Atlantic Herring − *Clupea harengus*

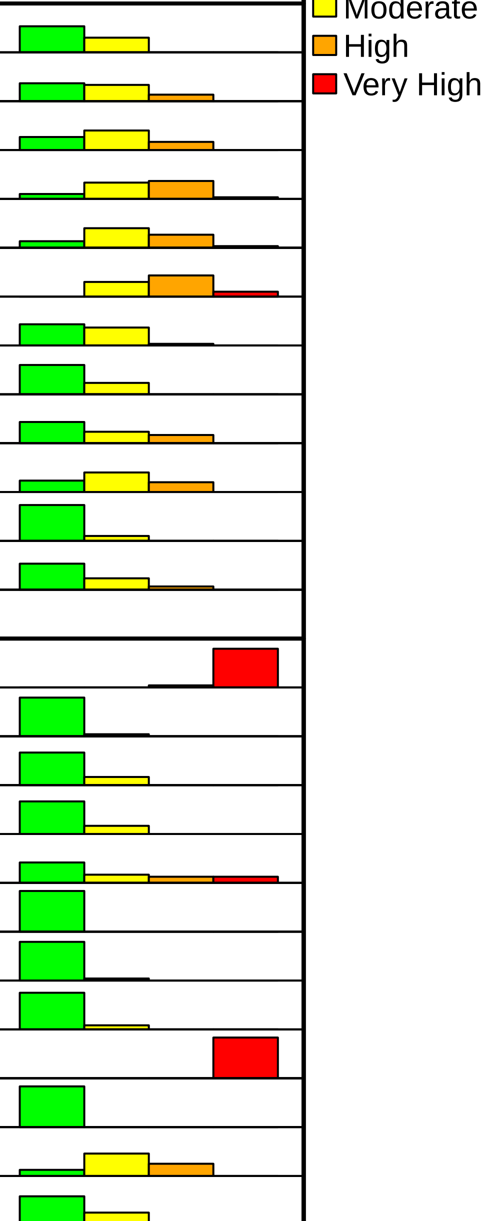
Overall Vulnerability Rank = Low

Biological Sensitivity = Low

Climate Exposure = High

Data Quality = 88% of scores ≥ 2

	Clupea harengus	Expert Scores	Data Quality	Expert Scores Plots (Portion by Category)
Sensitivity attributes	Stock Status	1.4	2.8	
	Other Stressors	1.7	1.9	
	Population Growth Rate	1.9	2.9	
	Spawning Cycle	2.4	3.0	
	Complexity in Reproduction	2.2	2.4	
	Early Life History Requirements	2.8	2.4	
	Sensitivity to Ocean Acidification	1.5	2.4	
	Prey Specialization	1.3	3.0	
	Habitat Specialization	1.7	3.0	
	Sensitivity to Temperature	2.0	3.0	
	Adult Mobility	1.1	3.0	
	Dispersal & Early Life History	1.4	3.0	
	Sensitivity Score	Low		
Exposure variables	Sea Surface Temperature	4.0	3.0	
	Variability in Sea Surface Temperature	1.0	3.0	
	Salinity	1.2	3.0	
	Variability Salinity	1.2	3.0	
	Air Temperature	1.9	3.0	
	Variability Air Temperature	1.0	3.0	
	Precipitation	1.0	3.0	
	Variability in Precipitation	1.1	3.0	
	Ocean Acidification	4.0	2.0	
	Variability in Ocean Acidification	1.0	2.2	
	Currents	2.1	1.0	
	Sea Level Rise	1.3	1.5	
	Exposure Score	High		
Overall Vulnerability Rank		Low		



Atlantic Herring (*Clupea harengus*)

Overall Climate Vulnerability Rank: **Low** (72% certainty from bootstrap analysis).

Climate Exposure: **High**. Two exposure factors contributed to this score: Ocean Surface Temperature (4.0) and Ocean Acidification (4.0). Exposure to ocean surface temperature and ocean acidification occurs during all life stages.

Biological Sensitivity: **Low**. The highest sensitivity attribute was Early Life History Requirements (2.8). Atlantic Herring spawn benthic eggs in distinct locations.

Distributional Vulnerability Rank: **High** (91% certainty from bootstrap analysis). Three of the attributes indicated vulnerability to distribution shift. Atlantic Herring have low Habitat Specialization. Adults are mobile and larval duration is long resulting in potentially broad larval dispersal.

Directional Effect in the Northeast U.S. Shelf: The effect of climate change on Atlantic Herring on the Northeast U.S. Shelf is estimated to be negative, but this estimate is uncertain (66-90% certainty in expert scores). Higher temperatures may decrease productivity and limit habitat availability for Atlantic Herring. But Atlantic Herring spawn in specific locations creating uncertainty as to the effect of climate change on adult distributions. Ocean acidification also may have a negative effect, but more research is needed.

Data Quality: 88% of the data quality scores were 2 or greater

Climate Effects on Abundance and Distribution: Several studies have indicated an effect of climate change on Atlantic Herring productivity. Gröger et al. (2009) linked recruitment dynamics to climate indices (NAO, AMO), but the mechanisms were not specified. Nash et al. (2005) found a negative relationship between age-0 and age-1 Atlantic Herring abundance and water temperature; they hypothesized a link through prey abundance. Other studies have suggested Atlantic Herring dynamics are linked more closely to species interactions (Möllmann et al., 2005; Richardson et al., 2008). Atlantic Herring larvae may be affected by ocean acidification; Franke and Clemmisen (2011) found evidence that the metabolism of embryos was negatively affected at elevated pCO_2 levels. Atlantic Herring distributions may be impacted by increasing temperatures (Murawski, 1993), but homing to spawning locations may limit ability to shift distributions (Wheeler and Winters, 1984; McQuinn, 1997).

Life History Synopsis**:** Atlantic Herring is a highly-mobile, marine, obligate-schooling species found on both sides of the North Atlantic, but from Labrador to Cape Hatteras, North Carolina, in the western North Atlantic (Stevenson and Scott, 2005). Atlantic Herring mature between 3 and 4 years (NEFSC, 2012). In United States waters, spawning occurs during summer-fall from inshore to mid-shelf in high-energy, saline environments with strong tidal currents (Stevenson and Scott, 2005). Major spawning grounds exist on Georges Bank, Nantucket Shoals, and the Gulf of Maine (Stevenson and Scott, 2005). Eggs are deposited on boulder, rocky, gravel, shell fragment, sand, or macrophyte substrate on the sea floor, and then are fertilized (Stevenson and Scott, 2005). Eggs are demersal and adhere to the substrate till hatching after about 2 weeks (Stevenson and Scott, 2005). Yolk-sac stage larvae stay near the bottom for several days, but become increasingly pelagic with strong diel vertical migrations (Munroe, 2002; Stevenson and Scott, 2005). Metamorphosis only occurs from April – October, so the larval period can last 4-8 months depending on when spawning occurred (Munroe, 2002; Stevenson and Scott, 2005). Metamorphosed juveniles form large schools and egress from estuaries and near-shore waters in summer and fall to enter deep bays or offshore bottom overwintering habitat, then return to inshore areas the following spring (Stevenson and Scott, 2005; Able and Fahay, 2010). Juveniles migrate only in the inshore-offshore direction, and so experience colder temperatures than adults. To survive these cold winter temperatures, juvenile Atlantic Herring produce antifreeze blood proteins (Munroe, 2002; Stevenson and Scott, 2005). Juvenile Atlantic Herring are pelagic but perform diel vertical migrations putting them deeper in the water column during the day (Stevenson and Scott, 2005). Adult Atlantic Herring occupy the water column from inshore (estuaries and embayments) to offshore and surface to 200 m (Munroe, 2002). Seasonal migrations span summer and fall spawning grounds in the northern part of the species' range to overwintering grounds to the south (Southern New England and the Mid-Atlantic; Stevenson and Scott, 2005). Changes in temperature drive distribution patterns, but salinity also plays a roll (Munroe, 2002; Stevenson and Scott, 2005). Diel vertical migrations of adults put the fish at the surface at night (Munroe, 2002; Stevenson and Scott, 2005). During all life history stages, Atlantic Herring are opportunistic planktivores, limited by the size of the prey and mouth size (Stevenson and Scott, 2005). Adults can alternate between filter feeding and biting behavior, and sometimes consume fish eggs and larvae (including Atlantic Herring larvae; Munroe, 2002; Stevenson and Scott, 2005). Atlantic Herring are also important prey fish throughout their life history, feeding a variety of piscivorous fish, elasmobranchs, marine mammals, squid, and seabirds (Stevenson and Scott, 2005). In fact, Spiny Dogfish, alone, may consume as many Atlantic Herring as are taken in the fishery (Stevenson and Scott, 2005). The Georges Bank-Nantucket Shoals stock collapsed in the early 1970s due to exploitation by foreign fishing fleets, but has since recovered (Stevenson and Scott, 2005). In the United States, the Atlantic States Marine Fishery Commission and the New England Fishery Management Council under Amendment 2 to the Interstate Fishery Management Plan for Atlantic Herring manage Atlantic Herring as a single coastal stock complex jointly (ASMFC, 2013). Based on the most recent benchmark assessment, Atlantic Herring is not overfished and overfishing is not occurring (NEFSC, 2012).

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