Supporting Information. Species Narratives.

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American Eel − *Anguilla rostrata*

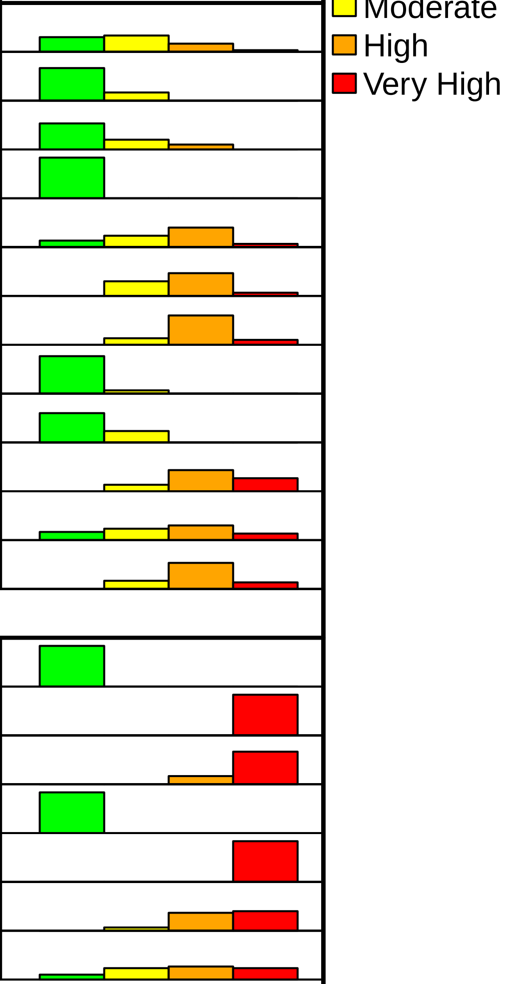
Overall Vulnerability Rank = High 🟧

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		



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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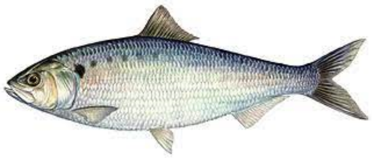
American Shad − *Alosa sapidissima*

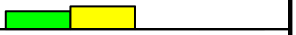
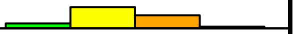
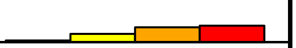
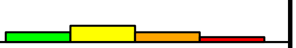


Overall Vulnerability Rank = Very High 🟥

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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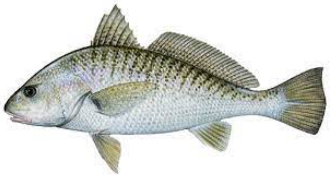
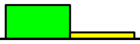
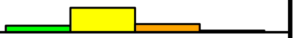
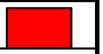
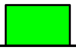
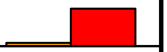
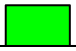
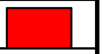
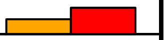
Atlantic Croaker − *Micropogonias undulatus*



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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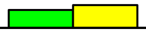
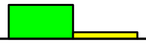
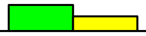
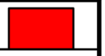
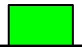
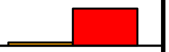
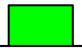
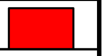
Atlantic Menhaden − *Brevoortia tyrannus*

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℃ (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℃ with a mean of 13.2℃ (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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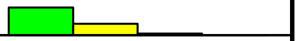
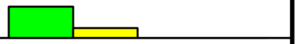
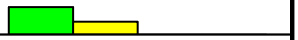
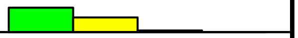
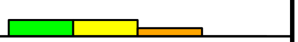
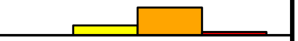
Atlantic Sharpnose Shark − *Rhizoprionodon terraenovae*

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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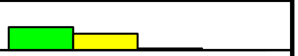
Atlantic and Gulf Sturgeon − *Acipenser oxyrinchus*

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℃ 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℃. 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℃, with mean temperature occurrence of 17℃ (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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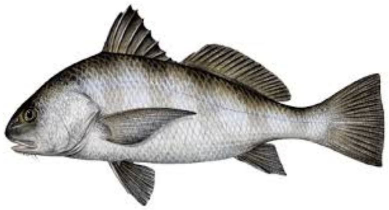
Black Drum − *Pogonias cromis*

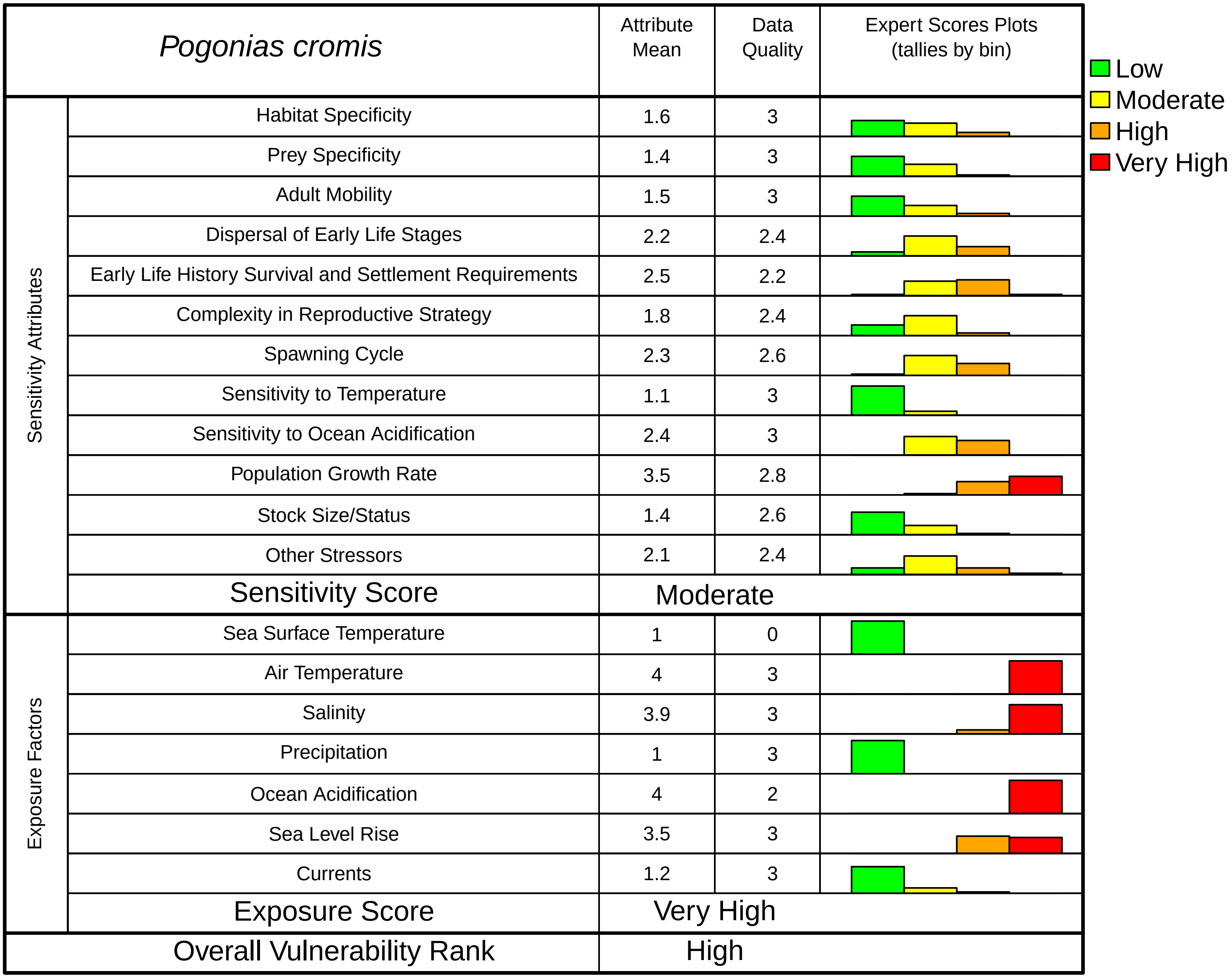


Overall Vulnerability Rank = High 🟧

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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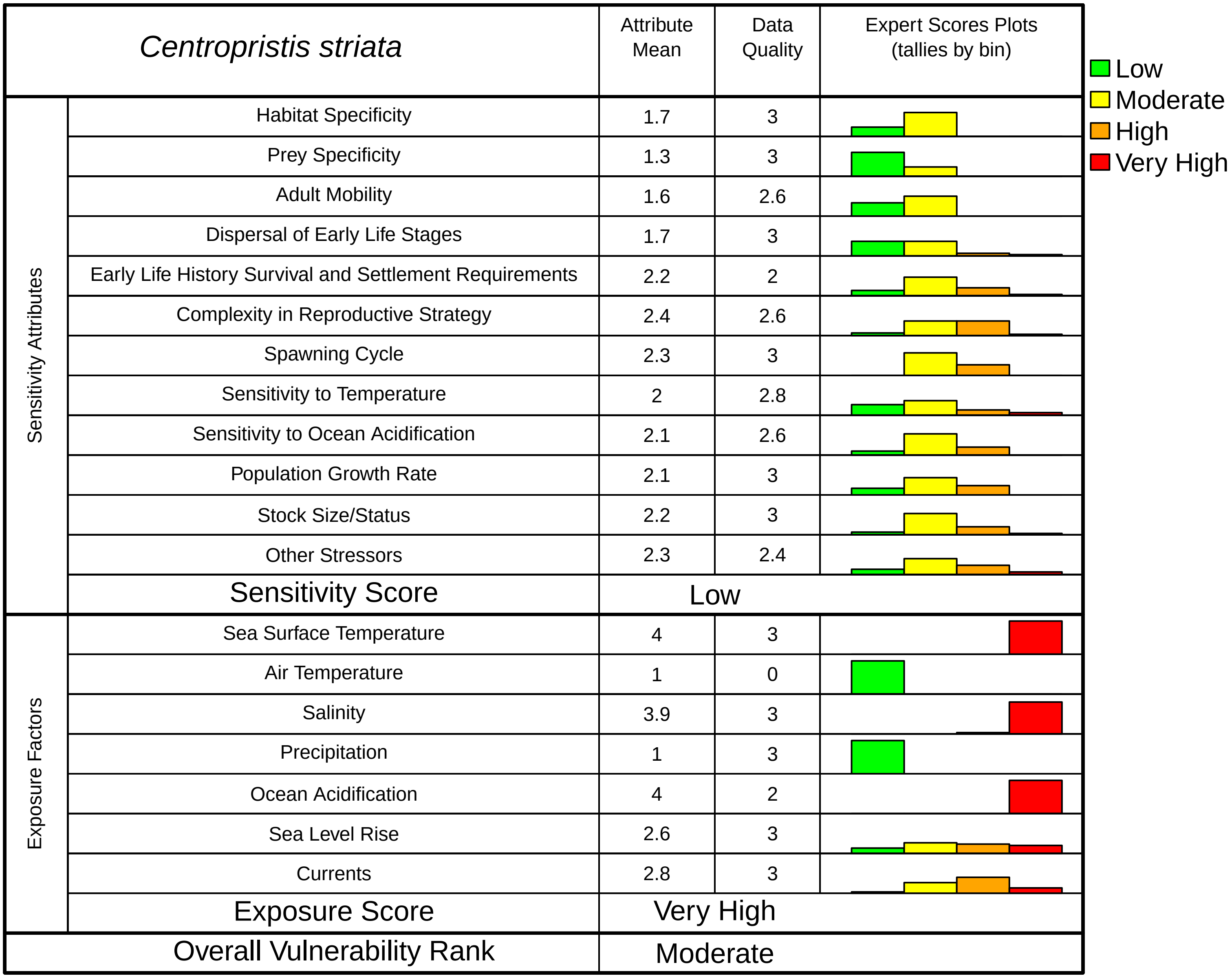
Black Sea Bass − *Centropristis striata*

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		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

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 ℃ (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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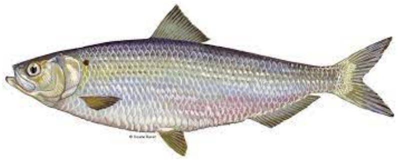
Blueback Herring − *Alosa aestivalis*



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 aestival***is**)

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℃. Larval survival is minimal above 28℃. 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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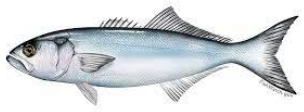
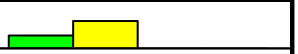
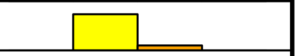
Bluefish − *Pomatomus saltatrix*



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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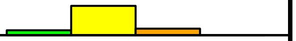
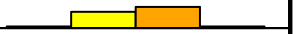
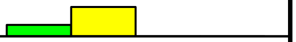
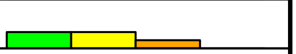
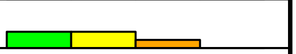
Cobia − *Rachycentron canadum*

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℃ to be lethal to juveniles. The juveniles tolerated temperatures down to 17.7℃, although they ceased feeding entirely at 18.3℃. 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℃; 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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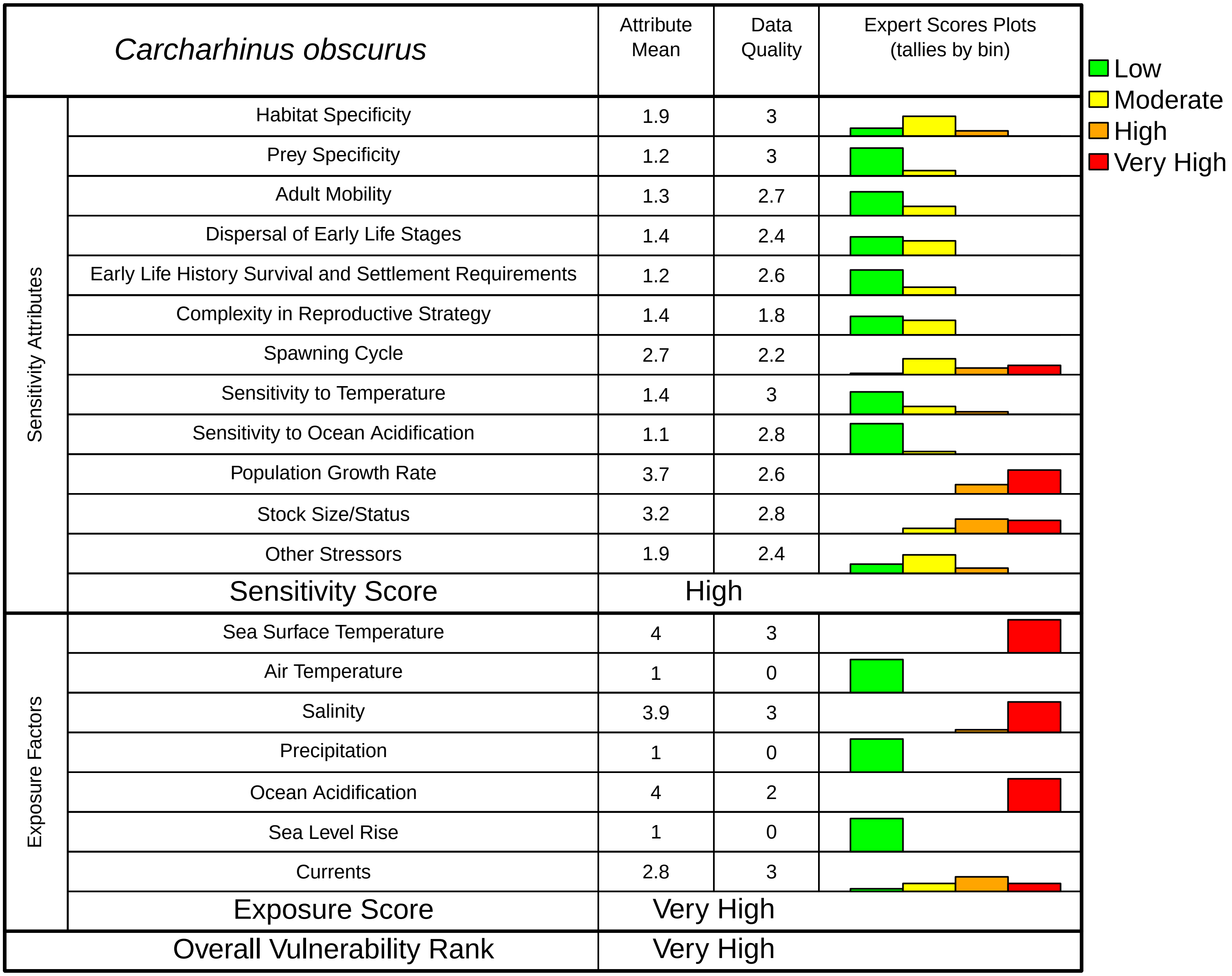
Dusky Shark − *Carcharhinus obscurus*

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℃ (mean 12.6℃). 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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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℃. 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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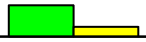
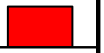
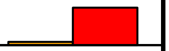
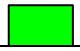
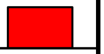
Red Drum − *Sciaenops ocellatus*

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℃, with 22-25℃ the optimal range, and a South Carolina study confirmed that spawning occurred as temperature dropped below 30℃ 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℃, with a mean occurrence of 24℃. 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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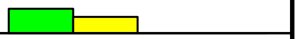
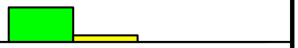
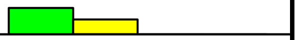
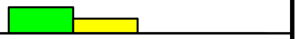
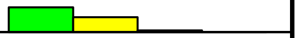
Sandbar Shark − *Carcharhinus plumbeus*

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

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℃, 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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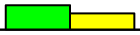
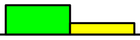
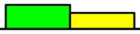
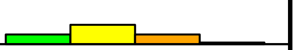
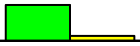
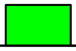
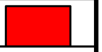
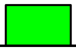
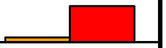
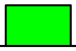
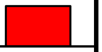
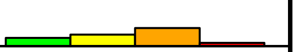
Sand Tiger Shark − *Carcharias taurus*

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

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℃, 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℃ but prefer temperate/subtropical waters, with the mean observed occurrence at 24.5℃ (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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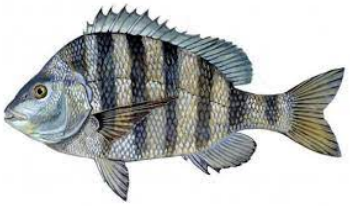
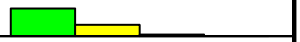
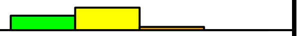
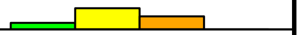
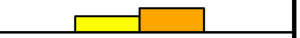
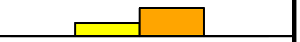
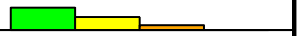
Sheepshead − *Archosargus probatocephalus*



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℃ (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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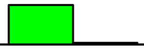
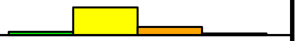
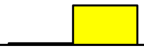
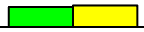
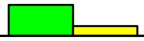
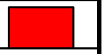
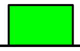
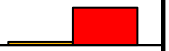
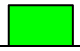
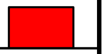
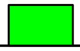
Spanish Mackerel − *Scomberomorus maculatus*

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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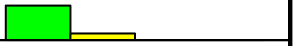
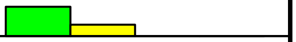
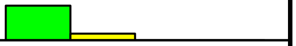
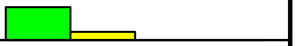
Spiny Dogfish − *Squalus acanthias*

Overall Vulnerability Rank = Moderate 🟨

Biological Sensitivity = Low 🟩
Climate Exposure = Very High 🟥

Data Quality = 100% of scores≥ 2

	Squalus acanthias	Attribute Mean	Data Quality	Expert Scores Plots (tallies by bin)
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		

🟩 Low
🟨 Moderate
🟧 High
🟥 Very High

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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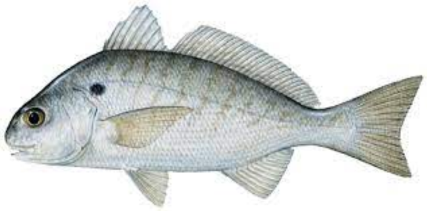
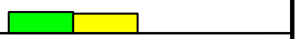
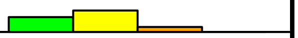
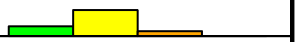
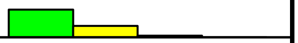
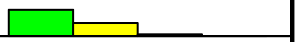
Spot − *Leiostomus xanthurus*



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℃. 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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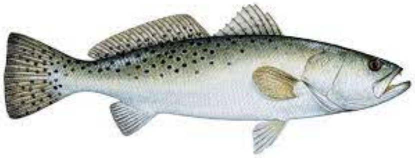
Spotted Seatrout − *Cynoscion nebulosus*

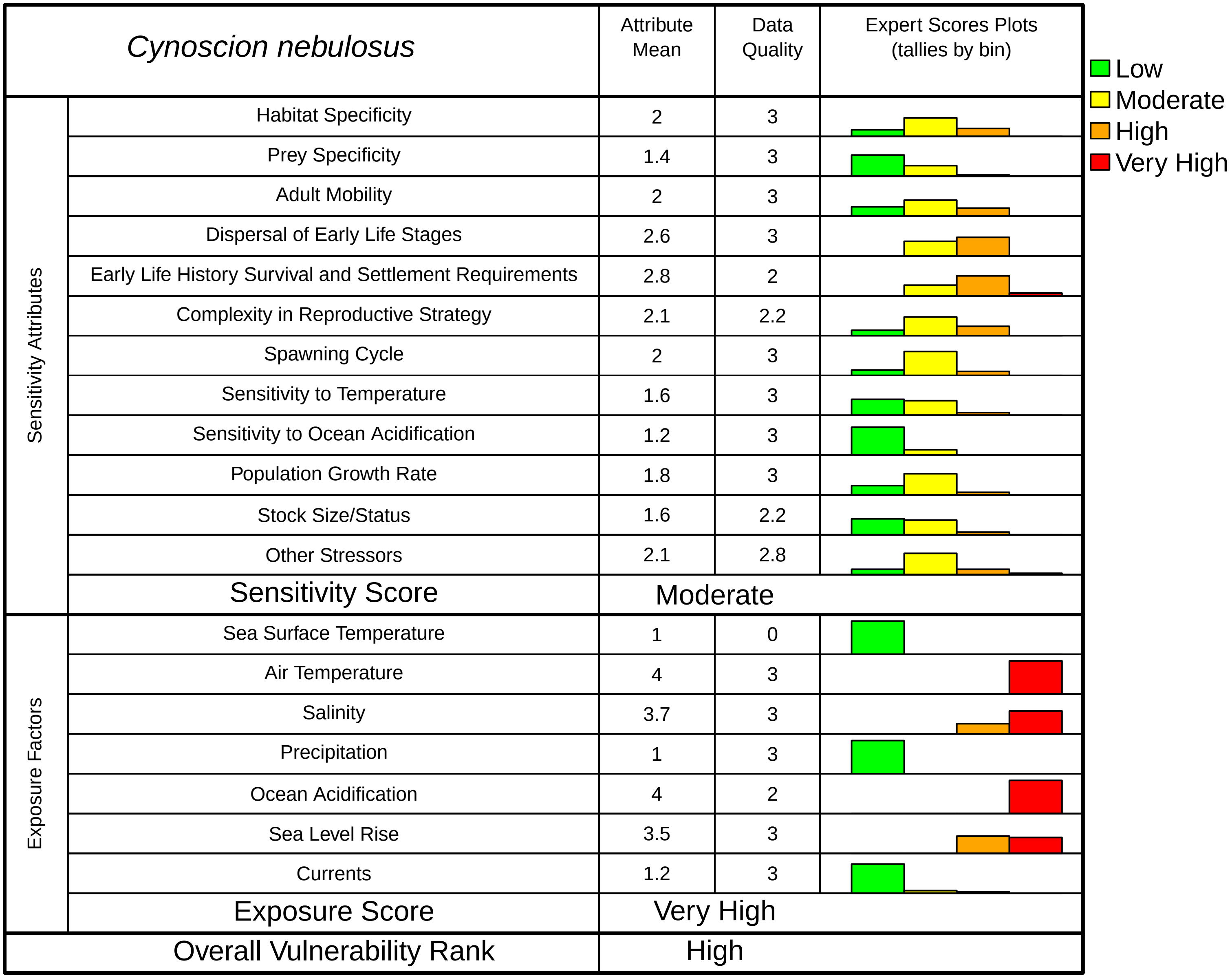


Overall Vulnerability Rank = High 🟧

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		

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℃ 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 ºC for adult Spotted Seatrout (Tabb 1958) and 23-33 ºC 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 ºC 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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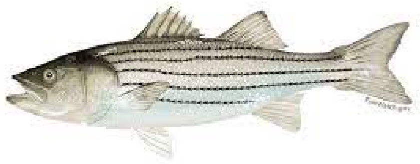
Striped Bass − *Morone saxatilis*

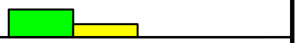
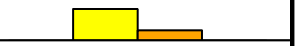
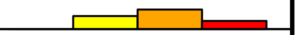
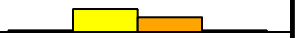
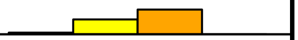


Overall Vulnerability Rank = Very High 🟥

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

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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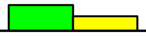
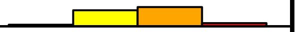
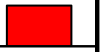
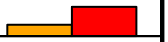
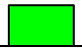
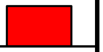
Weakfish − *Cynoscion regalis*

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℃ - 24.9℃. 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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