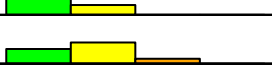
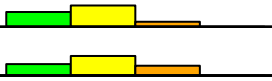
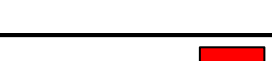
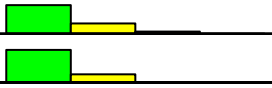
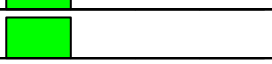
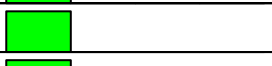
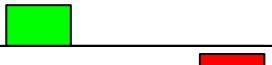
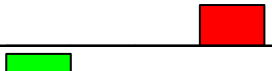
Atlantic Cod − *Gadus morhua*

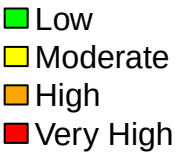
Overall Vulnerability Rank = Moderate

Biological Sensitivity = Moderate

Climate Exposure = High

Data Quality = 92% of scores ≥ 2

	Gadus morhua	Expert Scores	Data Quality	Expert Scores Plots (Portion by Category)
Sensitivity attributes	Stock Status	3.9	3.0	
	Other Stressors	2.0	2.5	
	Population Growth Rate	2.8	2.8	
	Spawning Cycle	2.0	3.0	
	Complexity in Reproduction	2.4	2.9	
	Early Life History Requirements	2.8	2.8	
	Sensitivity to Ocean Acidification	1.3	2.0	
	Prey Specialization	1.2	3.0	
	Habitat Specialization	1.8	3.0	
	Sensitivity to Temperature	2.0	3.0	
	Adult Mobility	2.2	2.8	
	Dispersal & Early Life History	1.4	2.8	
	Sensitivity Score	Moderate		
Exposure variables	Sea Surface Temperature	3.9	3.0	
	Variability in Sea Surface Temperature	1.0	3.0	
	Salinity	1.4	3.0	
	Variability Salinity	1.2	3.0	
	Air Temperature	1.0	3.0	
	Variability Air Temperature	1.0	3.0	
	Precipitation	1.0	3.0	
	Variability in Precipitation	1.0	3.0	
	Ocean Acidification	4.0	2.0	
	Variability in Ocean Acidification	1.0	2.2	
	Currents	2.1	1.0	
	Sea Level Rise	1.6	1.5	
	Exposure Score	High		
Overall Vulnerability Rank		Moderate		



Atlantic Cod (*Gadus morhua*)

Overall Climate Vulnerability Rank: **Moderate.** (90% certainty from bootstrap analysis).

Climate Exposure: **High**. Two exposure factors contributed to this score: Ocean Surface Temperature (3.9) and Ocean Acidification (4.0). All life stages of Atlantic Cod use marine habitats.

Biological Sensitivity: **Moderate**. Three sensitivity attributes scored above 2.5: Stock Status (3.9), Population Growth Rate (2.8), and Early Life History Requirements (2.8). Atlantic Cod is overfished and overfishing is occurring (NEFSC, 2014). Atlantic Cod are relatively slow growing and long-lived (17 years, Lough, 2004; NEFSC, 2013). Finally, the early life stages may be dependent on circulation patterns on Georges Bank for larval retention and specific habitats on the Bank or in coastal regions for juvenile nursery habitats (Fahay, 1999; Lough, 2004).

Distributional Vulnerability Rank: **High** (98% certainty from bootstrap analysis). Atlantic Cod are habitat generalists that are mobile, and have dispersive early life stages (Lough, 2004).

Directional Effect in the Northeast U.S. Shelf: The effect of climate change on Atlantic Cod on the Northeast U.S. Shelf is very likely to be negative (>95% certainty in expert scores). Decreases in recruitment have been linked to increases in temperature and climate-related changes in prey in the Gulf of Maine. Further the species is at the southern end of its range and continued warming will likely result in further reductions in available habitat.

Data Quality: 88% of the data quality scores were 2 or greater indicate that data quality is moderate.

Climate Effects on Abundance and Distribution: Atlantic Cod productivity and distribution are both likely negatively affected by climate factors in the Northeast U.S. Shelf. Drinkwater (2005) noted that Atlantic Cod in the Northeast U.S. Shelf is at the southern end of the range and that warming waters will have negative impacts. Fogarty et al. (2007) developed a stock-recruitment relationship that included temperature; as temperatures increased, recruitment decreased.Pershing et al. (2015) conducted similar moldeing with updated data and the results were similar, providing further evidence of a negative effect of temperature on recruitment. Fogarty et al. (2007) also modeled Atlantic Cod distributions a function of temperature; as temperatures increased, Atlantic Cod distributions shifted northwards.

Life History Synopsis**:** Atlantic Cod are a typical marine groundfish that occurs on both coasts of the North Atlantic, but from Greenland to Cape Hatteras, North Carolina, in the western north Atlantic (Fahay et al., 1999; Lough, 2004). Over the last half century, age at maturity has fluctuated (1.7 - 5 years) reaching a low in the 1990s due to declines in stock abundance and increased temperature (Klein-MacPhee, 2002). Age at maturity has increased slightly (2-3 years) in the last decade (Lough, 2004). Spawning occurs at or near the bottom at night with a peak during winter and early spring (5-7 °C water) (Fahay et al., 1999; Lough, 2004). Peak spawning shifts with latitude and is correlated to temperature (Fahay et al., 1999; Lough, 2004). Fecundity is particularly high for Atlantic Cod, especially for larger females who produce millions of eggs over the course of a spawning season (Klein-MacPhee, 2002). Fertilized eggs are pelagic and hatch after 8-60 days varying with temperature, but average 2-3 weeks in typical spring conditions (Fahay et al., 1999; Lough, 2004). Larvae are pelagic, occurring from near surface down to 75 m, inhabiting deeper water with age (Fahay et al., 1999; Lough, 2004). Larvae consume phytoplankton and abundant zooplankton, such as copepods and nauplii (Fahay et al., 1999;

Klein-MacPhee, 2002; Lough, 2004). Planktivorous fish such as Atlantic Herring and Atlantic Mackerel are the main predators of larval Atlantic Cod (Lough, 2004). The pelagic stage lasts approximately 3 months after hatching (Fahay et al., 1999; Lough, 2004). Metamorphosis occurs at around 20 mm, but juveniles remain in the water column until they reach sizes of 40-60 mm, usually in early summer, then settle to the benthos (Fahay et al., 1999; Lough, 2004). Juvenile Atlantic Cod consume molluscs and crustaceans, selecting mostly pelagic prey when young, but increasingly benthic prey items as they grow and settle (Fahay et al., 1999; Lough, 2004). Gravel substrate provides better refuge from predators, which include many fishes, primarily: Spiny Dogfish, Sea Raven, Fourspot Flounder, and adult Atlantic Cod (Fahay et al., 1999; Klein-MacPhee, 2002; Lough, 2004). Adults occur from nearshore to offshore in cool water, with seasonal shifts (coastal northern waters in summer and fall; deeper southern waters in winter and spring) and age (near spawning grounds when young, more widely distributed and deeper, colder, and more saline with age (Fahay et al., 1999; Klein-MacPhee, 2002; Lough, 2004). These migrations are longer in the northern and southern extent of Atlantic Cod range and shorter in the middle part of the range (Fahay et al., 1999; Lough, 2004). Adults prefer rocky substrate usually occurring within 2 m of the bottom, but have been known to follow prey fish into the water column (Klein-MacPhee, 2002). Atlantic Cod travel as a mass with largest fish in the lead and smallest fish at the end (Fahay et al., 1999; Lough, 2004). Adult Atlantic Cod consume a variety of prey including pelagic and benthic invertebrates and smaller fish (Fahay et al., 1999; Lough, 2004). Large sharks and seals are among the only predators of large Atlantic Cod (Fahay et al., 1999; Klein-MacPhee, 2002; Lough, 2004). Cod in United States' waters have been exploited since at least the 1500s (Klein-MacPhee, 2002) and are currently managed as two stocks: Gulf of Maine and Georges Bank and southward (Fahay et al., 1999) under the New England Fishery Management Council's Northeast Multispecies Fishery Management Plan (Klein-MacPhee, 2002). Atlantic Cod are overfished and overfishing is occurring in both stocks (NEFSC 2013).

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