scharf 2012), and a moderate growth coefficient (0.23-0.25). A 2012 assessment by the North Carolina Division of Marine Fisheries found that Southern Flounder, despite improvement in recent years, was still overfished and undergoing overfishing (NCDMF 2012). This was attributed to heavy exploitation of age-1 and age-2 fish, leading to several consecutive years of low recruitment. Clear genetic differences between Gulf and SEUS populations of southern flounder have been found in previous studies, but Wang et al. (2015) found only weak genetic structure among possible SEUS subpopulations, using both mtDNA and AFLP analyses. Southern Flounder are heavily dependent on estuarine and coastal habitats, and thus the potential exists for the species to be seriously impacted by anthropogenic activities such as pollution, changing water flows, and habitat alterations. The species could also be impacted by harmful algal blooms or anthropogenically induced hypoxic events.

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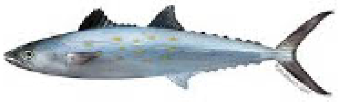
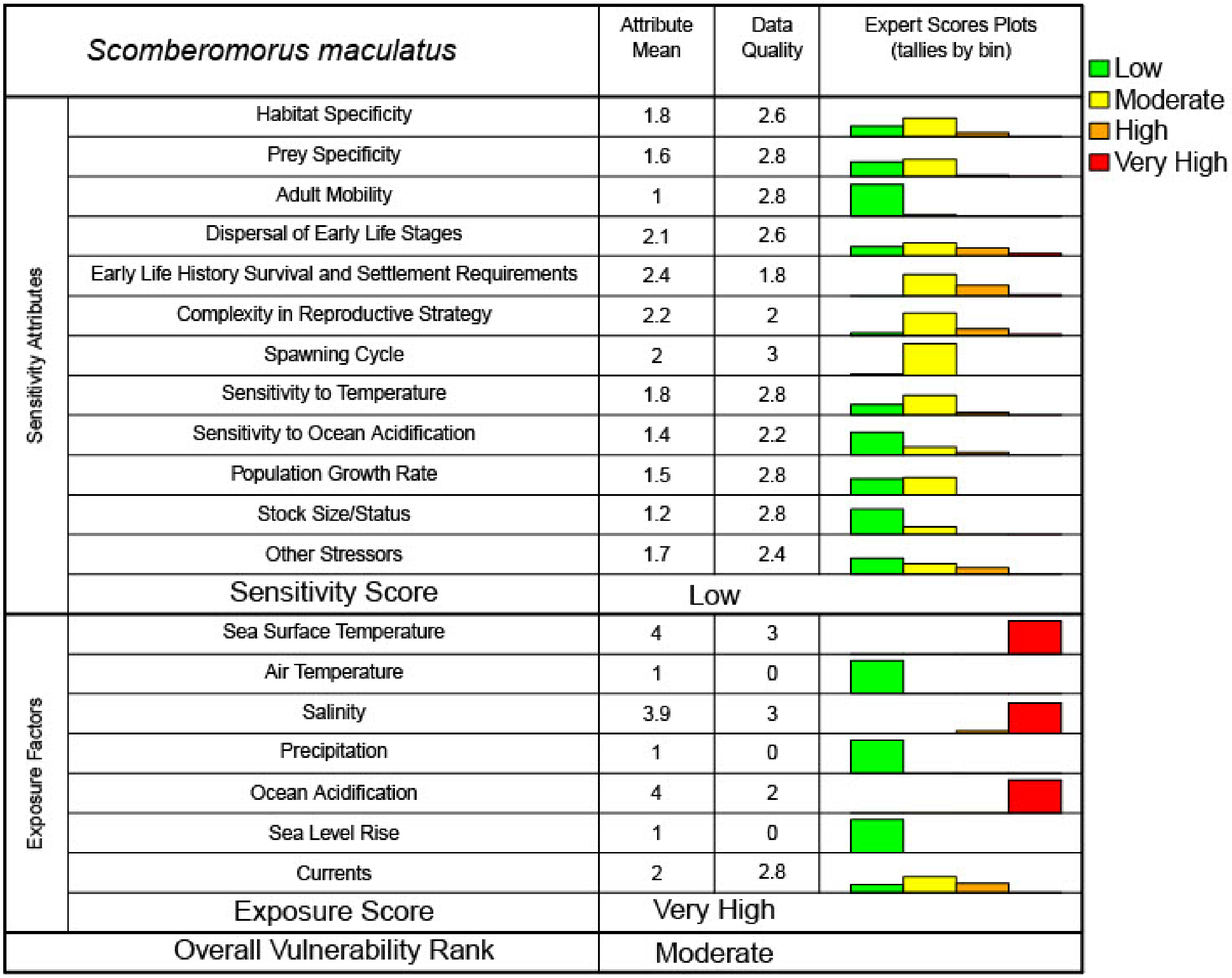
Spanish Mackerel − *Scomberomorus maculatus*



Overall Vulnerability Rank = Moderate 🟨

Biological Sensitivity = Low 🟩
Climate Exposure = Very High 🟥

Data Quality = 92% of scores ≥ 2



	Scomberomorus maculatus	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.8	2.6	
	Prey Specificity	1.6	2.8	
	Adult Mobility	1	2.8	
	Dispersal of Early Life Stages	2.1	2.6	
	Early Life History Survival and Settlement Requirements	2.4	1.8	
	Complexity in Reproductive Strategy	2.2	2	
	Spawning Cycle	2	3	
	Sensitivity to Temperature	1.8	2.8	
	Sensitivity to Ocean Acidification	1.4	2.2	
	Population Growth Rate	1.5	2.8	
	Stock Size/Status	1.2	2.8	
	Other Stressors	1.7	2.4	
	Sensitivity Score	Low		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	3.9	3	
	Precipitation	1	0	
	Ocean Acidification	4	2	
	Sea Level Rise	1	0	
	Currents	2	2.8	
	Exposure Score	Very High		
Overall Vulnerability Rank		Moderate		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Spanish Mackerel (*Scomberomorus maculatus*)

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

Climate Exposure: Very High. Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Salinity (3.9). Exposure to all three factors occurs during the life stages. Spanish Mackerel are a pelagic oceanodromous species found from the continental shelf to shallow coastal waters, often using estuaries as nursery areas.

Biological Sensitivity: Low. No sensitivity attributes scored ≥ 2.5.

Distributional Vulnerability Rank: High. Spanish mackerel are habitat generalists that are highly mobile, and have dispersive early life stages.

Directional Effect in the Southeast U.S. Shelf: The effect of climate change on Spanish Mackerel is estimated to be neutral. Spanish Mackerel have fairly wide thermal and salinity tolerances on the Southeast U.S. Shelf Ecosystem and abundance should remain stable. The effect of ocean acidification is likely to be negligible as Spanish Mackerel are primarily piscivores.

Data Quality: 92% of the data quality scores were 2 or greater. Early Life History Settlement and Survival Requirements scored marginally data-deficient (1.8), notable because that attribute was given the highest sensitivity score by experts (2.4).

Climate Effects on Abundance and Distribution: Spanish Mackerel are typically collected from waters ranging from 21 - 31 °C (70 - 88 °F), and temperature and salinity have been identified as factors controlling their geographic distribution (Berrian and Finian 1977, Gilmore et al. 1977). Increasing Ocean Surface Temperatures along the mid-Atlantic and northeastern U. S. shelf could allow for increases in abundance and distribution in these waters. Ocean Acidification will potentially have direct effects on Spanish Mackerel, such as decreased larval survival and growth (Bromhead et al. 2015), decreased hunting efficiency (Pistevos et al. 2015) and altered settlement or habitat preference cues (Munday et al. 2009). Although Spanish Mackerel are primarily piscivorous, their predominant invertebrate prey are cephalopods, and Wingar (2015) and Kaplan et al. (2013) have shown effects of increasing acidification on cephalopod development and survival.

Life History Synopsis**:** Spanish Mackerel inhabits coastal waters from the Gulf of Maine to the Yucatan Peninsula (Collette et al. 1978; Godcharles and Murphy 1986). During the summer months, they are commonly found as far north as Chesapeake Bay, while in fall and winter, they are most common in waters from North Carolina to central Florida. Larvae are found in surface waters between 19.6–29.8°C with a salinity of 28.3–37.4 ppt, and often utilize estuaries as nursery habitat. Adults 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. Adult Spanish Mackerel 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. Spanish Mackerel are a migratory species that moves north along the Atlantic coast of the United States and north and west along the Gulf of Mexico in the spring and returns in the fall (Collette and Russo 1984). They can also enter estuaries. 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). 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). 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. Spanish Mackerel are rarely reported from waters cooler than 18°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. The diet of Spanish Mackerel should not be affected a great deal by increased ocean acidification as they primarily consume schooling fishes. Spanish Mackerel have a high growth coefficient, an early age-at-maturity, a moderately low longevity, 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. Based on a 2012 SEDAR stock assessment, 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. 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 as well as sea level rise, storm surge, and extreme storms. Adults using nearshore coastal waters could be affected by pollution.

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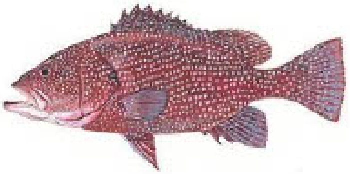
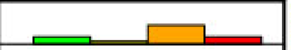
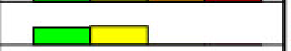
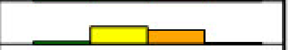
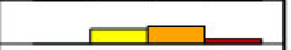
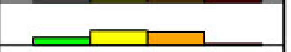
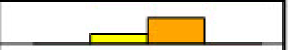
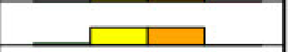
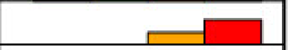
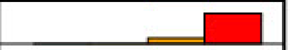
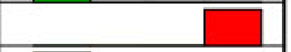
Speckled Hind – *Epinephelus drummondhayi*



Overall Vulnerability Rank = Very High 🟥

Biological Sensitivity = High 🟧
Climate Exposure = Very High 🟥

Data Quality = 58% of scores ≥ 2

Epinephelus drummondhayi		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.7	2.8	
	Prey Specificity	1.5	2.4	
	Adult Mobility	2.1	2.2	
	Dispersal of Early Life Stages	2.4	1.4	
	Early Life History Survival and Settlement Requirements	2.7	0.8	
	Complexity in Reproductive Strategy	2.2	1.9	
	Spawning Cycle	2.6	2.4	
	Sensitivity to Temperature	2.7	2.6	
	Sensitivity to Ocean Acidification	2.4	2	
	Population Growth Rate	3.7	2.3	
	Stock Size/Status	3.8	1.4	
	Other Stressors	1.9	1.6	
	Sensitivity Score	High		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	4	3	
	Precipitation	1	0	
	Ocean Acidification	4	2	
	Sea Level Rise	1	0	
	Currents	3.6	2.6	
	Exposure Score	Very High		
Overall Vulnerability Rank		Very High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Speckled hind (*Epinephelus drummondhayi*)

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

Climate Exposure: Very High. Four exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) Salinity (4.0) and Currents (3.6). Speckled Hind inhabit offshore rocky bottom shelf-edge habitats from 50-200 m depth, where they are exposed to all of these environmental factors.

Biological Sensitivity: High. Two sensitivity attributes scored ≥ 3.0: Population Growth Rate (3.7) and Stock Size/Status (3.8). Speckled Hind are long-lived, slow growing and mature at a late age (a study from the Campeche Banks, Mexico, found female to male sex change occurs between age-7 and age-14; Brule et al. 2000). While Speckled Hind is a species of management concern, it has not been assessed in the South Atlantic due to being data limited.

Distributional Vulnerability Rank: Moderate. Attributes indicating limited to moderate potential for distribution shift are adult mobility (capable of moving, but generally remain close to home habitat) and probable dispersal of early life stages, although little is known from the literature. Preferred habitat type (rocky hardbottom between 50-200 m), while not rare, is fairly specific.

Directional Effect in the Southeast U.S. Shelf: The directional effect of climate change on Speckled Hind on the Southeast U.S. Shelf is estimated to be neutral. There may be negative impacts from Ocean Acidification due to inclusion of crustaceans in their diet. Impacts from increasing sea surface temperature should be negligible given the depths where Speckled Hind occur.

Data Quality: 58% of the data quality scores were 2 or greater. Attributes identified as data-deficient and sensitive to climate change include Early Life History Settlement and Survival Requirements, Dispersal of Early Life Stages, Complexity in Reproductive Strategy, and Stock Size/Status.

Climate Effects on Abundance and Distribution: There have been no directed studies on climate effects on abundance and distribution of Speckled Hind. There may be impacts of Ocean Acidification due to inclusion in the diet of shrimp, crabs, lobsters and molluscs (Sosa-Cordero and Russell 2018). Changes to oceanic currents could affect distribution of pelagic larvae, which remain in the open ocean for 40-60 days (Sosa-Cordero and Russell 2018). Reported preferred temperature range is 17-25℃ (Fishbase), and given the depths Speckled Hind inhabit, it is unlikely that rising Ocean Surface Temperature will have an impact on Speckled Hind in the near future.

Life History Synopsis**:** Speckled Hind is a naturally rare grouper species that is distributed from North Carolina to the Florida Keys and the eastern Gulf of Mexico (Farmer and Karnauskas 2013; Sosa-Cordero and Russell 2018). Adults are extremely selective about habitat and typically are found in areas of very high relief at the continental shelf break in 50-100 m (Farmer and Karnauskas 2013). Juveniles may be found on hard bottom habitat in shallower water (Ross 1988). Speckled Hind are thought to spawn from April to September (Heemstra and Randall 1993). They are protogynous hermaphrodites, maturing as females at age 4-5 and transitioning to males at age 7-14. 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. 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 (Ziskin et al. 2011), with some estimates ranging to 60-80 years (Andrews et al. 2013). Stevens et al. (2019) gave L-infinity as 888 mm, von Bertalanffy *K* as 0.12, and theoretical age at length zero as -1.80 years. Speckled Hind are listed as undergoing overfishing, largely as a result of their assumed-high discard mortality. The stock is likely overfished, but due to a paucity of data, this classification has proven difficult to confirm. Habitat destruction as a result of trawling may impact juvenile Speckled Hind.

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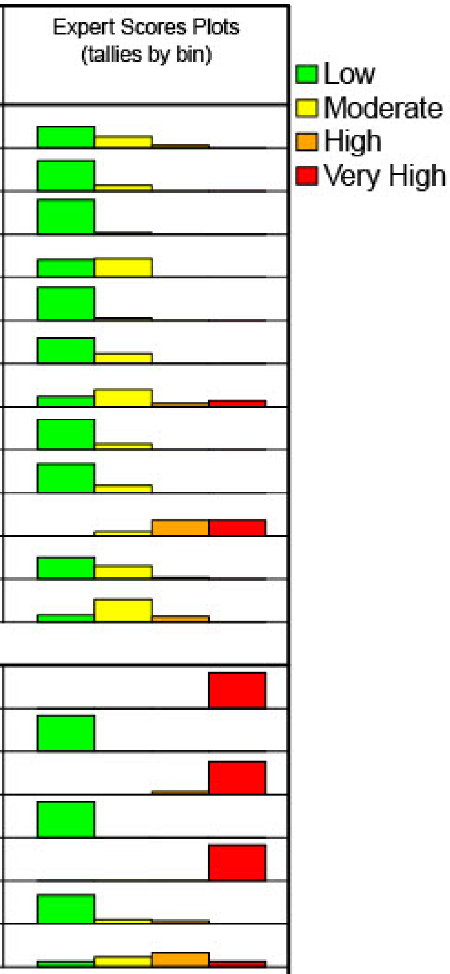
Spiny Dogfish – *Squalus acanthias*

Overall Vulnerability Rank = Moderate 🟨

Biological Sensitivity = Low 🟩
Climate Exposure = Very High 🟥

Data Quality = 100% of scores≥ 2

	Squalus acanthias	Attribute Mean	Data Quality
Sensitivity Attributes	Habitat Specificity	1.5	2.6
	Prey Specificity	1.2	3
	Adult Mobility	1	3
	Dispersal of Early Life Stages	1.5	2.4
	Early Life History Survival and Settlement Requirements	1.1	3
	Complexity in Reproductive Strategy	1.3	2.4
	Spawning Cycle	2.1	2.6
	Sensitivity to Temperature	1.2	3
	Sensitivity to Ocean Acidification	1.2	2.6
	Population Growth Rate	3.3	2.5
	Stock Size/Status	1.4	2.4
	Other Stressors	2	2
	Sensitivity Score	Low	
Exposure Factors	Sea Surface Temperature	4	3
	Air Temperature	1	0
	Salinity	3.9	3
	Precipitation	1	3
	Ocean Acidification	4	2
	Sea Level Rise	1.3	3
	Currents	2.6	3
	Exposure Score	Very High	
Overall Vulnerability Rank		Moderate	



Expert Scores Plots (tallies by bin)

Spiny Dogfish (*Squalus acanthias*)

Overall Climate Vulnerability Rank: Moderate. 97% bootstrap results in Moderate, 3% bootstrap results in High.

Climate Exposure: Very High. Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Salinity (3.9). Spiny Dogfish are an ocean-dwelling elasmobranch inhabiting waters from estuaries and bays out to the continental slope.

Biological Sensitivity: Low. One sensitivity attribute scored ≥ 2.5: Population Growth Rate (3.3). Spiny Dogfish are a long-lived (Bubley et al. 2012), slow-growing and late-maturing (Nammack et al. 1985) species.

Distributional Vulnerability Rank: High. Three attributes indicated high potential for distribution shift: high adult mobility, dispersive free-swimming early life stages,relatively low habitat specialization. Since the species is already widely distributed along most of the eastern seaboard, however, potential areas of expansion are uncertain.

Directional Effect in the Southeast U.S. Shelf: The effect of climate change on Spiny Dogfish is estimated to be negative. Spiny Dogfish inhabit cold-temperate waters (7-12℃) and warming temperatures in the southeast will likely lead to a reduction in productivity or abundance as the distribution shifts northward. There may be minor effects of Ocean Acidification as Spiny Dogfish do include crustaceans and molluscs in their diets, although their habit of opportunistic omnivory will likely limit these impacts.

Data Quality: 100% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution: There are no specific articles on climate effects on Spiny Dogfish in the literature but ocean warming and acidification were found to interact and reduce behavior associated with locating prey of Port Jackson sharks (Pistevos et al.2015) . They are primarily piscivorous and indirect impacts of Ocean Acidification on Spiny Dogfish due to effects on prey are likely to be minimal . They will likely be able to avoid the effects of increasing Ocean Surface Temperature by occupying deeper cooler waters.

Life History Synopsis**:** Spiny Dogfish is a small shark species distributed in temperate and subarctic waters of the continental shelf from Labrador through Florida, but is most abundant from Nova Scotia through Cape Hatteras NC. Juvenile Spiny Dogfish are a habitat generalist, selecting habitats based on prey availability or predators/competitors. They are found in depths of 11-500 m but are most common from 50-150 m and in water temperatures of 8-13 °C. Adult habitat preferences are similar. Primarily epibenthic, they are not known to associate with any particular habitat (McMillan and Morse 1999). While their habitats are not rare, they are known to use coastal estuaries seasonally, and these habitats could be vulnerable to climate-mediated changes. Spiny Dogfish are opportunistic omnivores, feeding on bony fishes (herring, mackerel, hakes, sand lance, menhaden), squid, ctenophores, polychaetes, crustaceans, and molluscs. Adult and juvenile diets are similar with a preference for larger prey as they increase in body size. They are not dependent on any specific shellfish for diets and therefore are not likely to be affected by increasing ocean acidification. Spiny Dogfish are considered highly migratory and are not limited in their mobility, undertaking both north-south migrations as well as inshore-offshore movements. They are known to travel in large dense packs, segregated by size and sex. Trawl studies have also indicated that spiny dogfish undertake daily vertical migrations, likely associated with prey movements. Spiny Dogfish exhibit lecithotrophic viviparity, wherein the mother births a litter of from 2-15 pups (average size 6.6 pups) on offshore wintering grounds after a gestation period of from 18-24 months. Pups are released alive and fully formed, and are usually between 20-33 cm long (Castro 1983). Spiny Dogfish are found in temperatures ranging from 4.2 to 18.7° C (Fishbase), while preferring temperatures from 7 to 12°C, and, in general, are found inshore in summer and in deeper offshore waters in winter. Seasonal migrations are associated with water temperature. Spiny Dogfish migrate north in spring and summer and south in fall and winter when temperatures decrease. Spiny Dogfish have a slow population growth rate, based on a low intrinsic rate of increase (0.034; Smith et al. 1998), an old maximum age (i.e., 35-40 years; Bubley et al. 2012) , a late age-at-maturity (12 yrs females, 6 yrs males; Nammack et al. 1985), a large maximum body size (1.25 m), and a low natural mortality rate (0.09; NEFSC 2003). The species is likely to be slow to recover from population depletions. A 2018 stock assessment update indicates the population is not overfished nor experiencing overfishing. The spawning stock biomass estimate of 235 million pounds is slightly above the SSB threshold of 175 million pounds, while the fishing mortality estimate (0.202) is just below the fishing mortality threshold (0.2439) (ASMFC 2019). Despite remaining above the threshold, biomass has declined in recent years, requiring a significant reduction in 2019-2020 to ensure that overfishing does not occur. The next benchmark stock assessment is currently scheduled for completion in 2022. It is unknown whether genetic variation of Spiny Dogfish has been compromised, but there have been large fluctuations in SSB, and variable recruitment (TRAC 2010). The primary threat to Spiny Dogfish is overfishing, while other potential stressors which could affect coastal or benthic habitat on which spiny dogfish or their prey rely are coastal development, pollution, dredging and bottom trawling (ASMFC 2002).

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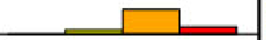
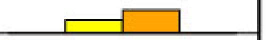
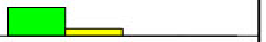
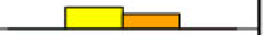
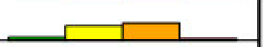
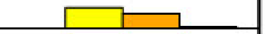
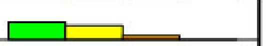
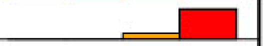
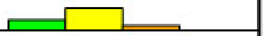
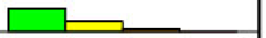
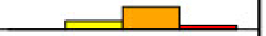
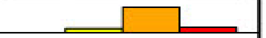
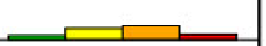
Spiny Lobster – *Panulirus argus*

Overall Vulnerability Rank = Very High 🟥

Biological Sensitivity = High 🟧
Climate Exposure = Very High 🟥

Data Quality = 92% of scores ≥ 2

	Panulirus argus	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	3.1	2.4	
	Prey Specificity	1.3	2.6	
	Adult Mobility	2.6	2.8	
	Dispersal of Early Life Stages	1.2	2.4	
	Early Life History Survival and Settlement Requirements	2.4	1.8	
	Complexity in Reproductive Strategy	2.5	2.2	
	Spawning Cycle	2.5	2.8	
	Sensitivity to Temperature	1.6	2.6	
	Sensitivity to Ocean Acidification	3.8	2.6	
	Population Growth Rate	1.8	2	
	Stock Size/Status	1.4	2.4	
	Other Stressors	2.9	2.4	
	Sensitivity Score	High		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	4	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	3	3	
	Currents	2.6	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		Very High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Caribbean Spiny Lobster (*Panulirus argus*)

Overall Climate Vulnerability Rank: Very High. 15% bootstrap results in [High], 85% bootstrap results in Very High.

Climate Exposure: Very High. Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Salinity (4.0). Exposure to all three factors occurs during the life stages. Larvae float in the oceanic plankton for 6-12 months, juveniles remain in seagrass beds and nearshore coral reefs for several months before becoming subadults and moving to deeper offshore coral reefs.

Biological Sensitivity: High. Two sensitivity attributes scored above 3.0: Habitat Specificity (3.1) and Sensitivity to Ocean Acidification (3.8). Additionally, Other Stressors scored borderline high at 2.9, likely due to exposure to anthropogenic impacts during estuarine residence. Spiny lobster will likely be affected by increasing ocean acidification (Ross & Behringer 2019; Gravinese et al. 2020).

Distributional Vulnerability Rank: Low. While spiny lobster have widely dispersing early life stages, adults are behaviorally limited in their mobility by predator avoidance, and they exhibit relatively high habitat specialization.

Directional Effect in the Southeast U.S. Shelf: The effect of climate change on Caribbean Spiny Lobster on the Southeast U.S. Shelf is estimated to be negative. Research suggests that crustaceans may be negatively impacted by ocean acidification (Mustafa et al. 2015) and chemosensory reception that may affect settlement and microhabitat utilization by larval and juvenile Caribbean Spiny Lobsters is impaired by ocean acidification (Ross & Behringer 2019; Gravinese et al. 2020). Caribbean Spiny Lobster utilize a variety of habitats that are likely to be negatively impacted by climate change (seagrass, mangroves, coral reefs). Larvae spend from 6-12 months in oceanic plankton and are dependent on currents for transport to suitable nursery habitat.

Data Quality: 92% of the data quality scores were 2 or greater. Early Life History Settlement and Survival Requirements was identified as an area with a paucity of data, while being scored as an attribute of moderate sensitivity to climate change.

Climate Effects on Abundance and Distribution: Caribbean Spiny Lobster are shell-forming invertebrates that consume a preponderance of smaller invertebrates (gastropods, bivalves, crustaceans, annelids and echinoderms) and are likely to be negatively affected by Ocean Acidification. However, studies on American Lobster (*Homarus americanus*) found that juvenile shell growth increased under lower aragonite saturation state, indicating there might be positive effects of ocean acidification (Ries et al. 2009), while larval growth decreased, development times increased, and chemosensory reception was impaired under lower pH conditions (Keppel et al. 2012; Ross & Behringer 2019; Gravinese et al. 2020). Growth and survival has been found to be affected at water temperatures exceeding 32 ºC (89.6 ºF) (Witham 1974; Aiken 1980).

Life History Synopsis**:** Caribbean Spiny lobsters occur from North Carolina south to Brazil including Bermuda, the Gulf of Mexico, West Indies and Caribbean. The northernmost extent of the range is North Carolina (Williams 1984). Larvae float in the oceanic plankton for 6-12 months before becoming second stage larvae, which then swim to nearshore shallow nursery grounds, usually seagrass or algal-mat habitats. After metamorphosing into juveniles, they remain in the seagrass beds, mangrove creeks or nearshore coral reefs for several months before becoming subadults and moving offshore to deep reefs, eventually transitioning to reproductively active adults (Alfonso et al. 1991; Hernkind 1980; Marx and Hernkind 1985; Moe 1991). Larvae feed on small snails and crabs. Adults will eat almost anything, and typical prey items include a variety of slow-moving or sedentary organisms including gastropods, bivalves, crustaceans, annelids and echinoderms. Adults are not limited in their mobility but stay in their dens during the day to avoid predators, coming out to forage for food at night. It is likely that predator avoidance may limit their mobility somewhat for periods of time. Caribbean Spiny lobster spawn from April to October in Florida, typically in nearshore and offshore reef fringes and other hardbottom areas (Kanciruk and Hernkind 1976; Lyons et al. 1981). Lyons et al. (1981) reported spawning begins when water temperatures reach 24º C in deeper reef areas. In Florida, there is little evidence that Caribbean Spiny Lobster spawn more than once per year. As water temperatures decrease in fall and winter months both sexes migrate offshore, sometimes in mass migration single file lines that stretch long distances. Eggs are carried by females until they turn brown and hatch, approximately three weeks after fertilization. The pelagic larval duration is one of the longest of any marine animal, and may result in larvae being carried thousands of kilometers by currents before settlement in vegetated areas of algal/seagrass beds or mangrove areas. While occurring from North Carolina to Brazil, they prefer areas where the minimum bottom water temperature is 20°C. The species is likely to be adversely affected by increasing ocean acidification, both directly (exoskeleton contains both chitin and calcium carbonate; growth and chemosensory effects) and indirectly (preferred food items include snails, crabs, clams and urchins). There is limited information available about the population growth rate of Caribbean Spiny Lobster. Based on moderate to high vulnerability imparted by a low growth coefficient, a moderate natural mortality rate, and a medium longevity, it is likely that this species would have some difficulty recovering from population disturbances. Caribbean Spiny Lobster stocks in the SEUS were not found to be overfished by a SEDAR stock assessment (SEDAR 2010). IUCN considers the species to be data deficient but stable in Florida. There is no information available about genetic variation. Mangrove and seagrass bed nursery areas are subject to coastal development disturbances such as propeller damage from boats, dredging/filling, agricultural runoff, and wastewater discharge. Changing climate effects such as sea level rise, storm surge, and extreme storms could also impact these habitats. Sponge loss negatively impacted lobster populations (Behringer and Hart 2017). Another major threat to species is PAV1 disease, affecting one in four recruits in the Caribbean. Climate change impacts (increased temperature, salinity, ocean acidification) could decrease the ability of Spiny Lobster to select appropriate shelter and avoid diseased conspecifics, thereby leading to a greater chance of infection (Ross and Behringer 2019).

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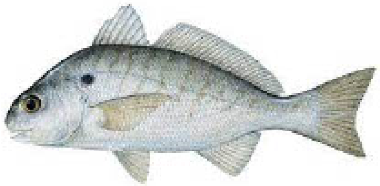
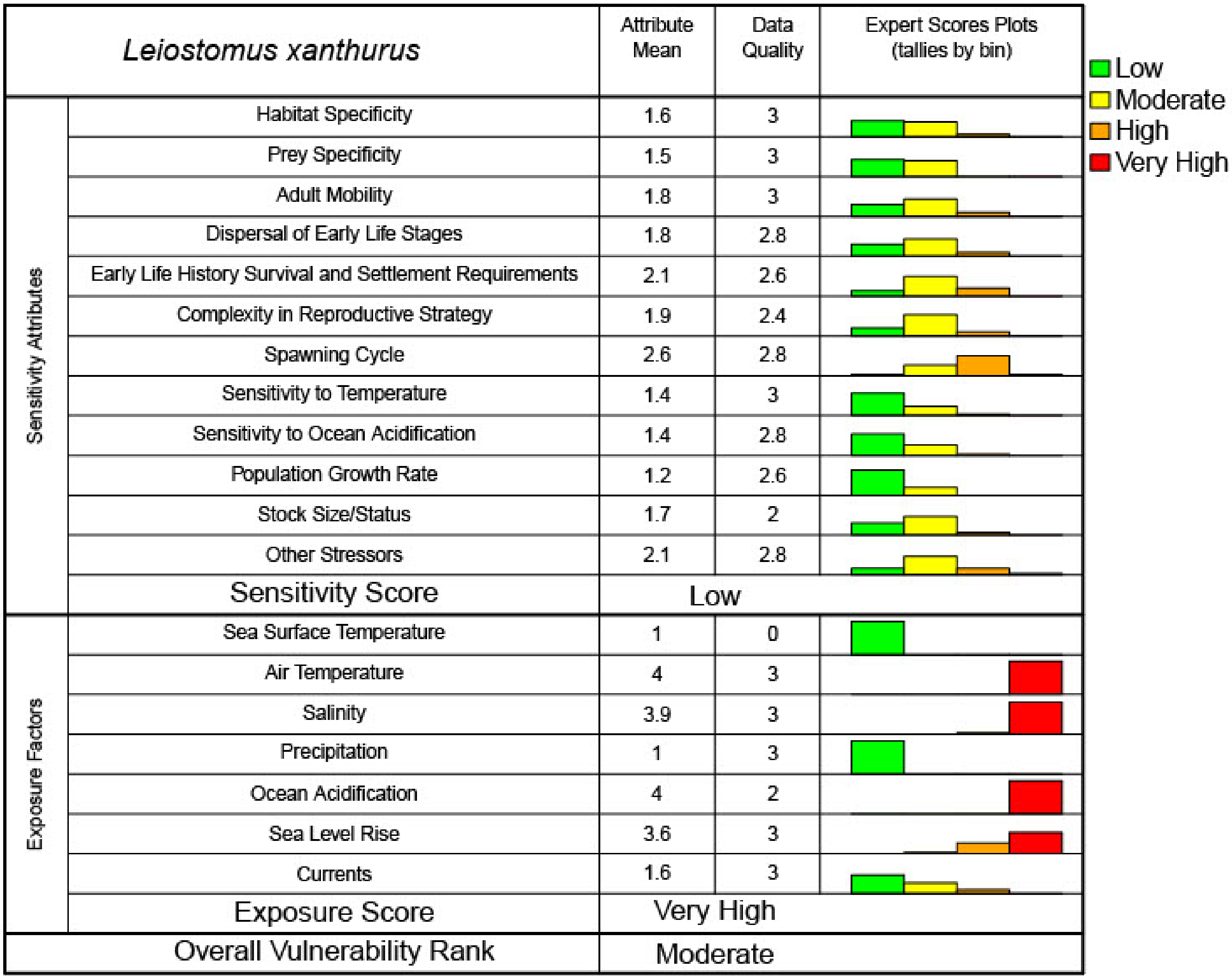
Spot – *Leiostomus xanthurus*



Overall Vulnerability Rank = Moderate 🟨

Biological Sensitivity = Low 🟩
Climate Exposure = Very High 🟥

Data Quality = 100% of scores≥ 2



	Leiostomus xanthurus	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.6	3	
	Prey Specificity	1.5	3	
	Adult Mobility	1.8	3	
	Dispersal of Early Life Stages	1.8	2.8	
	Early Life History Survival and Settlement Requirements	2.1	2.6	
	Complexity in Reproductive Strategy	1.9	2.4	
	Spawning Cycle	2.6	2.8	
	Sensitivity to Temperature	1.4	3	
	Sensitivity to Ocean Acidification	1.4	2.8	
	Population Growth Rate	1.2	2.6	
	Stock Size/Status	1.7	2	
	Other Stressors	2.1	2.8	
	Sensitivity Score	Low		
Exposure Factors	Sea Surface Temperature	1	0	
	Air Temperature	4	3	
	Salinity	3.9	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	3.6	3	
	Currents	1.6	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		Moderate		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Spot (*Leistomus xanthurus*)

Overall Climate Vulnerability Rank: Moderate. 100% bootstrap results in Moderate.

Climate Exposure: Very High. Four exposure factors scored ≥ 3.5: Salinity (3.9), Ocean Acidification (4.0), Air Temperature (4.0) and Sea Level rise (3.6). Spot are found in coastal and shelf waters as adults, and juveniles utilize seagrass meadows and tidal creeks as nursery habitat (Spitsbergen and Wolff 1976).

Biological Sensitivity: Low. A single sensitivity attribute scored ≥2.5: Spawning cycle (2.6).

Distributional Vulnerability Rank: High. Spot are habitat generalists that are mobile, and have dispersive early life stages. Additionally, they have a fairly broad temperature tolerance.

Directional Effect in the Southeast U.S. Shelf: The effect of climate change on Spot on the Southeast U.S. Shelf is estimated to be neutral. Spot are widely distributed along the eastern seaboard and warming temperatures may increase suitable habitat in northern areas, although changes to oceanic circulation patterns may affect recruitment from southern areas to the mid-Atlantic. There may be minor effects of ocean acidification from the inclusion of invertebrates in their diet.

Data Quality: 100% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution: Spot consume amphipods, gastropods, copepods, and other invertebrates, thus negative effects of Ocean Acidification on these prey items could have consequences for fitness of Spot. Increasing Ocean Surface Temperature could affect survival of larval and juvenile Spot, as upper thermal tolerance is approximately 35°C. Another temperature effect could be delayed movement of adult Spot offshore to spawn because the normal cue of falling temperature is delayed. Sea Level Rise, storm surge, and extreme storms could potentially affect the seagrass beds, marsh creeks and tidal creeks that postlarval and juvenile Spot prefer. Perez (1969) found that Spot were more active under lab conditions when salinity changed quickly, suggesting that they may actively try to avoid areas where salinity levels change rapidly.

Life History Synopsis**:** Spot is a small demersal member of the drum family (Sciaenidae) distributed in the western Atlantic Ocean from Cape Cod, MA along the east coast (absent south Florida and Florida Keys), and throughout the Gulf of Mexico to Campeche, Mexico (Bigelow and Schroeder 1953). Juvenile Spot prefer shallow water (<8m) areas with fine sediment (Stickney and Cuenco 1982; Phillips et al. 1989). Seagrass meadows and tidal creeks are important nursery habitats for postlarval and juvenile Spot (Spitsbergen and Wolff 1976). These areas are common, but are increasingly impacted by anthropogenic activities (urbanization, pollution). Adult Spot occur in coastal and shelf waters in late summer and fall in order to spawn, and are found in estuaries and bays during other portions of the year. They are tolerant of salinities of up to 60 ppt, but are less abundant in low salinity areas. Semi-demersal, they are usually found over sandy and muddy bottoms. They are generalists that utilize both physical (sandy bottoms) and biological (seagrasses in estuaries),but are not entirely dependent on these habitats. Juvenile Spot are benthic, grazing generalists (Hodson et al. 1981a; Woodward 1981; Livingston 1982) that forage effectively regardless of substrate type, though they prefer sand or mud (Ross 1980; Cowan and Birdsong 1985). Juvenile Spot from 40-99 mm feed on ostracods, copepods, isopods, amphipods, small gastropods, foraminifera, calanoids and nematodes (Philips et al. 1989). Adults are generalist as well, consuming zooplankton and benthic infauna, with polychaetes most frequently observed in gut contents. Other prey types included amphipods, cumaceans, gastropods, nematodes, mysids, and copepods (Chao and Musick 1977). Adult Spot do not have limited mobility, and undertake movements from inshore habitat to spawning habitat on the continental shelf. Spot spawn in relatively deep waters on the continental shelf, usually from October through March, peaking in December and January, in the southeastern U. S. (Townsend 1956; Lewis and Judy 1983; Warlen and Chester 1985). Hettler and Powell (1981) reported spawning occurred at 17-25ºC in the laboratory. Spot embryos did not develop at temperatures below 14ºC; however, larvae can tolerate temperatures as low as 5 ºC. (Hettler and Clements 1978). Eggs hatch approximately 24 hrs after fertilization, and larvae, with limited swimming ability, drift with currents for up to 40-50 days (Powell and Gordy 1980; Warlen and Chester 1985). The Gulf Stream likely aids larval Spot transport to estuaries and bays along the southeast US Atlantic coast. Larval Spot aggregate at estuary openings during ingress (Phillips et al. 1989), and predator increases during this period could potentially affect the stock. Settlement occurs near the openings of estuaries and bays (Phillips et al. 1989), likely triggered by reductions in salinity. Changes to freshwater flow (either increases or decreases) may affect successful settlement in these locations. Spot have a preferred temperature range of 13.2 -26.37 ℃, mean 24 ℃. The species has a limited depth distribution, but moves to deeper waters during winter months. No diel vertical migrations are noted in the literature. Spot prey upon many invertebrates, including pteropods, copepods, and bivalves, making them potentially vulnerable to an increasingly acidic ocean. Spot have a high population growth rate, as indicated by a low maximum age (6 years), a moderately high natural mortality rate (0.54), a small maximum body size (36 cm), a young age at maturity (2-3 years, Hales and van Den Avyle 1989). The species should be quick to recover from population disturbances. Despite being a major component of trawl catches in the southeast, there is no stock status survey in any state except for Virginia. Trends in abundance, both juvenile and adult, have fluctuated with no apparent trends for the last several years. There are no indications of significant population declines, and IUCN lists Spot as a species of least concern. There are no studies in the literature indicating genetic structure in populations on the east coast. Because of their use of estuaries and bays, anthropogenic and urbanization impacts to these habitats (coastal development, dredging, hypoxia, reduction in seagrass beds, changes in timing and volume of freshwater inputs) are a major potential stressor.

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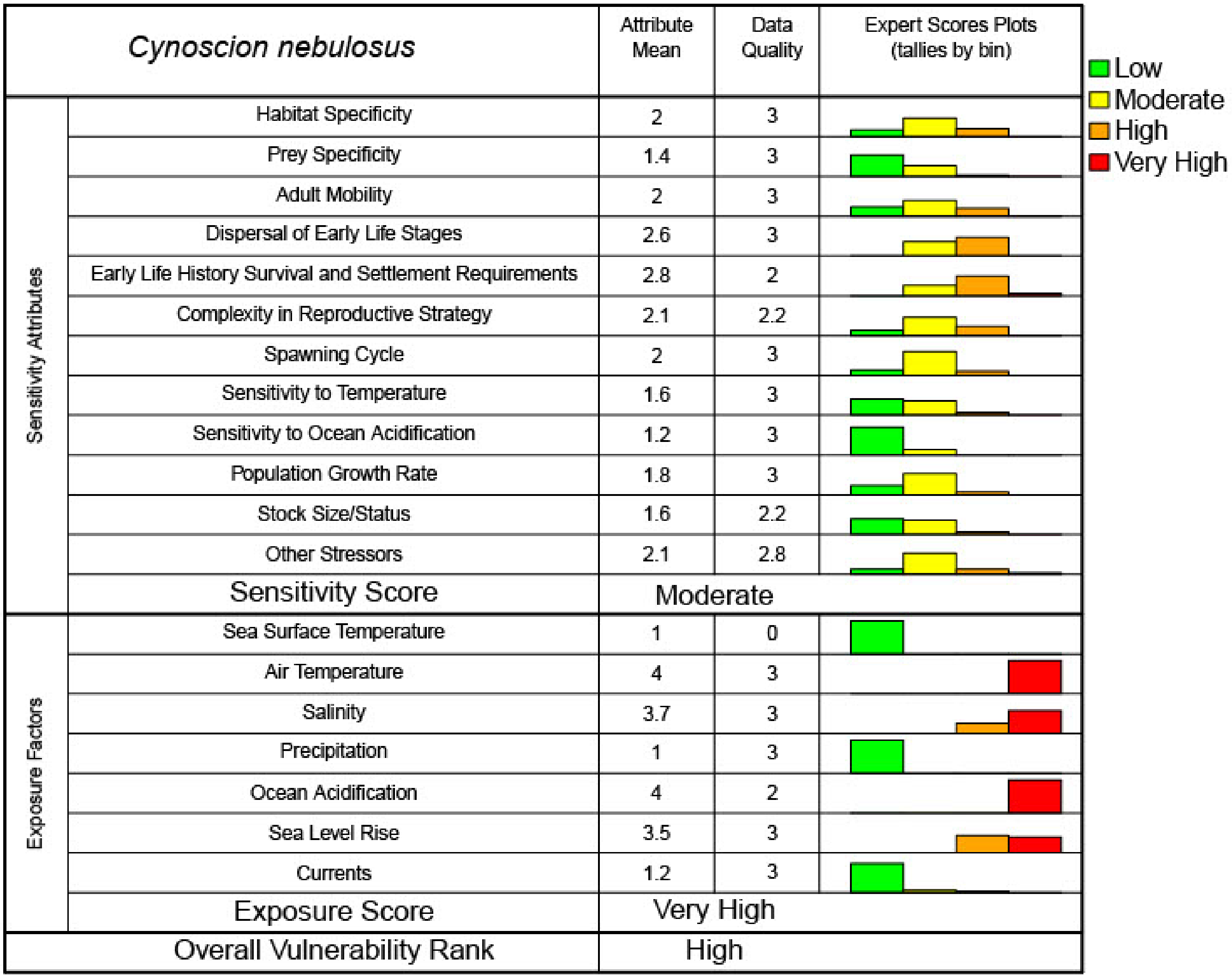
Spotted Seatrout − *Cynoscion nebulosus*

Overall Vulnerability Rank = High 🟧

Biological Sensitivity = Moderate 🟨
Climate Exposure = Very High 🟥

Data Quality = 100% of scores≥ 2



	Cynoscion nebulosus	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2	3	
	Prey Specificity	1.4	3	
	Adult Mobility	2	3	
	Dispersal of Early Life Stages	2.6	3	
	Early Life History Survival and Settlement Requirements	2.8	2	
	Complexity in Reproductive Strategy	2.1	2.2	
	Spawning Cycle	2	3	
	Sensitivity to Temperature	1.6	3	
	Sensitivity to Ocean Acidification	1.2	3	
	Population Growth Rate	1.8	3	
	Stock Size/Status	1.6	2.2	
	Other Stressors	2.1	2.8	
	Sensitivity Score	Moderate		
Exposure Factors	Sea Surface Temperature	1	0	
	Air Temperature	4	3	
	Salinity	3.7	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	3.5	3	
	Currents	1.2	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Spotted Seatrout (*Cynoscion nebulosus*)

Overall Climate Vulnerability Rank: High. 28% bootstrap results in Moderate, 72% bootstrap results in High.

Climate Exposure: Very High. Four exposure factors scored ≥ 3.5: Air Temperature (4.0), Ocean Acidification (4.0), Salinity (3.7), and Sea Level Rise (3.5). Spotted seatrout use a range of habitats including lower estuarine areas, nearshore beach areas, and seagrass beds, where they are exposed to all of these environmental exposure factors.

Biological Sensitivity: Moderate. Two sensitivity attributes scored ≥: 2.5: Early Life History Settlement and Survival Requirements (2.8) and Dispersal of Early Life Stages (2.6). Spotted Seatrout spawning outside of estuaries require tidal stream transport of propagules into estuaries to ensure survival.

Distributional Vulnerability Rank: Moderate**.** Spotted Seatrout adults are mobile, though they tend to remain close to their natal bays. Early life stages are either spawned in estuaries or in nearshore waters close to estuarine nursery areas. Preferred habitat type is not rare but they do require estuaries or seagrass beds for nursery function.

Directional Effect in the Southeast U.S. Shelf: The effect of climate change on Spotted Seatrout on the Southeast U.S. Shelf is estimated to be positive. Adult distribution may extend northwards as warming continues, but the magnitude of this extension could be minimal. The effect of ocean acidification is expected to be moderate due to a reliance on crustaceans in their diet. Sea Level Rise effects on obligate estuarine habitat could have an impact on Spotted Seatrout.

Data Quality: 100% of the data quality scores were 2 or greater. Early Life History Settlement and Survival Requirements was scored as marginally data-deficient (2.0), likely due to lack of information about environmental cues necessary to stimulate settlement.

Climate Effects on Abundance and Distribution: There is little information about the effect of climate on Spotted Seatrout productivity or distribution. Working in the Gulf of Mexico, Froeschke and Froeschke (2011) found that distribution of juvenile Spotted Seatrout was strongly associated with temperature and salinity, as was timing of spawning (Brown-Peterson et al. 2002). Kearney et al. (2015) found minimal decreases in Spotted Seatrout habitat availability under several climate change scenarios in Florida Bay.

Life History Synopsis**:** Spotted Seatrout are distributed in the western Atlantic from Long Island, New York south along the U.S. coast and throughout the Gulf of Mexico except for Cuba (Chao et al. 2015). Center of abundance for the species is the Gulf of Mexico and Florida waters (Pearson 1929). Larvae prefer seagrass habitats and utilize shallow marsh habitats in South Carolina, North Carolina, and Georgia in areas lacking submerged aquatic vegetation. Juveniles utilize seagrass beds as major habitat, and are also found less commonly in unvegetated backwaters (McMichael and Peters 1989). Juvenile habitat is widespread but subject to anthropogenic disturbance. Adults use a range of habitats including lower estuarine areas, seagrass beds, live oyster beds, creek mouths, drop-offs and structures (jetties, stumps, pilings, wrecks) and nearshore beach areas (Chao et al. 2015). These habitats are not rare but are often disturbed. Spotted Seatrout larval diet is dominated by copepods and bivalve larvae. Juveniles eat mysids and caridean shrimp; larger juveniles eat penaeid shrimp and fishes, including killifish and mojarras (Able and Fahay 2010, Johnson and Seaman 1986). Adults are opportunistic carnivores, consuming primarily fishes, including anchovies, pinfish, mullets, silvesides, and croakers. Diet may vary by season and habitat (Able and Fahay 2010, Chao et al 2015, Johnson and Seaman 1986). Spotted Seatrout are highly mobile, yet behaviorally they will stay in or within close proximity to their natal bay for their entire life (Bortone et al. 2003). A Georgia tagging study of adult Spotted Seatrout found the average distance moved to be <9km, although one fish travelled 105 km (Music 1981). Spotted Seatrout spawn in nearshore and estuarine waters (Mercer 1984) and spawning is strongly influenced by temperature and salinity, with optimal conditions to be 25-28°C and 30-35 ppt (Johnson and Seaman 1986). If spawning occurs outside the estuaries then those eggs and larvae are dependent upon tidal stream transport into the estuary for survival. They are multiple spawners with an average time between spawns of 3.6 days (Brown-Peterson et al. 1988). This indicates that a female may spawn 9 - 60 times in a spawning season, and release 3 - 20 million eggs annually (Murphy et al. 1999). Eggs can be either demersal or pelagic depending upon salinity (Powell et al. 2004), and hatch approximately 18 hours after fertilization (Holt et al. 1985). The larvae persist for 20 days before metamorphosis (Holt et al. 1985). Settlement is into estuarine habitats, and preferred larval/juvenile food (copepods, bivalve larvae) should be readily available year round (Holt and Holt 2000). Optimum temperatures are 15-27 °C for adult Spotted Seatrout (Tabb 1958) and 23-33 °C for larvae (Taniguchi 1980). Spotted Seatrout usually avoid winter kills due to cold temperatures by migrating to deeper, warmer channels or offshore waters, usually when air temperatures drop below 7 °C for 12 hours or more, remaining in these deeper areas through the winter (Tabb 1958). Spotted Seatrout also migrate in response to high water temperatures in hot summer months, with Mahood (1974) reporting that they seek out colder, deeper waters in the warmest summer months. Spotted Seatrout will likely be affected by increased ocean acidification as crustaceans are a primary diet item of juveniles. Spotted Seatrout have a moderate population growth rate, with a young age-at- maturity and a medium longevity indicating resilience to population disturbance, but a low growth coefficient, large maximum size and a moderately high natural mortality rate indicating some vulnerability. The species is likely to have some difficulties responding to depletion events. A stock assessment for Spotted Seatrout in Mississippi waters found the species to be overfished (Leaf et al. 2016), but extreme caution should be used before applying these results to east coast populations. Due to the non-migratory habits of the species, there has been no coast-wide assessment of the species by the ASMFC, rather the individual states conduct age-structured assessments. Significant genetic variation was found between populations in different Atlantic coast estuaries (O'Donnell et al 2014). Other potential stressors include anthropogenic effects on estuarine habitat, where they spend the majority of their life cycle. Harmful algal blooms have a major impact on populations in the Gulf of Mexico, but could also impact east coast fish as well.

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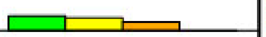
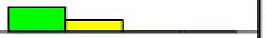
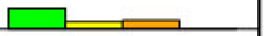
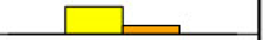
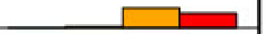
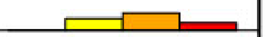
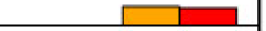
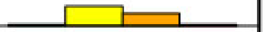
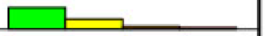
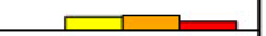
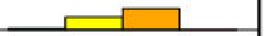
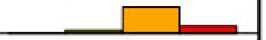
Striped Bass − *Morone saxatilis*

Overall Vulnerability Rank = Very High 🟥

Biological Sensitivity = High 🟧
Climate Exposure = Very High 🟥

Data Quality = 92% of scores ≥ 2

Morone saxatilis		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.8	3	
	Prey Specificity	1.3	3	
	Adult Mobility	1.7	2.6	
	Dispersal of Early Life Stages	2.2	3	
	Early Life History Survival and Settlement Requirements	3.4	3	
	Complexity in Reproductive Strategy	2.9	3	
	Spawning Cycle	3.5	3	
	Sensitivity to Temperature	2.4	2.6	
	Sensitivity to Ocean Acidification	1.6	1.8	
	Population Growth Rate	2.9	2.8	
	Stock Size/Status	2.6	2.6	
	Other Stressors	3.1	2.8	
	Sensitivity Score	High		
Exposure Factors	Sea Surface Temperature	1	0	
	Air Temperature	4	3	
	Salinity	3.5	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	3.3	3	
	Currents	1.5	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		Very High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

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Striped Bass (*Morone saxitilis*)

Overall Climate Vulnerability Rank: Very High. 32% bootstrap results in High, 68% bootstrap results in Very High.

Climate Exposure: Very High. Three exposure factors contributed to this score: Salinity (3.5), Ocean Acidification (4.0) and Air Temperature (4.0). Exposure to all three factors occurs during the life stages. Striped bass are found in inshore coastal, estuarine and riverine habitats.

Biological Sensitivity: High. Three sensitivity attributes scored ≥ 3.0: Early Life History Settlement and Survival Requirements (3.4), Spawning Cycle (3.5) and Other Stressors (3.1). Striped bass are exposed to a variety of anthropogenic stressors during their estuarine/riverine residence. The species is anadromous, spawning once a year. There is some evidence that larval and year class success is tied to the amount of zooplankton available, which could be temperature-linked.

Distributional Vulnerability Rank: High. Three attributes indicated high potential for distribution shift: high adult mobility, moderately dispersive early life stages, and low habitat specialization.

Directional Effect in the Southeast U.S. Shelf: The effect of climate change on Striped Bass on the Southeast U.S. Shelf is overwhelmingly projected to be negative (85% of scores). Increasing temperatures could lead to reduced levels of dissolved oxygen in water, decreasing the amount of suitable habitat (Coutant 1990). Higher water temperatures may also affect the timing of striped bass spawning, creating a mismatch between the production of young striped bass and their food. Higher precipitation may increase recruitment, but combined with sea-level rise may decrease the salt wedge area where Striped Bass spawn. Additionally there may be some effects of ocean acidification on the invertebrates consumed by Striped Bass.

Data Quality: 92% of the data quality scores were 2 or greater. Sensitivity to Ocean Acidification was scored as low (1.8) but was not determined to be a highly sensitive attribute, likely because although striped bass may include shelled organisms in their diet, experts believed they are enough of a diet generalist to overcome any effects of ocean acidification on their diet.

Climate Effects on Abundance and Distribution: Several studies indicated that Striped Bass productivity can be influenced by climate change. Increasing summer temperatures resulted in a reduction of habitat in Chesapeake Bay (Coutant and Benson 1990). North and Houde (2003) found that egg and larval distribution relative to the position of the salt wedge and estuarine turbidity maximum affected recruitment success. In a study from the Hudson River, O'Connor et al. (2012) found that larval abundance was greater in years with higher freshwater inputs. These studies indicate that temperature, precipitation, and sea-level rise have the potential to affect population productivity of Striped Bass.

Life History Synopsis: Striped Bass is a large (historically to 125-140 pounds; Smith 1907, Franklin 2007, NEFSC 2019), long-lived (maximum documented age to 31 years, Appleman et al. 2019, ASMFC 2019, NEFSC 2019), anadromous, schooling species which ranges from the Canadian maritimes (Dadswell et al. 2020) and along the US Atlantic Coast from Maine to the St. Johns River on the Florida east coast (Lee et al. 1980; Fay et al. 1983; Hill et al. 1989; Rago 1992; Rulifson and Dadswell 1995; Richards and Rago 1999; Laney 2009; ASMFC 2019). It also occurs in northern rivers of the Gulf of Mexico. The Atlantic slope riverine populations south of the Roanoke River in North Carolina are largely non-migratory (Boreman and Lewis 1987, Laney 2009, ASMFC 2019), therefore this account focuses on the anadromous Atlantic Migratory Striped Bass stock which has historically used the Atlantic Ocean from New England to North Carolina as summer, fall and winter habitat (Boreman and Lewis 1987, Laney 2009, Callihan et al. 2014, Callihan et al. 2015, ASMFC 2019). Juvenile anadromous Striped Bass are found within their natal rivers and gradually move downstream to estuaries and shoreward during their first summer, using a wide variety of microhabitats (see review in Laney 2009; also see Callihan et al. 2014). The major estuaries serving as primary nursery areas for the Atlantic migratory stock are Long Island Sound, Delaware Bay, Chesapeake Bay and Albemarle and Pamlico Sounds (Laney 2009, Callihan et al. 2015, ASMFC 2019). Sexually mature Striped Bass (45 % of females mature by age 6, 100% by age 9; ASMFC 2019) home to natal rivers to spawn in the spring (Callihan et al. 2015, Harris and Hightower 2017), using temperature as a primary cue for migration and spawning, therefore they may be particularly susceptible to respond to increasing temperatures resulting from climate change (Najjar et al. 2000, Najjar et al. 2010, Aldous et al. 2011, Peer and Miller 2014, Dugdale et al. 2018). Estuarine habitats in which adult Striped Bass reside either permanently or temporarily are already subject to "habitat squeeze" (Coutant and Benson 1987) as a result of their relatively narrow dissolved oxygen and temperature preferences, and their habitats are projected to shrink even further under projected climate changes, but could expand further north as the growing season there lengthens (Limburg et al. 2016, Dugdale et al. 2018, Lleras 2019). Analysis also suggests that some diseases, as well as harmful algal blooms, may also increase Striped Bass mortality as temperatures increase (Vogelbein et al. 2009). Striped Bass are more generalist predators as adults but undergo ontogenetic shifts from eating zooplankton, mysids, chironomids and amphipods as juveniles (Cooper et al. 1998), to benthic crustaceans, cephalopods, and fishes as adults (Manooch 1973, Nelson et al. 2003, Rudershausen et al. 2005, Nelson et al. 2006, Howe et al. 2008, Overton et al. 2008, Murphy 2018, Staudinger et al. 2020). Striped Bass in the northern portions of their range prey on federally-listed Atlantic Salmon (Andrews et al. 2019a-b, Daniels et al. 2019), and may derive a significant portion of their diet and nutrition from benthic prey, including American Lobster (Murphy 2018), invasive Green Crab (Davidsohn 2019) and Sand Lance (Staudinger et al. 2020). Striped Bass may not be affected by increased ocean acidification given that their riverine, estuarine and oceanic diet is largely piscivorous (Manooch 1973, Rudershausen et al. 2005, Nelson et al. 2006, Overton et al. 2008). However, they sometimes prey more heavily, especially seasonally (Nelson et al. 2006), upon crustacean species (i.e., American Lobster and Blue Crab juveniles, see Nelson et al. 2006, Overton et al 2008) for which additional research on the impacts of ocean acidification is needed (Whiteley 2011, Jewett et al. 2020). There is some evidence that ocean acidification can affect shell quality in chitinous shells (Mustafa et al. 2015), and thus might affect the productivity of Striped Bass. Migratory Striped Bass have complex reproduction and spawn in their natal rivers throughout their Atlantic Coast geographic range from the Roanoke and Chowan rivers in North Carolina north to the St. Lawrence River in spring and summer months (Hocutt et al. 1990, Laney 2009, Callahan et al. 2015, Harris and Hightower 2017). Ecological criteria for spawning include: appropriate riverine flow regimes at various temporal scales, including suitable spring attractant flows for stocks migrating to inland spawning grounds, and suitable flows during the spawning season; appropriate temperature regimes; appropriate dissolved oxygen levels; absence of adverse levels of turbidity, pH, and contaminants; and suitable prey resources for larval Striped Bass (Laney 2009). The spawning season occurs in spring and is thought to be triggered by a combination of photoperiod and water temperature. Mature adults usually initiate spawning runs when temperatures reach 14.4°C, exhibit peak activity from 15.8 to 19.4°C, and cease spawning at 20 to 25°C (Laney 2009). Other temperature extremes reported for spawning were a low of 10°C (IEM 1973) and a high of 26.5°C (Combs 1979). Adults are highly mobile, yet also show high spawning site fidelity (philopatry; McBride 2014) to their natal rivers (Callahan et al. 2015) as well as site fidelity to summer feeding areas in New England and the Mid-Atlantic (Ng et al. 2007; Mather et al. 2009, 2010; Murphy 2018). Smaller (400-500 mm total length) Striped Bass migrated hundreds of kilometers along the Atlantic Ocean coast, but ceased their mobile lifestyle in summer when they used a relatively localized area for foraging and returned to those same foraging areas in subsequent years (Mather et al. 2009, Pautzke et al. 2010). Striped Bass occur across a fairly wide range of temperatures within their geographic distribution. The thermal niche of adult striped bass, based on a literature review by Coutant (1985), was 18 to 25°C (centered around 20°C). Because Striped Bass, especially those living in the US south Atlantic portion of the range, are already close to thermal and DO limits, they are particularly susceptible to increasing temperatures (Lleras 2019), and projections indicated that their spawning window and habitat conditions may change significantly in the future (Muhling et al. 2019, Nack et al. 2019). Striped Bass had a higher "exploratory potential index" than any other east coast anadromous species assessed by Massiot-Granier et al. (2018). This metric estimates the capacity of a species to initiate the act of leaving their current habitats and to reach new ones outside of their range, at a rate fast enough to keep pace with climate change. Survival of striped bass eggs to hatching is primarily associated with relatively narrow tolerances to certain physicochemical factors, including temperature, dissolved oxygen, and current velocity. Development rates of striped bass egg and larval stages are temperature dependent, within the range of temperatures at which the stages remain viable. Appropriate dissolved oxygen levels and current velocities are also required to maintain viability and keep egg and early larval stages in suspension (Cooper and Polgar 1981, Laney 2009). Several authors documented hatching at approximately 48 hours after fertilization at a temperature of 18°C (Bain and Bain 1982). In other studies, hatching time varied from 29 hr at 22°C to 80 hr at 11°C (Pearson 1938; Raney 1952; Mansueti 1958; Hardy 1978). Larvae drift downstream with riverine currents. Timing of larval drift and arrival in locations where prey are abundant is highly dependent on river discharge and other factors (Rulifson 1984). Striped Bass have variable individual growth rates, depending on season, age, sex, competition and location (NEFSC 2019). A 35-inch (889 mm) striped bass can be 7 to 15 years of age and a 10-pound (4.5 kg)

Striped Bass can be 6 to 16 years old (ODU CQFE 2020). They also have an old maximum age (i.e., 31 years; Laney 2009, ASMFC 2019, NEFSC 2019), historically low natural mortality rate after age 6 (NEFSC 2019), and large maximum body size. Since 1997, the arrival of mycobacteriosis disease in the Chesapeake Bay has increased the natural mortality rate (NEFSC 2019). Female SSB for Atlantic striped bass in 2017 was 68,476 mt, below the SSB threshold, indicating the stock is overfished (ASMFC 2019). F in 2017 was 0.307, above the F threshold, indicating the stock is experiencing overfishing (ASMFC 2019). Although the ASMFC assesses coastal Atlantic migratory Striped Bass as a single stock, the species homes to natal rivers for spawning and in actuality consists of multiple biological populations, with 50-80 percent of the ocean migrants historically derived from the Chesapeake Bay ecosystem, and lesser percentages from the Hudson River, Delaware River and Roanoke Rivers (Laney 2009, Callihan et al. 2015, Harris and Hightower 2017, ASMFC 2019). Other potential stressors for Atlantic migratory Striped Bass include increased likelihood of disease and harmful algal blooms under climate change, as well as potential increased susceptibility to environmental contaminants due to extreme storm events. Vogelbein et al. (2009) note that "Climatic factors that increase the frequency and duration of hypoxic episodes may exacerbate mycobacteriosis [in Striped Bass]. A future climate that includes warmer summers with weak summer winds, highly variable precipitation, and rising sea level with increasing salinities in the [Chesapeake] Bay may have such an effect." Groner et al. (2018) conclude that "…these fish are living at their maximum thermal tolerance and that this is driving increased disease and mortality…." The complex interactions between climate change and pollutants may also be particularly problematic for species living at the edge of their physiological tolerance range where acclimation capacity may be limited (Noyes et al. 2009).

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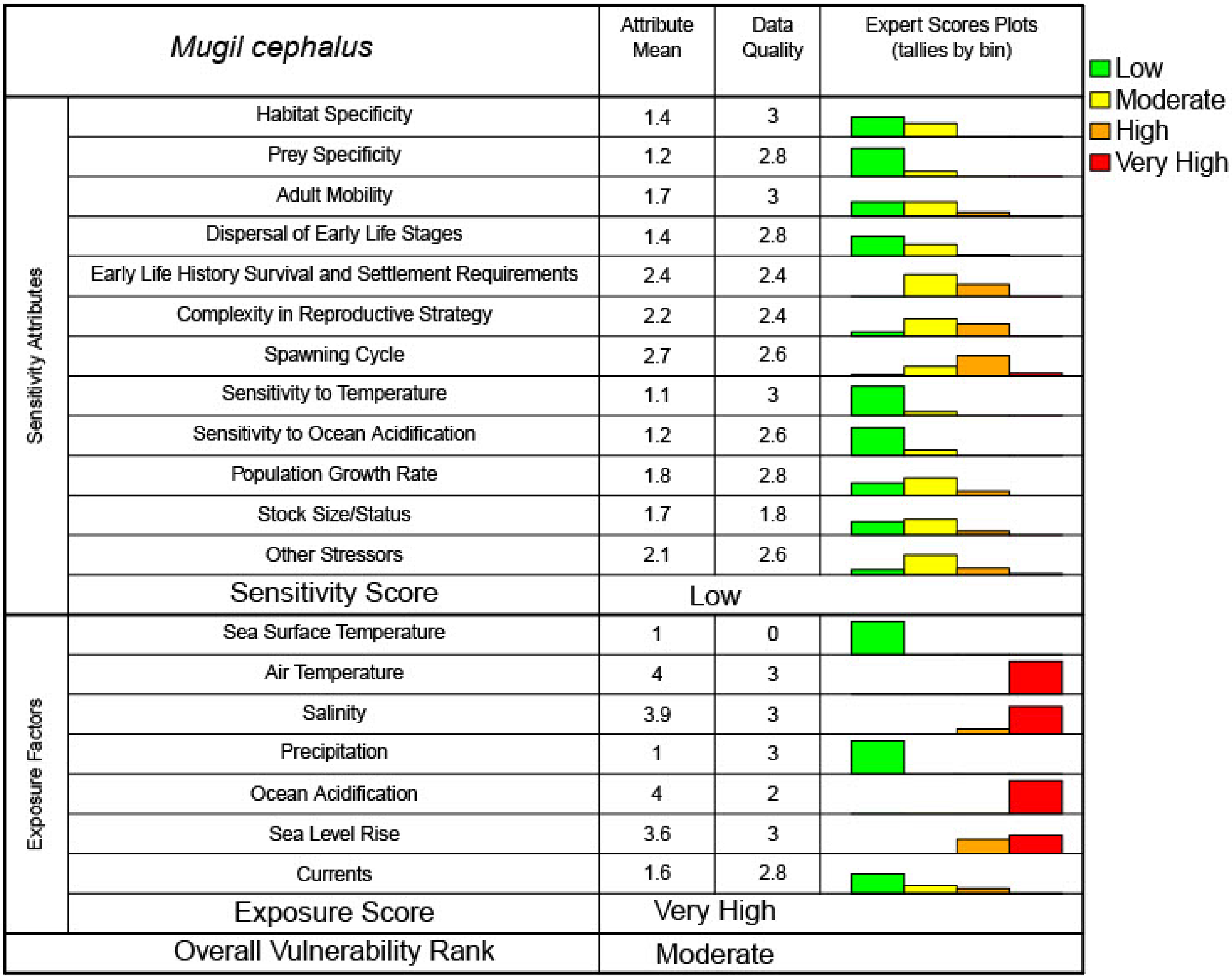
Striped Mullet − *Mugil cephalus*

Overall Vulnerability Rank = Moderate 🟨

Biological Sensitivity = Low 🟩
Climate Exposure = Very High 🟥

Data Quality = 92% of scores ≥ 2



	Mugil cephalus	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.4	3	
	Prey Specificity	1.2	2.8	
	Adult Mobility	1.7	3	
	Dispersal of Early Life Stages	1.4	2.8	
	Early Life History Survival and Settlement Requirements	2.4	2.4	
	Complexity in Reproductive Strategy	2.2	2.4	
	Spawning Cycle	2.7	2.6	
	Sensitivity to Temperature	1.1	3	
	Sensitivity to Ocean Acidification	1.2	2.6	
	Population Growth Rate	1.8	2.8	
	Stock Size/Status	1.7	1.8	
	Other Stressors	2.1	2.6	
	Sensitivity Score	Low		
Exposure Factors	Sea Surface Temperature	1	0	
	Air Temperature	4	3	
	Salinity	3.9	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	3.6	3	
	Currents	1.6	2.8	
	Exposure Score	Very High		
Overall Vulnerability Rank		Moderate		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Striped Mullet (*Mugil cephalus*)

Overall Climate Vulnerability Rank: Moderate. (91% bootstrap results in Moderate, 9% bootstrap results in High).

Climate Exposure: Very High. Four exposure factors contributed to this score: Salinity (3.9), Ocean Acidification (4.0), Air Temperature (4.0) and Sea Level Rise (3.6). Striped Mullet are a euryhaline, pelagic nearshore species. It inhabits inshore marine waters, estuaries, lagoons and rivers where it is exposed to all these exposure factors.

Biological Sensitivity: Low. One sensitivity attribute scored ≥ 2.5: Spawning Cycle (2.7).Striped mullet form large aggregations prior to migrating offshore to spawning grounds. These aggregations are temporally and spatially predictable and subject to exploitation. Spawning season is discrete (2-3 months).

Distributional Vulnerability Rank: High. Three attributes indicated high potential for distribution shift: high adult mobility, dispersive early life stages, and relatively low habitat specialization.

Directional Effect on the Southeast U.S. Shelf: The effect of climate change on Striped Mullet on the Southeast U.S. Shelf is estimated to be positive, although there are conflicting signals. Striped Mullet are eurythermal and euryhaline, and abundance will likely increase as a result of warming temperatures in regions outside the southeast. However, Lan et al. (2017) showed that increasing sea surface temperatures, interacting with excessive levels of exploitation, led to successive years of poor recruitment of Striped Mullet populations in Taiwan. Timing of migrations to offshore spawning grounds is thought to be cued by falling water temperatures and could be delayed by warming. Changes in existing oceanic circulation could have an effect on Striped Mullet populations (the Pacific Decadal Oscillation affected sea surface temperature variations, affecting the abundance and migration behavior of Grey Mullet in the Taiwan Strait; Lan et al. 2017).The effect of ocean acidification is likely to be negligible.

Data Quality: 92% of the data quality scores were 2 or greater. Stock Size/Status was determined to be data-deficient. North Carolina populations were determined to have declined from 2011 to 2018 (NCDMF 2018), and the state is in the process of updating its stock assessment.

Climate Effects on Abundance and Distribution: Striped Mullet are distributed along the entire eastern seaboard and up into Canada, occupying a wide range of salinities and temperatures. Critical thermal maxima for juvenile mullet ranged from 30°C to 42.5°C (Major 1978), indicating that Striped Mullet may be forced to move from the southern end of their range in the face of elevated temperatures. There is some evidence from the literature that productivity could be inhibited by extreme temperatures, as growth of embryos was retarded at temperatures above 26°C (Kou et al.1974). Dindo et al. (1978) reported that initiation of rapid gonadal growth and reproductive readiness was linked to shortening photoperiod and declines in water temperature, indicating that warming ocean temperature could delay spawning and thereby influence productivity.

Life History Synopsis: Striped mullet is a euryhaline, pelagic nearshore species; it sometimes forages in lagoons, estuaries and lower courses of rivers and can tolerate freshwater. It inhabits inshore marine waters, estuaries, lagoons and rivers where it can tolerate wide ranges of temperature and salinity. Juveniles are most common in impounded areas, around mangroves, in seagrass beds, and offshore throughout the late fall and winter, and are able to tolerate salinities from 0-35 ppt (Bester 2004). Adults often enter estuaries and rivers and form schools over sand or mud bottoms (Eschmeyer et al. 1983, Thompson 1986, Allen 1991, Yamada et al. 1995, Allen et al. 2002). Adults are found in waters ranging from 8 - 24℃, and 0 - 75 ppt respectively. The species is benthopelagic and catadromous, and is usually found at depths of 0-10 m, but can be found as deep as 120 m (Moreira 1992, Harrison 1995, Riede 2004). Juvenile Striped Mullet feed on detritus, micro-algae and benthic organisms (Blaber 1976, Tung 1981, Cardona 2000). Adults feed on these as well but are more flexible in their diets. Bishop and Miglarese (1978) found that the principal food sources of adult Striped Mullet are detritus and epiphytic algae, but observed Striped Mullet feeding opportunistically on swarming polychaetes (*Nereis* spp.). The species will select food with higher caloric value whenever presented with the opportunity (Odum 1970). Striped Mullet are highly mobile, but there is variability in the extent they migrate, with some populations undertaking extensive migrations 40-50 miles offshore in water 1000 ft deep in the Gulf of Mexico (FL museum) and other studies (again from the GoM) reporting that they do not make extensive migrations in the region and return to their original bay system after spawning (Funicelli et al. 1989; Hill 2004). In general Striped Mullet do not move or migrate extensively, and the greatest distance moved occurs during fall-winter spawning migrations to offshore waters (Leard et al 1995). Mature Striped Mullet aggregate near river mouths, inlets, and lower reaches of estuaries in the early fall in preparation for migrating offshore to spawn. Environmental cues such as falling water temperatures, passage of cold fronts, and falling barometric pressure are thought to trigger aggregation and subsequent migration (Mahmoudi 2000). Spawning occurs on the continental shelf, at depths of 40-1650 m, approximately 50-100 km offshore (McEachran and Fechhelm 1998, Ibanez et al. 2012). They are isochronal spawners, meaning all eggs mature at the same time, but females release the eggs in batches, spawning on successive nights until all yolked eggs are spawned (Render et al. 2012). Spawning occurs from October to mid-January, with peak spawning occurring in November and December (Ditty and Shaw 1996). Eggs are shed and fertilized in the water column, and hatch within 48 hours (Render et al. 1995). Newly hatched larvae of *M. cephalus* measure approximately 2.2 - 2.6 mm (Bensam 1987; Eda et al. 1990). Pelagic larval duration of Striped Mullet is 42 days, and larvae utilize tidal stream transport currents to reach suitable settlement habitat in estuarine and riverine habitats. Striped Mullet have a preferred temperature range 11.3-27.9℃, mean 23℃. Juveniles occupy the high intertidal zone of estuaries where water temperatures and salinity fluctuate greatly. Older fish inhabit deeper, more stable waters. Striped Mullet are not likely to be vulnerable to changes in ocean acidification, as they are highly flexible in their diets, but primarily feed on detritus and epiphytic algae. Striped Mullet have a fairly rapid population growth rate, based on a high growth coefficient ($k = 0.39$), a high natural mortality rate ($M = 0.59$), and maximum age of approximately 15 years. Age at maturity was between 3 and 4 years, and a maximum size of approximately 100 cm indicates an increased vulnerability to population depletions, but the preponderance of the evidence indicated this species should rebound from population depletions fairly successfully. A 2013 stock assessment by the Florida Fish and Wildlife Conservation commission (Chagaris et al. 2014) found that $B_{2013}/B_{SPR35\%} = 1.74$ and $F_{2013}/F_{SPR35\%} = 0.41$. These reference points indicate that the stock was not overfished historically or undergoing overfishing currently. The IUCN lists the species asLeast Concern due to its fast growth rate, high fecundity, and relatively low age-at-maturity. Analysis of molecular variance (AMOVA) results support the existence of a single population with high levels of gene flow along the Gulfof Mexico and north-west Atlantic coasts (Rocha-Olivares et al 2000). Due to their obligate estuarine/riverine residence, Striped Mullet are vulnerable to anthropogenic stressors such as habitat degradation, pollution, hypoxia from eutrophication, and altered runoff patterns/river flow. Additionally, Striped Mullet are highly vulnerable to harmful algal blooms (Mahmoudi 2000).

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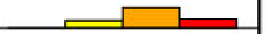
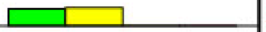
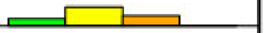
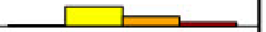
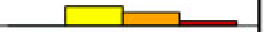
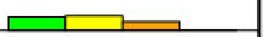
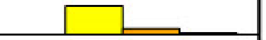
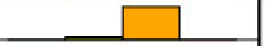
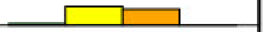
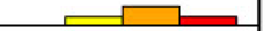
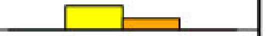
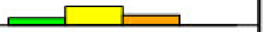
Golden Tilefish – *Lopholatilus chamaeleonticeps*

Overall Vulnerability Rank = Very High 🟥

Biological Sensitivity = High 🟧
Climate Exposure = Very High 🟥

Data Quality = 58% of scores ≥ 2

Lopholatilus chamaeleonticeps		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	3	2.8	
	Prey Specificity	1.5	2.8	
	Adult Mobility	2.1	2.2	
	Dispersal of Early Life Stages	2.5	1.6	
	Early Life History Survival and Settlement Requirements	2.6	1.2	
	Complexity in Reproductive Strategy	1.9	1.7	
	Spawning Cycle	2.2	3	
	Sensitivity to Temperature	2.9	2.8	
	Sensitivity to Ocean Acidification	2.4	1.7	
	Population Growth Rate	3	2.5	
	Stock Size/Status	2.3	3	
	Other Stressors	2.1	1.6	
	Sensitivity Score	High		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	3.9	3	
	Precipitation	1	0	
	Ocean Acidification	4	2	
	Sea Level Rise	1	0	
	Currents	3.7	2.8	
	Exposure Score	Very High		
Overall Vulnerability Rank		Very High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Tilefish (*Lopholatilus chamaeleonticeps* Goode & Bean, 1879)

Overall Climate Vulnerability Rank: Very High**.** (57% bootstrap results in High, 43% bootstrap results in Very High).

Climate Exposure: Very High. Four exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0), Salinity (3.9) and Currents (3.7). Exposure to all factors occurs during all life stages.

Biological Sensitivity: High. Two sensitivity attributes were ≥ 3.0: Habitat Specialization (3.0) and Population Growth Rate (3.0). Tilefish are a relatively long-lived fish with relatively low population growth rates (Steimle and Shaheen 1999). The species occupies a specific habitat type, burrows located in mud-clay-silt bottoms on the outer continental shelf and upper slope (Able et al. 1982, Low and Ulrich 1983, Grossman et al. 1985).

Distributional Vulnerability Rank: Moderate. Three attributes indicated moderate potential for distribution shift: adult mobility, dispersal of early life stages, and moderate sensitivity to temperature.

Directional Effect on the Southeast U.S. Shelf: The effect of climate change on Tilefish on the Southeast U.S. Shelf is estimated to be neutral. Tilefish has specific habitat requirements (structural and thermal) and the effect of warming on habitat availability is uncertain, although warming could make more habitat in the northeast available. Changes in oceanic current patterns could affect transfer of nutrients to depth. The effect of ocean acidification is uncertain, as Tilefish do consume crustaceans and given their habitat specificity and sedentary nature it is uncertain if they can switch completely to fish if necessary.

Data Quality: 58% of the data quality scores were 2 or greater. Attributes identified as data-deficient with increased sensitivity include Dispersal of Early Life Stages, Complexity in Reproductive Strategy, and Other Stressors.

Climate Effects on Abundance and Distribution: Tilefish may be moderately affected by Ocean Acidification due to inclusion of invertebrates in their diet (Freeman and Turner 1977; Steimle et al. 1999). Climate-mediated changes to oceanic current patterns could affect transport of larvae out of the Gulf of Mexico to the eastern seaboard and up into the South Atlantic Bight (Katz et al. 1983). While there are no specific references to effects of changing temperature or salinity on Tilefish, the species lives in a fairly narrow thermal range and it is conceivable that a warming ocean may have some effect on fitness or survival.

Life History Synopsis**:** Tilefish is a relatively large, slow-growing, long-lived (40 years), and late-maturing deep-water species found on the upper continental slope, mainly on unconsolidated or semi-consolidated sediments (Able et al. 1982, SEDAR 2011). Tilefish are found from Nova Scotia to Surinam, but off the U.S. coast Tilefish habitat is a relatively restricted band on the upper slope, approximately 80-540 m deep and at 8-17°C (Steimle et al. 1999). Within this band, Tilefish are more abundant near the 15°C isotherm which occurs between 100-240 m (Steimle et al. 1999). Tilefish construct vertical burrows in clay sediments, which are found on the upper continental slope and in submarine canyons. Tilefish burrows contain numerous smaller burrows of associated crabs, lobsters and fishes, and are a focus for biological activity (Able et al. 1982). Tilefish may play an important role in structuring outer continental shelf communities (Able et al. 1982) and those may be affected by changes in

Tilefish abundance or distribution. Tilefish are gonochoristic and in spawning condition in the southeast in all months except October and December (Sedberry et al. 2006). The peak of spawning occurs in April through June, primarily on the upper slope of the continental shelf. Spawning females have been captured off Florida through South Carolina at depths of 190-300 m where the bottom temperature was 10.2-14.9°C (Sedberry et al. 2006). Eggs are buoyant and hatch within 40 hours (Steimle et al. 1999). Larvae occur in the plankton from July to September in the Middle Atlantic Bight. Early juveniles have not been reported from the southeast, but 51-82 mm specimens have been collected at 100-200 m during April-July along the outer edge of the Middle Atlantic Bight shelf (Steimle et al. 1999). Tilefish consume mainly brittle stars and crustaceans. Crabs (true crabs, anomurans, galatheids) dominate the diet and a few fishes, mollusks, polychaetes, holothurians and anemones are consumed. Juveniles eat more echinoderms and mollusks than do larger Tilefish (Steimle et al. 1999). Tilefish are primarily a commercial species, although recreational catches have increased in recent years (Schertzer et al. 2019). Tilefish is neither overfished nor undergoing overfishing (https://www.fisheries.noaa.gov/national/population-assessments/fishery-stock-status-updates).

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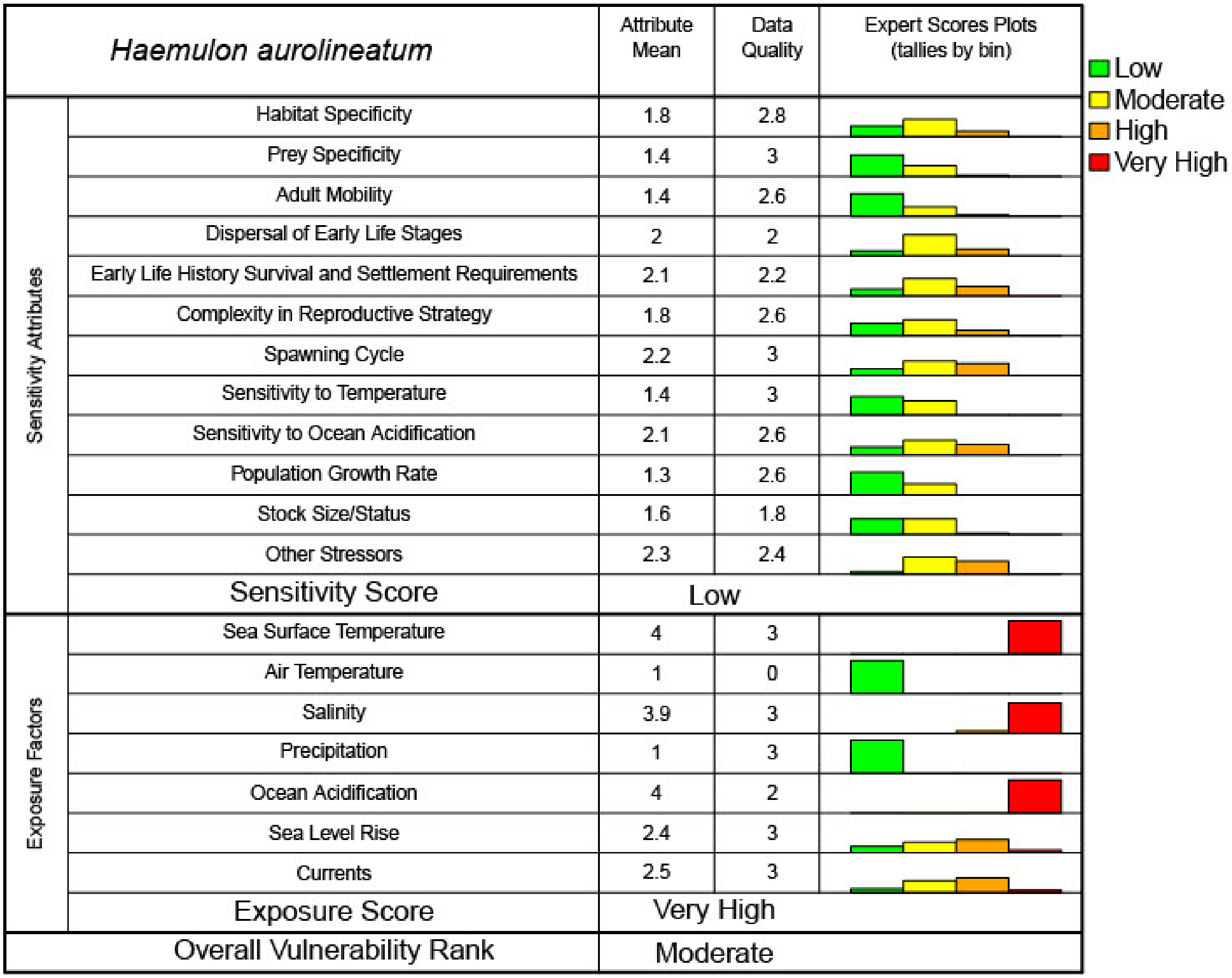
Tomtate − *Haemulon aurolineatum*

Overall Vulnerability Rank = Moderate 🟨

Biological Sensitivity = Low 🟩
Climate Exposure = Very High 🟥

Data Quality = 92% of scores ≥ 2



Haemulon aurolineatum		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.8	2.8	
	Prey Specificity	1.4	3	
	Adult Mobility	1.4	2.6	
	Dispersal of Early Life Stages	2	2	
	Early Life History Survival and Settlement Requirements	2.1	2.2	
	Complexity in Reproductive Strategy	1.8	2.6	
	Spawning Cycle	2.2	3	
	Sensitivity to Temperature	1.4	3	
	Sensitivity to Ocean Acidification	2.1	2.6	
	Population Growth Rate	1.3	2.6	
	Stock Size/Status	1.6	1.8	
	Other Stressors	2.3	2.4	
	Sensitivity Score	Low		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	3.9	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	2.4	3	
	Currents	2.5	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		Moderate		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Tomtate (*Haemulon aurolineatum*)

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

Climate Exposure: Very High. Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Salinity (3.9). Tomtate is a marine species found on patch and coral reefs, rocky hardbottom ledge habitats, and, as juveniles, in seagrass beds (Manooch and Barans 1982).

Biological Sensitivity: Low. No sensitivity attributes scored ≥ 2.5.

Distributional Vulnerability Rank: High. Tomtate are habitat generalists that are mobile, and have dispersive early life stages.

Directional Effect on the Southeast U.S. Shelf: The effect of climate change on Tomtate on the Southeast U.S. Shelf is estimated to be positive. Tomtate is a subtropical species commonly found from the Chesapeake Bay southward. Projected warming sea surface temperature could increase thermally available habitat in more northern areas. The effect of ocean acidification is likely to be moderate given their diet of crustaceans and molluscs. There are no other indications of negative directional effects of climate change on Tomtate.

Data Quality: 92% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution: There is little information on climate effects on abundance and distribution of Tomtate. Their preferred temperature range of 23-28°C likely limits widespread expansion into waters north of North Carolina currently but future warming ocean temperatures could allow them to expand their range. Productivity could be affected by increasing ocean acidification, which is expected to impact a component of their diet, crustaceans and molluscs.

Life History Synopsis**:** Tomtate is a small reef-associated schooling species 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. Its depth range is 1-40 m. Occurrence is uncommon north of Cape Hatteras NC. Juvenile and adult Tomtate occupy similar habitats: seagrass beds, sand flats, patch reefs, natural hardbottom and coral, artificial reefs (McEachran and Fechhelm 2005, Manooch and Barans 1982). One study found juvenile individuals tended to be caught in warmer waters than adults in fall and winter (Manooch and Barans 1982). Coral reef and seagrass habitats have undergone considerable degradation from human activity and water quality fluctuations. Juvenile Tomtate have a generalist diet dominated by zooplankton at small sizes. Alheit and Schiebel (1982) found that diets of small juveniles consisted primarily of benthic harpacticoid copepods, although diets increased in diversity (fish and crustaceans) as the fish increased in size. Adults tend to be generalist carnivores, feeding on small benthic invertebrates including crustaceans and mollusks, as well as zooplankton and fish (Anderson et al. 2015; Courtenay and Sahlman 1978; Norberg 2015). There is limited information in the literature about the mobility of Tomtate. 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). There is no evidence they are mobility-limited either behaviourally or physically, although no large-scale migratory observations are reported, nor is there information on home range, activity space, or other metrics of movement. Tomtate spawning females were found throughout the US Southeast shelf, over May-July, in waters from 20.16-28.04°C, on mid and outer-shelf reefs, depths from 15-54 m, and at latitudes ranging from 27-33°N (Sedberry et al. 2006). Munro et al. (1973) postulated that Tomtate spawn year round in the tropical Caribbean. Grunts produce spherical pelagic eggs with a single oil droplet. Eggs hatch 1-2 days after fertilization. There is little information on the planktonic stage of Tomtate, but the planktonic larval duration of other grunts is approximately 15 days, at which time the larvae settle to the bottom (McFarland 1980, Brothers and McFarland 1981). Some larvae likely rely on tidal currents for transport into suitable nursery habitat such as seagrass beds. Tomtate have a preferred temperature range of 23-28°C (fishbase.org). Tomtate may be affected by increased ocean acidification because their diets include some shell-forming invertebrate species that may themselves be sensitive to ocean acidification. Tomtate have a moderate to high population growth rate, as evidenced by low vulnerability maximum age, age at maturity and maximum length, and a moderate vulnerability growth coefficient statistic. IUCN lists Tomtate as a species of least concern, with a generation length of 5-6 years (Anderson et al. 2015). It is the most abundant species in many areas. Tomtate have not been assessed and likely won't be anytime soon. While the species is considered exploited in the Florida Keys and Dry Tortugas (Smith et al. 2011), they are not thought to be overfished or undergoing overfishing. No information is available on genetic population structure in Tomate. 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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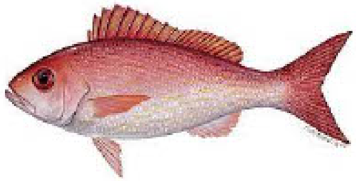
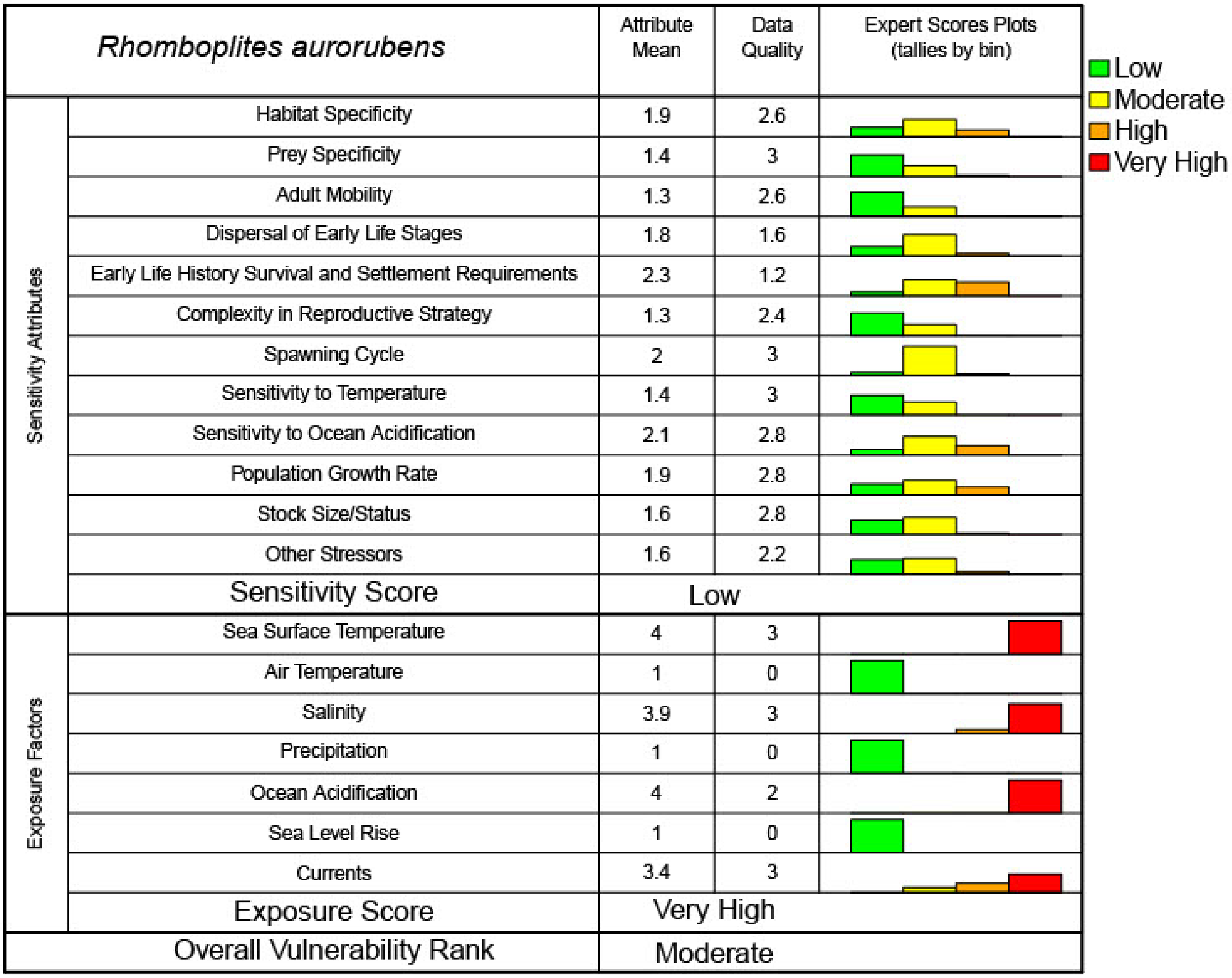
Vermilion Snapper – *Rhomboplites aurorubens*



Overall Vulnerability Rank = Moderate 🟨

Biological Sensitivity = Low 🟩
Climate Exposure = Very High 🟥

Data Quality = 83% of scores ≥ 2



Rhomboplites aurorubens		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.9	2.6	
	Prey Specificity	1.4	3	
	Adult Mobility	1.3	2.6	
	Dispersal of Early Life Stages	1.8	1.6	
	Early Life History Survival and Settlement Requirements	2.3	1.2	
	Complexity in Reproductive Strategy	1.3	2.4	
	Spawning Cycle	2	3	
	Sensitivity to Temperature	1.4	3	
	Sensitivity to Ocean Acidification	2.1	2.8	
	Population Growth Rate	1.9	2.8	
	Stock Size/Status	1.6	2.8	
	Other Stressors	1.6	2.2	
	Sensitivity Score	Low		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	3.9	3	
	Precipitation	1	0	
	Ocean Acidification	4	2	
	Sea Level Rise	1	0	
	Currents	3.4	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		Moderate		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Vermilion Snapper (*Rhomboplites aurorubens*)

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

Climate Exposure: Very High. Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Salinity (3.9). Exposure to all three factors occurs during the life stages. Vermilion Snapper are found in coastal marine environments over rocky, gravel or sand bottoms.

Biological Sensitivity: Low. No sensitivity attributes scored ≥ 2.5, but Early Life History Settlement and Survival Requirements (2.3) was considered borderline sensitive, likely due to a lack of scientific literature on this topic.

Distributional Vulnerability Rank: High. Vermilion Snapper are habitat generalists that are highly mobile, and their pelagic early life stages are likely widely dispersed. While currently distributed from North Carolina southward, projected warming in mid-Atlantic or northeastern waters could lead to more suitable thermal habitat becoming available.

Directional Effect on the Southeast U.S. Shelf: The effect of climate change on Vermilion Snapper on the Southeast U.S. Shelf is estimated to be positive (65% of scores). Vermilion Snapper are known to vacate shallower reefs for deeper habitat if the temperature falls below 16°C (Parker 1990). Ocean acidification may have some moderate effects as Vermilion Snapper consumes shrimps, crabs, and other benthic invertebrates, as well as pelagic plankton. There is little evidence to suggest an overall negative directional effect of climate change on Vermilion Snapper.

Data Quality: 83% of the data quality scores were 2 or greater. Early Life History Settlement and Survival Requirements was determined to be data-deficient and moderately sensitive.

Climate Effects on Abundance and Distribution: There is little information in the literature on climate effects on distribution of Vermilion Snapper. Productivity could be moderately affected by increasing Ocean Acidification and its effects on diet items such as shrimps, crabs, polychaetes, and other benthic invertebrates.

Life History Synopsis**:** Vermilion Snapper are a moderately sized lutjanid species often found in sizable schools, and are often associated with structure of some kind. The species ranges in the western Atlantic from North Carolina south to Santa Catarina, Brazil, including Bermuda, the Bahamas, the Gulf of Mexico and the Caribbean Sea (Allen 1985). The species utilizes depths of 20-300 m. Young Vermilion Snapper usually inhabit shallower waters, while adults are found in moderately deep waters, most commonly over rock, gravel or sand bottoms near the edge of continental and island shelves (Fishbase.org). Estuarine use by the species is not known. Juveniles are generalist feeders, feeding on infaunal, epifaunal and pelagic invertebrates, including copepods, decapods, larvae of barnacles stomatopods and decapods, nematodes polychaetes and fish eggs (Sedberry and Cuellar 1993). Adults are also opportunistic feeders with prey items including fishes, shrimps, crabs, polychaetes, other benthic invertebrates, cephalopods and planktonic organisms. There is good evidence from diet studies that they are water column foragers as well as bottom feeders (Dixon 1975; Grimes 1979). Adults are highly mobile and do not appear to be behaviorally or physically constrained in their movements. Vermilion Snapper are gonochoristic, have minimally complex reproduction and are thought to spawn in offshore habitats throughout the year, with peak spawning off the east coast of the U. S. occurring from April to September (Cuellar and Sedberry 1996). They often spawn at multispecies spawning sites, often near the shelf edge (Farmer et al. 2018). Little information is available on the early life history of Vermilion Snapper. Similar lutjanid species have egg stages of 1-3 days and pelagic larval durations of 23-30 days. Offshore currents likely aid larval transport along the southeast US Atlantic coast to suitable settlement areas offshore, but settlement locations are poorly known. The species occurs in temperatures ranging from 18°C-27°C (Fishbase). They may be less affected than some species by increasing ocean temperatures due to their offshore habitat. While Vermilion Snapper are opportunistic feeders as juveniles and adults, they may be moderately affected by increased ocean acidification because their diets include some invertebrate species that may themselves be sensitive to ocean acidification. They may be less affected if they are able to substitute diet items. Vermilion Snapper have a moderately slow population growth rate, with an early age-at-maturity (1-2 years) and a smaller maximum body size being offset by a low growth coefficient, a high maximum age, and a natural mortality rate of 0.22 (SEDAR 2018). These factors indicate this species might be slow to rebound from population disturbances. The species is not currently overfished, with SSB_{2016}/SSB_{MSY} = 1.13 (SEDAR 2018). Bagley et al. (1999) reported that Vermilion Snapper in the South Atlantic Bight are likely one genetic stock based on microsatellite analysis. Lionfish predation is a likely stressor for Vermilion Snapper (Dahl and Patterson 2014). Because of their preference for structure, coral bleaching and temperate reef degradation are other potential stressors.

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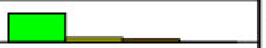
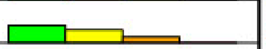
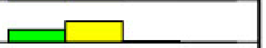
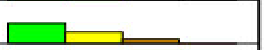
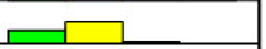
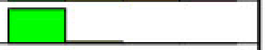
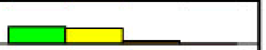
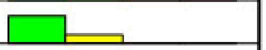
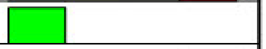
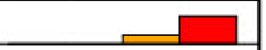
Wahoo − *Acanthocybium solandri*

Overall Vulnerability Rank = Moderate 🟨

Biological Sensitivity = Low 🟩
Climate Exposure = Very High 🟥

Data Quality = 83% of scores ≥ 2

Acanthocybium solandri		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.3	2.7	
	Prey Specificity	1.7	2.6	
	Adult Mobility	1	3	
	Dispersal of Early Life Stages	1.7	2.7	
	Early Life History Survival and Settlement Requirements	1.6	2	
	Complexity in Reproductive Strategy	1.2	1.8	
	Spawning Cycle	1.7	2.6	
	Sensitivity to Temperature	1.5	3	
	Sensitivity to Ocean Acidification	1	3	
	Population Growth Rate	1.2	2.4	
	Stock Size/Status	1.6	1.7	
	Other Stressors	1.2	2.3	
	Sensitivity Score	Low		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	4	3	
	Precipitation	1	0	
	Ocean Acidification	4	2	
	Sea Level Rise	1	0	
	Currents	3.8	2.8	
	Exposure Score	Very High		
Overall Vulnerability Rank		Moderate		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Wahoo (*Acanthocybium solandri*)

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

Climate Exposure: Very High. Four exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) Salinity (4.0), and Currents (3.8). Wahoo resides in offshore pelagic waters where it is exposed to all these factors during its life.

Biological Sensitivity: Low. No sensitivity attributes scored above 2.5.

Distributional Vulnerability Rank: High. Wahoo are highly mobile habitat generalists with widely dispersive early life stages.

Directional Effect on the Southeast U.S. Shelf: The directional effect of climate change on Wahoo on the Southeast U.S. Shelf is estimated to be positive. The species is piscivorous with no reliance on crustaceans and thus no effects of ocean acidification are expected. Wahoo are a tropical-warm temperate epipelagic species and should be minimally impacted by projected increases in sea surface temperature. There is little evidence for a negative directional effect of climate change.

Data Quality: 83% of the data quality scores were 2 or greater. While Complexity in Reproductive Strategy and Stock Size Status were identified as data-deficient, they were not considered highly sensitive. While little is known specifically of Wahoo reproduction, they are known to have high reproductive output (Brown-Peterson et al. 2000) and high genetic connectivity with no documented cases of variation in reproductive success (Collette et al. 2011).

Climate Effects on Abundance and Distribution: There are no published studies we could find on climate effects on abundance and distribution of Wahoo. Such effects are likely to be minimal and may include limited range expansion into waters north of their current distribution as ocean temperatures increase. The species is not reliant on shell-forming invertebrates, thus productivity should not be affected by Ocean Acidification. The species relies on currents to disperse larvae to suitable patches of oceanic habitat where food is available, thus disruption of existing oceanic circulation could affect productivity and survival of early life stages.

Life History Synopsis**:** Wahoo is an epipelagic, oceanic member of the Scombrid family which has a circumtropical and subtropical distribution throughout the world's oceans (Wollam 1969) ranging from 45°S to 59°N. Wahoo are fast swimmers, occur in open ocean environments, and are often associated with seamounts, mid-ocean ridges, temperature and current edges, and deep water adjacent coral reefs (Garber et al. 2005; Collette and Nauen 1983; Theisen and Baldwin 2012); their habitat is abundant and generally undisturbed. Wahoo grow rapidly and attain a size of up to 900 mm by age-1. Adults, and presumably juveniles, feed on a wide variety of teleost fishes (12 families and over 38 species by one study) including epipelagics such as scombrids, clupeids, carangids, and exocoetids (flying fish); cephalopods are also prominent in the diet, while crustaceans are mostly absent (Manooch and Hogarth 1983). Wahoo tend to spawn in the vicinity of open ocean currents and subsequently have broad larval dispersal (Iversen and Yoshida 1957; Matsumoto 1968). Spawning season in the Gulf of Mexico and the

Bahamas is May-August with a peak in June; individual fish may spawn once every 2-6 days for a total number of 20-62 spawning events over the season (Brown-Peterson et al. 2000; Jenkins and McBride 2009). Wahoo larval stage is approximately two weeks and juveniles grow rapidly (SAFMC 2000; Garber et al. 2005). Larvae presumably disperse into patches of oceanic habitat where food is abundant; juveniles, like adults, are carnivores consuming a wide variety of teleosts and cephalopods. Rapid growth suggests that predator abundance is not an issue to juveniles which do not occur in estuaries. Wahoo tend to be solitary, but may form loose aggregations while foraging and for spawning (Melo et al. 2011). The stock does not appear dependent on vulnerable habitats for a particular life stage. Preferred temperature range is reported as 18-27.6°C; tagging studies report Wahoo tend to occur in water temperatures between 17.5-27.5°C with a preference for water temperatures >22°C; daytime habitat preference may be the upper mixed layer in the water column and an average depth of 18 m (Nobrega et al. 2009; Theisen and Baldwin 2012; Fishbase.org). Wahoo exhibited rapid growth with a von Bertalanffy k of 0.38 (McBride et al. 2008). They mature at age-1 and may live up to nine years, although median age at capture from published studies was <age-2 (Brown-Peterson et al. 2000; Jenkins and McBride 2009). Current stock assessments for Wahoo do not exist, yet the species is extremely fecund with each female estimated to produce 1.1 million eggs per spawn and a total of 30-92 million eggs per spawning season (Brown-Peterson et al. 2000). There are currently no known other stressors to Wahoo in their oceanic habitat.

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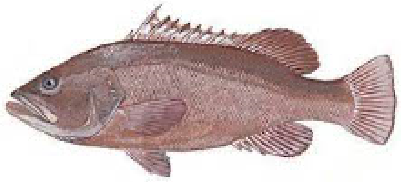
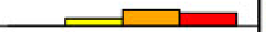
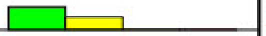
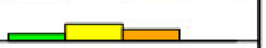
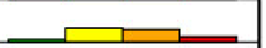
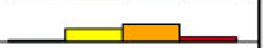
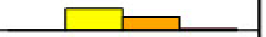
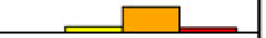
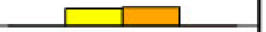
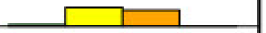
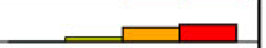
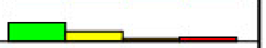
Warsaw Grouper − *Epinephelus nigritus*



Overall Vulnerability Rank = Very High 🟥

Biological Sensitivity = High 🟧
Climate Exposure = Very High 🟥

Data Quality = 50% of scores ≥ 2

	Epinephelus nigritus	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	3.2	2.6	
	Prey Specificity	1.4	2	
	Adult Mobility	2.1	1.6	
	Dispersal of Early Life Stages	2.6	1.5	
	Early Life History Survival and Settlement Requirements	2.7	0.8	
	Complexity in Reproductive Strategy	2.4	1.7	
	Spawning Cycle	3	2.6	
	Sensitivity to Temperature	2.5	2.6	
	Sensitivity to Ocean Acidification	2.4	2	
	Population Growth Rate	3.8	2.2	
	Stock Size/Status	3.4	1.4	
	Other Stressors	1.8	1.2	
	Sensitivity Score	High		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	4	3	
	Precipitation	1	0	
	Ocean Acidification	4	2	
	Sea Level Rise	1	0	
	Currents	3.7	2.6	
	Exposure Score	Very High		
Overall Vulnerability Rank		Very High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Warsaw Grouper (*Hyporthodus nigritus*)

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

Climate Exposure: Very High. Four exposure factors scored ≥ 3.5: Ocean Surface Temperature (4.0), Ocean Acidification (4.0), Salinity (4.0) and Currents (3.7). Warsaw Grouper inhabit rocky hardbottom habitat on the deep continental shelf, and likely rely on ocean currents for dispersal of larvae.

Biological Sensitivity: High. Four sensitivity attributes scored above 3.0: Habitat Specificity (3.2), Population Growth Rate (3.8), Stock Size/Status (3.4) and Spawning Cycle (3.0). Warsaw Grouper are a long-lived, slow growing, late-maturing fish (Aguilar-Perera et al. 2018). The species resides in fairly specific habitat, rocky hardbottom on the deep continental shelf, and has a fairly discrete spawning season (Garcia-Cagide et al. 1994).

Distributional Vulnerability Rank: Moderate. Two attributes indicated moderate potential for distribution shift: adult mobility and early life stages that are likely widely dispersive (larvae thought to remain in the open ocean for 40-60 days). Warsaw Grouper do exhibit relatively high habitat specialization, however, which might inhibit distributional shift.

Directional Effect on the Southeast U.S. Shelf: The directional effect of climate change on Warsaw Grouper on the Southeast U.S. Shelf is estimated to be neutral (70% of expert scores were neutral, 30% were negative). There may be moderate negative impacts of Ocean Acidification due to inclusion of crustaceans in their diet, but Warsaw Grouper are opportunistic piscivores and may overcome any indirect effects. Impacts from increasing sea surface temperature should be negligible given the depths that the species utilizes. There was no evidence in the literature of positive climate effects, likely due to their low population growth rate affecting their ability to respond to climate-forced population disturbances.

Data Quality: 50% of the data quality scores were 2 or greater. Attributes identified as data-deficient and of moderate to high sensitivity include Dispersal of Early Life Stages, Early Life History Settlement and Survival Requirements, Complexity in Reproductive Strategy and Stock Size/Status.

Climate Effects on Abundance and Distribution: There are no specific studies on effects of climate change on abundance and distribution of Warsaw Grouper. Productivity of Warsaw Grouper could be impacted by effects of Ocean Acidification on both primary diet items (crabs, shrimp, lobsters and molluscs) and on *Oculina* coral habitat utilized by Warsaw Grouper. The species relies on existing oceanic circulation to transport larvae to suitable nursery habitat, and climate-forced disruption of these circulation patterns could affect survival and/or productivity.

Life History Synopsis**:** Warsaw Grouper are a deepwater demersal species distributed from Massachusetts to Florida and the Gulf of Mexico. The adults prefer depths on the outer continental shelf of at least 55 m but more commonly 200-500 m, though juveniles may be found closer to shore (Aguilar-Perera et al. 2018). Warsaw Grouper are likely generalist carnivores, eating mollusks, crustaceans, and other fishes (Aguilar-Perera et al. 2018), and no distinction is made between diets of juveniles and adults. Eggs and larvae are presumed to be pelagic, with an approximate larval duration pre-settlement of 40-60 days (Aguilar-Perera et al.

2018). No information is known about larval settlement requirements, though it is possible that Warsaw grouper larvae use chemical and/or auditory cues to find suitable habitat. Warsaw Grouper are thought to be protogynous hermaphrodites, though little is known about their age at transition (Musick et al. 2000). Warsaw Grouper attain sexual maturity around age 9 (Parker and Mays 1998). Maximum reported age for Warsaw grouper is 56 years (Sanchez et al. 2019). Stevens et al. (2019) reported maximum length (L-infinity) as 2394 mm total length and the von Bertalanffy growth coefficient *K* as 0.05. Warsaw Grouper are currently undergoing overfishing, but no determination has been made regarding their overfished status due to deficient data (NOAA Fisheries 2018). Given the depth in which adults live, they are unlikely to be affected by many anthropogenic impacts.

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Musick, J.A., Harbin, M.M., Berkeley, S.A., Burgess, G.H., Eklund, A.M., Findley, L., Gilmore, R.G., Golden, J.T., Ha, D.S., Huntsman, G.R. and McGovern, J.C., 2000. Marine, estuarine, and diadromous fish stocks at risk of extinction in North America (exclusive of Pacific salmonids). *Fisheries*, *25*(11), pp.6-30.

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Parker, R.O. and Mays, R.W. 1998. Southeastern U.S. deepwater reef fish assemblages, habitat characteristics, catches, and life history summaries. NOAA NMFS Technical Report 138: 1-41.

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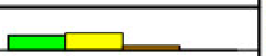
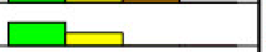
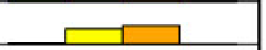
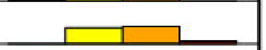
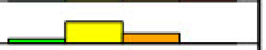
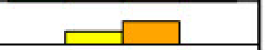
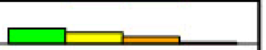
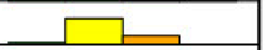
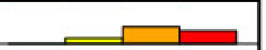
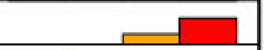
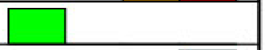
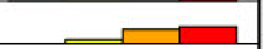
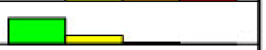
Weakfish − *Cynoscion regalis*

Overall Vulnerability Rank = High 🟧

Biological Sensitivity = Moderate 🟨
Climate Exposure = Very High 🟥

Data Quality = 100% of scores≥ 2

	Cynoscion regalis	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	1.7	3	
	Prey Specificity	1.4	3	
	Adult Mobility	1.6	3	
	Dispersal of Early Life Stages	2.5	2.8	
	Early Life History Survival and Settlement Requirements	2.6	2.2	
	Complexity in Reproductive Strategy	2.2	2.2	
	Spawning Cycle	2.6	3	
	Sensitivity to Temperature	1.8	3	
	Sensitivity to Ocean Acidification	1.2	3	
	Population Growth Rate	2.2	2.8	
	Stock Size/Status	3.2	2.4	
	Other Stressors	2.6	3	
	Sensitivity Score	Moderate		
Exposure Factors	Sea Surface Temperature	1	0	
	Air Temperature	4	3	
	Salinity	3.7	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	3.4	3	
	Currents	1.3	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		High		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

Weakfish (*Cynoscion regalis*)

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

Climate Exposure: Very High. Three exposure factors scored ≥ 3.5: Salinity (3.7), Ocean Acidification (4.0) and Air Temperature (4.0). Weakfish use estuaries as nursery areas and move to nearshore coastal waters when air and water temperatures begin to drop.

Biological Sensitivity: Moderate. Five sensitivity attributes scored ≥ 2.5: Dispersal of Early Life Stages (2.5), Early Life History Settlement and Survival Requirements (2.6), Spawning Cycle (2.6), Stock Size/Status (3.2) and Other Stressors (2.6). Weakfish spawn near the mouths of bays and estuaries so transport of larvae is limited (Mercer 1989). Spawning occurs over a protracted time period but is cued by warming temperatures. Use of estuarine nursery areas likely exposes Weakfish to other anthropogenic stressors. Recent assessments by the Atlantic States Marine Fisheries Commission have determined Weakfish have been depleted for 13 years in a row (ASMFC 2016).

Distributional Vulnerability Rank: High. Three attributes indicated high potential for distribution shift: high adult mobility,widely dispersing early life stages, and a habitat generalist habit.

Directional Effect on the Southeast U.S. Shelf: The directional effect of climate change on Weakfish on the Southeast U.S. Shelf is estimated to be neutral. Weakfish are already distributed into the mid-Atlantic and northeast U.S., but warming temperatures could alter timing of temperature-dependent migrations. There is likely to be an effect of ocean acidification on Weakfish due their dietary reliance on molluscs and crustaceans.

Data Quality: 100% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution: Relatively little work has been done on the effect of climate on distribution and productivity of Weakfish. In a study from Delaware Bay, Lankford and Targett (1994) found an interactive effect of salinity and temperature on juvenile Weakfish growth, suggesting changes in temperature, precipitation, and sea level could affect productivity. Howell and Auster (2012) suggest a northward shift in distribution based on increasing abundance at the northern end of their geographic range.

Life History Synopsis**:** Weakfish are large coastal sciaenids distributed in the western Atlantic from Nova Scotia (Canada) south along the U.S. coast to southeastern Florida (Page et al. 2013). Juveniles utilize estuarine areas as nursery grounds and are most frequently found in the deeper waters of rivers, bays, sounds, and other estuarine areas, usually over sand or sandy grass bottom (Mercer 1989). Adult Weakfish are more of a habitat generalist, found over common sand and sandy mud bottoms. Adult weakfish migrate seasonally between inshore and offshore waters (Merriner 1973; Wilk 1979). When waters warm in the spring, weakfish move from offshore wintering grounds into the estuaries. Weakfish smaller than 20 cm TL feed mostly on crustaceans, while larger juveniles eat what is readily available, with small clupeids and anchovies probably dominant (Bowman et al. 2000). Adult Weakfish feed on a variety of species, including annelids, mollusks, penaeid and mysid shrimp, and other fish, mostly clupeids and anchovies. Adults are mobile and are known to undertake seasonal migrations prompted by warming coastal waters in the spring and consisting of northward movements along the coast followed by a return migration in autumn to overwinter in warmer, southern waters including nearshore sounds, bays, and estuaries. Weakfish are gonochoristic and usually found in 50:50 sex ratios. Spawning occurs after spring migrations back inshore from coastal waters, usually in response to increasing water temperatures and photoperiod. In North Carolina waters spawning occurs from March to September, with peak spawning occurring April-June (Merriner 1976). Adults are known to aggregate at the mouths of estuaries. Eggs hatch in 36-40 hours (Welsh and Breder 1923).Planktonic larval duration is approximately 21 days (Mercer 1989). Larval ingress to estuaries is aided by selective tidal stream transport, but due to proximity of spawning sites to estuaries, distance needed is usually short. Metamorphosis to juvenile stage may occur while still in nearshore waters and juveniles are transported into estuaries. Larvae eat a variety of prey and mismatch of prey species with timing of spawning is not a concern (Pryor and Epifanio 1993). The preferred temperature range of Weakfish is 7.2°C - 24.9°C. Weakfish generally remain in shallow coastal or estuarine waters, moving into deeper waters as a refuge from colder temperatures. There are no reports of known diel vertical migrations by the species. Weakfish are likely to be affected by increased ocean acidification due to their reliance on mollusks and crustaceans in their diets (Mercer 1989). Weakfish are likely to encounter some difficulty recovering from population disturbances based on their life history characteristics. While an extremely high natural mortality rate (Krause et al. 2020), very early age-at-maturity, and moderate growth coefficient impart low vulnerability for recovery, a large maximum size and maximum age indicate difficulty recovering. The species is likely to have some inherent difficulties in the event of population depletions. An ASMFC assessment found that the Atlantic Weakfish stock has been depleted for the last 13 years. In 2014 SSB was estimated at 5.62 million lbs., well below the $SSB_{30\%}$ threshold for depletion of 15 million lbs (ASMFC 2016). A mtDNA study from the east coast (NY-FL) found no genetic variation among sampling sites, indicating considerable gene flow along the coast, and recommending management of the species as a single unit stock (Graves et al. 1991). Obligate estuarine habitats have been degraded through urbanization impacts including hypoxia, reduction in seagrass beds and changes in timing and volume of freshwater inputs. Pollution is another stressor which has likely led to fin rot disease in northern populations. Harmful algal blooms could impact the species as well.

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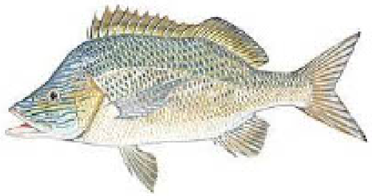
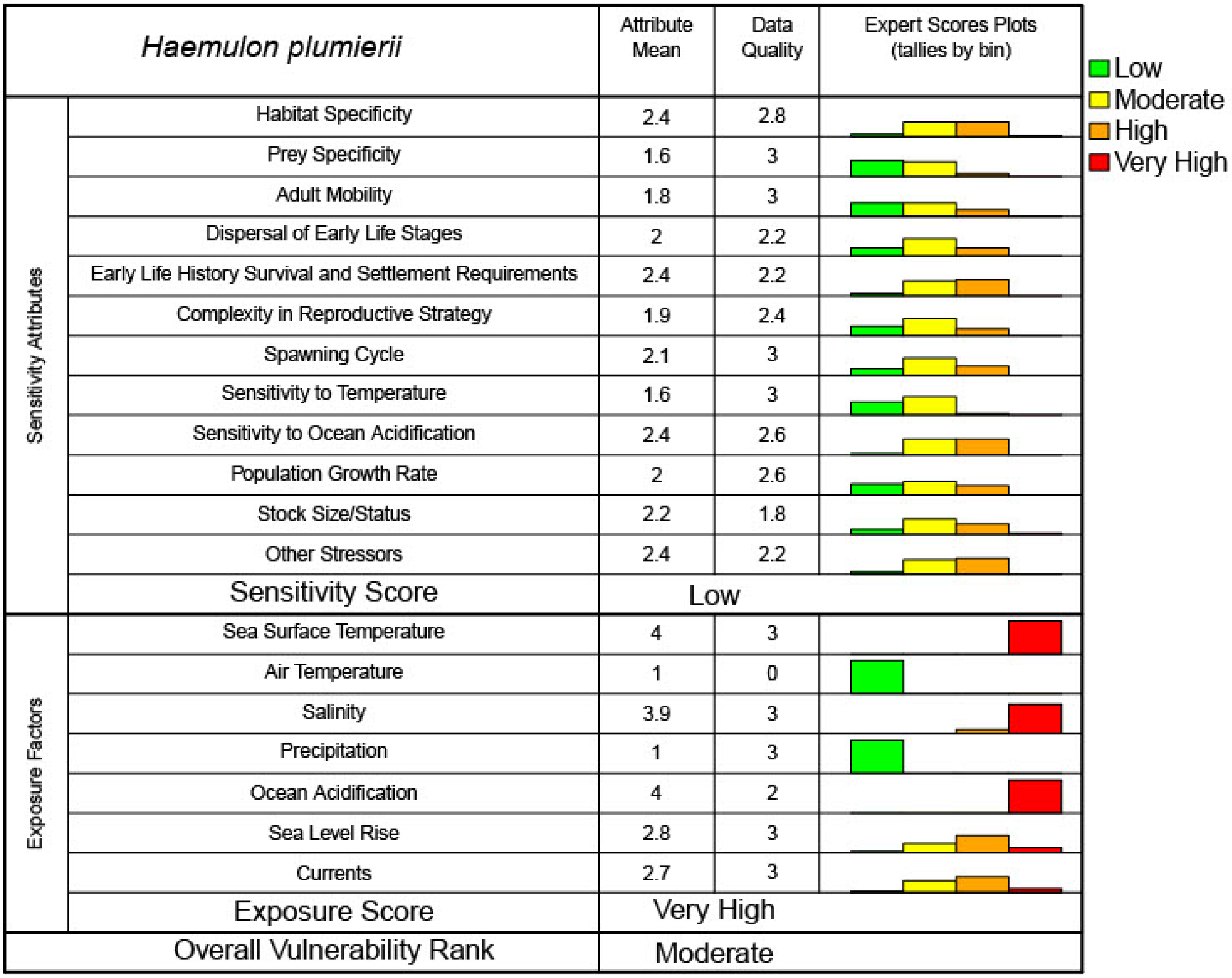
White Grunt − *Haemulon plumierii*



Overall Vulnerability Rank = Moderate 🟨

Biological Sensitivity = Low 🟩
Climate Exposure = Very High 🟥

Data Quality = 92% of scores ≥ 2



	Haemulon plumierii	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.4	2.8	
	Prey Specificity	1.6	3	
	Adult Mobility	1.8	3	
	Dispersal of Early Life Stages	2	2.2	
	Early Life History Survival and Settlement Requirements	2.4	2.2	
	Complexity in Reproductive Strategy	1.9	2.4	
	Spawning Cycle	2.1	3	
	Sensitivity to Temperature	1.6	3	
	Sensitivity to Ocean Acidification	2.4	2.6	
	Population Growth Rate	2	2.6	
	Stock Size/Status	2.2	1.8	
	Other Stressors	2.4	2.2	
	Sensitivity Score	Low		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	3.9	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	2.8	3	
	Currents	2.7	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		Moderate		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

White Grunt (*Haemulon plumieri*)

Overall Climate Vulnerability Rank: Moderate. (68% bootstrap results in Moderate, 32% bootstrap results in High).

Climate Exposure: Very High. Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Salinity (3.9). White Grunt are marine reef fish found on coral reefs and temperate hard bottom ledge habitat as adults and in seagrass beds and mangrove habitats as juveniles (Sedberry and Carter 1993). Exposure to all three factors occurs during all life stages.

Biological Sensitivity: Low. No sensitivity attributes scored ≥ 2.5.

Distributional Vulnerability Rank: High. Three attributes indicated high potential for distribution shift: adult mobility, widely dispersive early life stages, and relatively low habitat specialization.

Directional Effect on the Southeast U.S. Shelf: The directional effect of climate change on White Grunt on the Southeast U.S. Shelf is estimated to be positive (65% of expert scores were positive, 30% were neutral). There may be moderate dietary impacts of Ocean Acidification, but White Grunt are also known to feed on fishes. The species is a tropical-warm temperate species and impacts from increasing sea surface temperature should be negligible.

Data Quality: 92% of the data quality scores were 2 or greater. Stock Size/Status was the only attribute identified as data-deficient, as a result of the species not having been assessed by fishery managers.

Climate Effects on Abundance and Distribution: We found no specific studies of climate effects on abundance and distribution of White Grunt in the scientific literature. Given the reliance of juvenile White Grunt on crustaceans and molluscs in their diet, and the subsequent reliance of adults on shrimps, crabs and molluscs, Ocean Acidification is likely to have some effect on fitness (productivity). Chapman et al. (1999) determined that the northern genetic lineage was more tolerant of lower temperatures, indicating that White Grunt from the Carolinas might expand their distribution north in the event of warming ocean temperatures.

Life History Synopsis**:** White Grunt are a small-medium-sized temperate demersal reef fish distributed in the western Atlantic Ocean from Chesapeake Bay to Brazil, including Bermuda, the Bahamas, throughout the Gulf of Mexico and Caribbean Sea, utilizing depths from 1-55 m. The species has a subtropical-tropical-temperate distribution, ranging latitudinally from 39°N to 23°S. Preferred temperature range is 23.4-28°C, mean 25.9°C. While capable of thriving in oceanic reef environments as well as estuarine habitats, Lindeman and Toxey (2002) note that members of the family Haemulidae in general are only rarely encountered at very low salinities. Juveniles are known to utilize mangrove habitats and seagrass beds in south Florida . Newly-settled and early juvenile life stages are encountered in very shallow hard-bottom and vegetated habitats throughout its range, commonly in *Thalassia testudinum* beds (Cervigón et al. 1992). Older juveniles/subadults use backreef habitats (Nagelkerken 2009). Adult White Grunt can be found in a variety of habitats, including in and around coral reefs, mangrove creeks, seagrass beds, sand-rubble zones and temperate hard-bottom ledge reefs. Juveniles are reported to feed primarily on benthic invertebrates including crustaceans, worms, and molluscs. Adults likely consume similar, if somewhat larger, invertebrate prey including shrimp, crabs, and molluscs. This dietary dependence on shell-forming invertebrates could make White Grunt vulnerable to increased ocean acidification. White grunt tend to exhibit high site fidelity, making only short-range foraging movements, moving off-reef to vegetated habitats (usually at night) and then moving back to their home patch reef afterwards. One tagging study in Puerto Rico and Florida found most movements usually didn't exceed 100 m from their apparent home habitat on a reef (Tulevech and Recksiek 1994). Eggs are pelagic. Fertilized eggs hatched within 20 hours of collection. The larvae began actively feeding after 48 hrs post hatch, upon consumption of the oil droplet and yolk sac. Larval growth is most rapid in the first 30 days. By 100 days they have reached a size of a 24-39 mm SL juvenile. There is limited information about how far the eggs travel during the planktonic stage. Saskena and Richards (1975) reported that they collected White Grunt eggs off the dock at the University of Miami lab at Biscayne Bay FL. It is likely they are spawned close to shore, and tidal transport is required by currents to inshore seagrass habitats. No specific information was found on temperature effects on reproduction, but the species is temperate-tropical, spending most of its life in warmer nearshore/coastal waters. There is no reporting of White Grunt forming spawning aggregations. Thought to spawn on their reef habitat, and eggs are carried inshore to seagrass beds. Male White Grunt in the US Atlantic peak in spawning activity from March through to June, a similar spawning season to White Grunt from the west coast of Florida (de Silva and Murphy 2001). Munro et al. (1973) reported the species likely spawns year round in the southern portion of the range (Caribbean). White Grunt mature relatively quickly, with 50% of females maturing by age-1, 88% by age-2 and 99% by age-3 (Padgett 1997). Longevity was found to be 27 years for fish from North Carolina/South Carolina (Padgett 1997). Natural mortality was estimated to be 0.25 (Potts and Brennan 2001). Von Bertalanffy growth coefficients indicate relatively slow growth to maximum size, 0.09 for northern fish and 0.19 for southern fish (Potts and Manooch 2001). The species has not been assessed in the southeastern United States. There is no evidence of compromised genetic variation. Chapman et al. (1999) determined there were three distinct genetic lineages of White Grunt, NC-SC, a Florida Keys-south lineage, and a distinct lineage from Trinidad. There is no reporting in the literature of large variations in reproductive success or population sizes, or local extinctions. White Grunt are often reported as one of the most abundant species in its range. Utilization of inshore habitats by early life stages may be affected by habitat degradation and pollution, and juveniles/subadults occupying nearshore hardbottom habitats would be vulnerable to lionfish predation.

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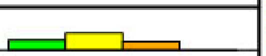
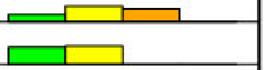
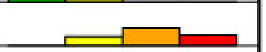
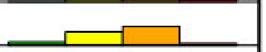
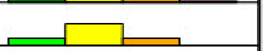
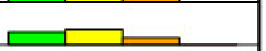
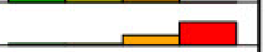
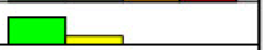
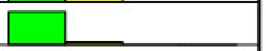
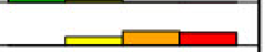
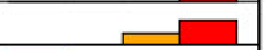
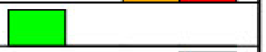
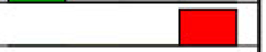
White Shrimp − *Litopenaeus setiferus*

Overall Vulnerability Rank = Very High 🟥

Biological Sensitivity = High 🟧
Climate Exposure = Very High 🟥

Data Quality = 100% of scores≥ 2

Litopenaeus setiferus		Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2	3	
	Prey Specificity	1.1	3	
	Adult Mobility	2.2	3	
	Dispersal of Early Life Stages	1.5	2.8	
	Early Life History Survival and Settlement Requirements	3	2.4	
	Complexity in Reproductive Strategy	2.5	2.8	
	Spawning Cycle	2	3	
	Sensitivity to Temperature	1.8	2.8	
	Sensitivity to Ocean Acidification	3.5	2.8	
	Population Growth Rate	1.2	2.4	
	Stock Size/Status	1.1	3	
	Other Stressors	3.1	2.8	
	Sensitivity Score	High		
Exposure Factors	Sea Surface Temperature	1	0	
	Air Temperature	4	3	
	Salinity	3.7	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	3.6	3	
	Currents	1.6	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		Very High		

- 🟩 Low
- 🟨 Moderate
- 🟧 High
- 🟥 Very High

White Shrimp (*Litopenaeus setiferus*)

Overall Climate Vulnerability Rank: Very High. (7% bootstrap results in High, 93% bootstrap results in Very High).

Climate Exposure: Very High. Four exposure factors contributed to this score: Ocean Acidification (4.0), Air Temperature (4.0), Salinity (3.7) and Sea Level Rise (3.6). Exposure to all factors occurs during the life stages. White Shrimp are a shelled invertebrate with an obligate estuarine residency in areas that may be threatened by sea level rise. Juveniles prefer lower salinity waters than Brown or Pink Shrimp, and projected increasing salinity could force them further toward the upper reaches of estuaries, areas vulnerable to anthropogenic habitat degradation.

Biological Sensitivity: High. Three sensitivity attributes scored ≥ 3.0: Early Life History Settlement and Survival Requirements (3.0), Sensitivity to Ocean Acidification (3.5), and Other Stressors (3.1). White Shrimp are likely to be impacted by anthropogenic habitat alteration and pollution during early life stages.

Distributional Vulnerability Rank: High. Three attributes indicated high potential for distribution shift: high adult mobility, widely dispersing early life stages, and fairly robust maximum temperature tolerance. White Shrimp have a moderate degree of habitat specialization, preferring sandy-mud habitats.

Directional Effect on the Southeast U.S. Shelf: The effect of climate change on White Shrimp is projected to be neutral, with 80% of expert scores in the positive or neutral category and 20% of scores in the negative category. White Shrimp growth is restricted at temperatures below 16℃, and increasing temperatures could lead to increases in suitable thermal habitat in northern areas. Juvenile White Shrimp prefer low salinity portions of estuaries, and effects of projected salinity increases in the southeast will depend on the magnitude and onset of those changes. Increasing ocean acidification could also affect shell formation (Mustafa et al. 2015) as well as negatively affecting production and availability of crustaceans and bivalves that are a major portion of White Shrimp diets (McTigue and Zimmerman 1998).

Data Quality: 100% of the data quality scores were 2 or greater.

Climate Effects on Abundance and Distribution: White Shrimp habitats (vegetated marshes, oyster reefs) will likely be negatively affected by Sea Level Rise. Increasing Ocean Acidification will impact White Shrimp both directly (shell formation, Mustafa et al. 2015) and indirectly (inclusion of crustaceans and molluscs in diet, Muncy and Feller 1987).

Life History Synopsis**:** The White Shrimp was the first species of commercially important shrimp in the U.S., with the fishery for this species dating back to 1709 (Muncy 1984). Geographic distribution extends from New York to Florida, and throughout the Gulf of Mexico to Campeche, Mexico. Juvenile White Shrimp prefer muddy substrata rich in loose peat and sandy mud

(Williams 1958). Anderson (1966) and Rulifson (1981) reported that ideal nursery grounds for juvenile White Shrimp are muddy bottom areas in waters with low to moderate salinity. They are also found in vegetated *Spartina* marsh and oyster reef habitat (Shervette and Gelwick 2008), preferring salinities <10 ppt. Adult White Shrimp commonly inhabit estuaries and the inner littoral zone along coasts to depths of approximately 30 m. In the Gulf of Mexico, White Shrimp can be found in depths as great as 80 m; however, they are most abundant in brackish wetlands with connections to shallow, coastal areas. White Shrimp prefer the lower salinity upper reaches of estuaries, and have been found as far as 210 km upriver (Perez-Farfante 1969). Juvenile and adult White Shrimp diets are similar (benthic omnivores), feeding on detritus, plants, microorganisms, small crustaceans, bivalves, oligochaetes, polychaete worms, and small fish (Beseres and Feller 2007;Hunter and Feller 1987; McTigue and Zimmerman 1991, 1998). Cannibalism of juveniles by adults is common. Mark-recapture studies documented extensive along-shore movements of White Shrimp (Lindner and Anderson 1956). The species generally does not migrate into waters deeper than 30 m, as they prefer specific sediment types (sandy-mud) found in shallower water, although they have infrequently been found in deeper water (DeLancey et al. 2005; Williams 1958). Offshore spawning of White Shrimp is initiated by increasing offshore bottom water temperatures during spring months. Spawning in waters off North Carolina and South Carolina occurs from May-September. Spawning occurs as far as 9 km from the shore, in water depths of at least 9 m (Whitaker 1983a), with females discharging eggs directly to the water column without brooding them as is common in other crustaceans. During copulation, which occurs between hard-shelled individuals, the male attaches a spermatophore to the thelycum of a female. Spermatozoa are released simultaneously with eggs from the female, with fertilization occurring in the water column. Eggs are opaque with a blue-tinged chorion (Linder and Cook 1970) and measure approximately 0.19 - 0.20 mm in diameter. Eggs sink to the bottom of the water column as they are released, and hatch within 10 - 12 hours into planktonic nauplii larvae that measure approximately 0.3 mm in length. Fecundity is high, with between 500,000 to 1 million eggs released per spawn. The larval period in *L. setiferus* lasts 10 days or more. Perez-Farfante (1969) reported 5 naupliar stages, 3 protozoeal stages, 3 mysis stages, and 2 postlarval stages before the juvenile stage is reached. The non-feeding nauplius stage undergoes 5 molts over 24 - 36 hours to the protozoeal stage which measures approximately 1 mm in length. Feeding behavior is initiated with the first protozoeal stage. Protozoea grow to a length of approximately 2.5 mm before achieving the mysis stage. Following a third mysis stage, the postlarval stage is attained. Postlarvae are planktonic, relying on tidal transport to reach inshore estuarine nursery areas (Whitaker 1983b). Upon reaching estuaries postlarvae become benthic (Williams 1965). In North and South Carolina, postlarvae enter estuaries from June through September; in Georgia, postlarvae may enter estuaries as early as April and May. In northeastern Florida, postlarvae first begin to appear in early June. White Shrimp remain in estuaries for approximately six months, before moving offshore to deeper waters in the fall as subadults or adults. Preferred temperature range for White Shrimp is 15-27°C (Sealifebase.org). Growth occurs above 20°C (Etzold and Christmas 1977) and usually ceases below 16°C. White Shrimp are not known to burrow in response to cold temperatures, as brown and pink shrimp do, likely because they arrive at estuaries at the beginning of summer, when water temperatures are warmer. White Shrimp may be affected by increasing ocean acidification indirectly, as they consume small crustaceans and molluscs in their diet. The species has a fairly robust population growth rate, as indicated by life history characteristics (fast growth rate, early age at maturity, small body size, high natural mortality rate, and short lifespan. The species is likely to respond quickly to population disturbance events. White Shrimp were not overfished or undergoing overfishing, B_{curr}/B_{msy} for the Atlantic population is 8.33 (NMFS 2021). While there appears to be some weak genetic differentiation between Gulf of Mexico and Atlantic populations (McMillen-Jackson and Bert 2003; Ball and Chapman 2003), White Shrimp from the east coast populations (North Carolina through Florida) exhibited broad scale homogeneity and little population structure (Ball and Chapman 2003). Other potential stressors affecting White Shrimp populations include pollution in estuarine habitat, anthropogenic habitat alteration, upstream changes in hydrology and the effects on salinity in the estuaries, changes in rainfall affecting required low salinities, sea level rise and its impact on estuarine salinities, hypoxia and harmful algal blooms, resources and habitat competitions with invasive species such as tiger prawns, and parasites and diseases such as the highly virulent White Spot Syndrome Virus (WSSV), introduced from aquaculture operations.

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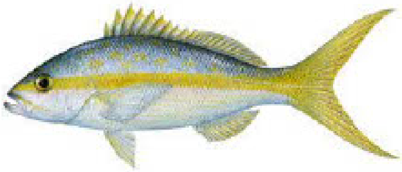
Yellowtail Snapper – *Ocyurus chrysurus*

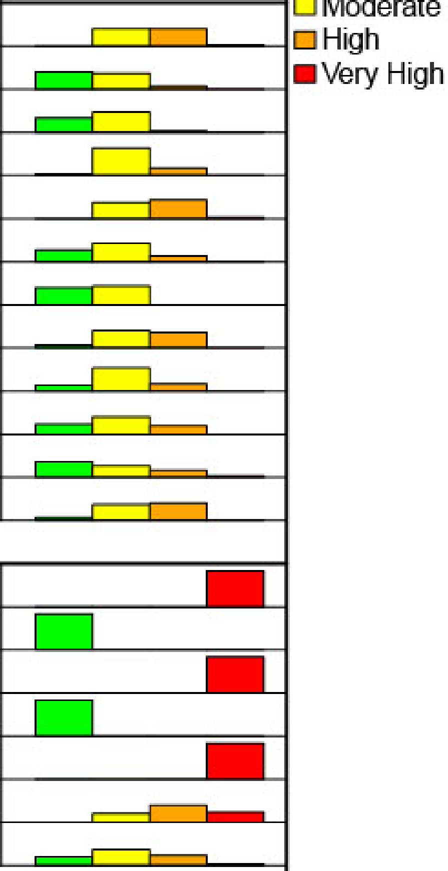


Overall Vulnerability Rank = High 🟧

Biological Sensitivity = Moderate 🟨
Climate Exposure = Very High 🟥

Data Quality = 100% of scores≥ 2

	Ocyurus chrysurus	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
Sensitivity Attributes	Habitat Specificity	2.6	3	
	Prey Specificity	1.6	2.8	
	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	
	Complexity in Reproductive Strategy	1.8	2.2	
	Spawning Cycle	1.5	3	
	Sensitivity to Temperature	2.4	3	
	Sensitivity to Ocean Acidification	2	2.8	
	Population Growth Rate	2	2.8	
	Stock Size/Status	1.8	2.2	
	Other Stressors	2.4	2.4	
	Sensitivity Score	Moderate		
Exposure Factors	Sea Surface Temperature	4	3	
	Air Temperature	1	0	
	Salinity	4	3	
	Precipitation	1	3	
	Ocean Acidification	4	2	
	Sea Level Rise	3	3	
	Currents	2.1	3	
	Exposure Score	Very High		
Overall Vulnerability Rank		High		



Yellowtail Snapper - *Ocyurus chrysurus*

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

Climate Exposure: Very High. Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Salinity (4.0). Exposure to all three factors occur during the life stages of Yellowtail Snapper, which take place in shallow seagrass beds as well as shallow and deeper coral reef-hardbottom habitat .

Biological Sensitivity: Moderate. Two sensitivity attributes scored ≥ 2.5: Habitat Specificity (2.6) and Early Life History Settlement and Survival Requirements (2.6). Yellowtail Snapper are primarily found associated with coral reefs in the Florida Keys and southeastern Florida (McClellan and Cummings 1998).

Distributional Vulnerability Rank: Moderate. While Yellowtail Snapper are mobile, they tend to exhibit site fidelity to a fairly specific preferred habitat type. Data on stock structure/population genetics and larval modeling work indicate local production of recruits rather than resupply from outside areas (Paris et al. 2005). Their preference for specific habitat types (seagrass beds for juveniles, coral reef habitat for adults) might inhibit their ability to expand their distribution beyond the southeastern U. S.

Directional Effect on the Southeast U.S. Shelf: The directional effect of climate change on Yellowtail Snapper on the Southeast U.S. Shelf is estimated to be positive (distribution of expert scores: 55% positive, 35% neutral, 10% negative). Effects of Ocean Acidification are expected to be moderate, perhaps affecting the species' preferred coral reef habitat. The species is a tropical-warm temperate species and projected warming may allow increases in suitable thermal habitat north of the Florida Keys and southeast Florida, the current center of population abundance.

Data Quality: 100% of the data quality scores were 2 or greater. Early Life History Settlement and Survival Requirements scored as marginally data-deficient as well as being moderately sensitive.

Climate Effects on Abundance and Distribution: We found no specific studies on climate effects on abundance and distribution of Yellowtail Snapper in the literature. Ocean Acidification could have some impacts as Yellowtail Snapper consume crabs, shrimp and gastropods (Randall 1967, Allen 1985). Wallace reported that the upper thermal limit for Yellowtail Snapper was 33.5°C, indicating that projected warming of south Florida waters could cause Yellowtail Snapper to expand their distribution northward to seek more habitable temperatures.

Life History Synopsis**:** : Yellowtail Snapper is a coastal and estuarine species widely distributed from Massachusetts through Brazil, including Bermuda, the Bahamas, and throughout the Gulf of Mexico and Caribbean Sea; 42° N - 26° S, 98° W - 31° W (Fischer 1979, Kaschner et al. 2010), although the species is not abundant north of southern Florida (Anderson 2002). The preferred temperature range is 21.7 - 27.9°C, with a mean of 25.9°C (Fishbase.org). Juveniles commonly utilize inshore seagrass beds as nursery habitats, as well as shallow hardbottom or back-reef habitats (Nagelkerken et al. 2009). With growth, individuals move to shallow coral reef areas (Nagelkerken et al. 2000). Adults inhabit clear coastal waters, mostly around hardbottom and coral reefs, usually occurring above the bottom, and frequently in aggregations. Yellowtail Snapper are commonly found in salinities ranging from brackish estuarine to open ocean values, likely 16-35 ppt. The upper lethal temperature for Yellowtail Snapper was 33.5-34.0°C (Wallace 1977). Yellowtail Snapper are not limited in their mobility, and Moe (1972) reported the species to be semi-pelagic wanderers over reef habitats. Adults tend to remain in an area once they have become established (Beaumariage 1969; Bortone and Williams 1986). Acoustic tracking of five individual Yellowtail Snapper near no-take marine reserves in the Dry Tortugas, Florida, estimated an average home range of about 4.17 km^2 (Farmer and Ault 2011). Little information exists in the literature concerning their diet. Larval/juvenile Yellowtail Snapper feed primarily on plankton, while Randall (1967) reported adults eat crabs (23%), shrimp (16%), and fishes (15.9%). Off Cuba, Piedra (1969) reported Yellowtail Snapper stomach contents included fish (82%), and shrimp (17%). Smaller fishes, crustaceans, marine worms, gastropods, and cephalopods have also been reported in the diet (Allen 1985). The spawning season is likely protracted, with seasonal peaks in activity (Erdman 1976). Munro et al. (1973) reported ripe individuals from March through May in nearshore waters off Jamaica, but noted that Yellowtail Snapper spawn year-round in offshore waters. Off Cuba, Piedra (1969) reported females were ripe between March and August. Allen (1985) reported Yellowtail Snapper spawning from April to August in the Florida Keys. The species is thought to form large spawning aggregations seasonally off the coasts of Cuba, the Turks and Caicos Islands, U.S. Virgin Islands, and during May-July southwest of Key West, FL, at Riley's Hump off of the Dry Tortugas (Lindeman et al. 2000). Spawning probably occurs in open waters over high-relief hard bottom areas such as coral reefs, banks, and shelf areas, but has not been directly observed. Eggs are pelagic (Bortone and Williams 1986) and hatch after approximately 20 hours. Larvae likely rely on tidal currents for transport into estuaries where they utilize seagrass beds as nursery habitat. Settlement of larvae into seagrass habitats occurs around 3-4 weeks after hatching (Bortone and Williams 1986) at about 20 mm SL (Bartels and Ferguson 2006). Longevity is moderate, estimated as between 13-17 years for Yellowtail Snapper from the Atlantic (SERO 2011). 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). Claro et al. (2001) report a mean size at maturity for Cuban fish as 30.8 cm TL and two years of age. Maximum size is reported to be 810 mm, but most specimens captured are much smaller than this. Natural mortality was reported as 0.19. Combined, these characteristics indicate the species may be moderately to largely vulnerable to recovering from population disruptions or exploitations. A recent stock assessment of Yellowtail Snapper found that the stock was not overfished and overfishing was not occurring (SEDAR 2020). Little evidence of population structuring between the Florida Keys, southeast Florida, and Puerto Rico has been found (Hoffman et al. 2003). Saillant et al. (2012) examined Yellowtail Snapper collected from the Florida Keys, Puerto Rico, and the US Virgin Islands (USVI), and their findings add further support for a single stock of Yellowtail Snapper off of southern Florida. Other stressors likely to impact Yellowtail Snapper include environmental alterations of their nursery habitat due to development (dredge/spoil disposal), pollution, harmful algal blooms, lionfish predation on juveniles and subadults on nearshore reefs, and possibly increasing temperatures.

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