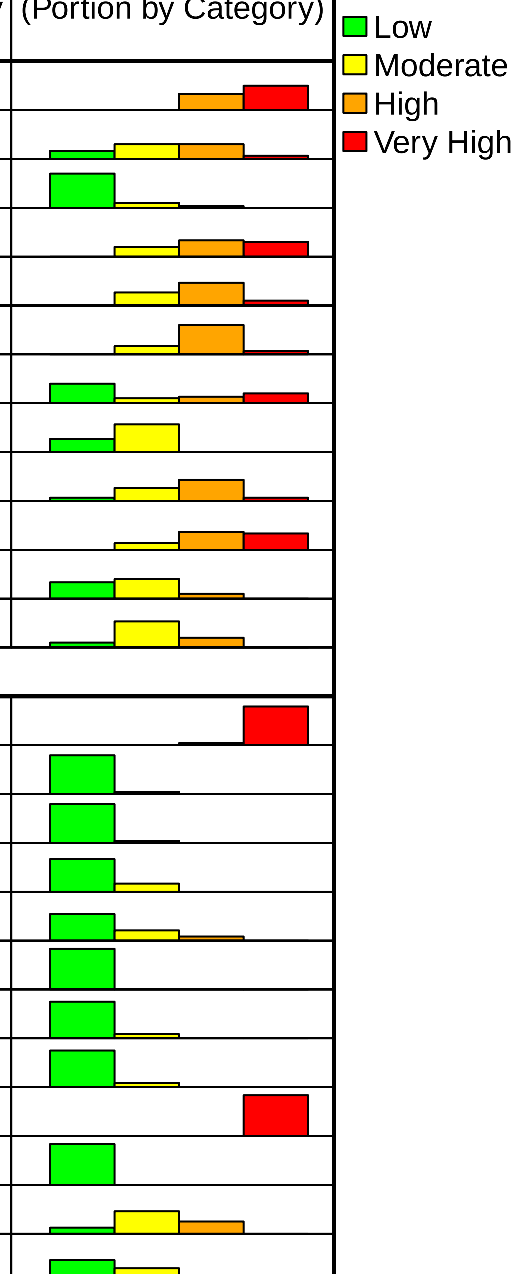
Northern Shrimp − *Pandalus borealis*

Overall Vulnerability Rank = High

Biological Sensitivity = High
Climate Exposure = High
Data Quality = 83% of scores ≥ 2

	Pandalus borealis	Expert Scores	Data Quality	Expert Scores Plots (Portion by Category)
Sensitivity attributes	Stock Status	3.6	1.4	
	Other Stressors	2.3	2.0	
	Population Growth Rate	1.2	2.8	
	Spawning Cycle	3.1	3.0	
	Complexity in Reproduction	2.8	2.2	
	Early Life History Requirements	2.9	1.8	
	Sensitivity to Ocean Acidification	2.2	2.6	
	Prey Specialization	1.7	2.4	
	Habitat Specialization	2.6	3.0	
	Sensitivity to Temperature	3.2	3.0	
	Adult Mobility	1.7	2.6	
	Dispersal & Early Life History	2.1	2.2	
	Sensitivity Score	High		
Exposure variables	Sea Surface Temperature	4.0	3.0	
	Variability in Sea Surface Temperature	1.0	3.0	
	Salinity	1.0	3.0	
	Variability Salinity	1.2	3.0	
	Air Temperature	1.4	3.0	
	Variability Air Temperature	1.0	3.0	
	Precipitation	1.1	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	1.6	1.5	
	Exposure Score	High		
Overall Vulnerability Rank		High		



Northern Shrimp (*Pandalus borealis*)

Overall Climate Vulnerability Rank: **High** (99% certainty from bootstrap analysis).

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

Biological Sensitivity: **High**. Three sensitivity attributes scored above 3.0: Stock Size (3.6), Spawning Cycle (3.1), and Sensitivity to Temperature (3.2). Northern Shrimp in the Gulf of Maine is at very low population sizes. They migrate offshore to spawn in the summer, and spawning is sensitive to temperature (Koeller et al., 2009).

Distributional Vulnerability Rank: **High** (96% certainty from bootstrap analysis).

Directional Effect in the Northeast U.S. Shelf: The effect of climate change on Northern Shrimp on the Northeast U.S. Shelf is very likely to be negative (>95% certainty in expert scores). Effects of ocean acidification on crustaceans are equivocal, but warming decreases population productivity and reductions in recruitment have already been observed.

Data Quality: 83% of the data quality scores were 2 or greater indicate that data quality is moderate.

Climate Effects on Abundance and Distribution: The productivity of Northern Shrimp in the Gulf of Maine is affected by ocean temperatures. Reduced recruitment in recent years has been linked with increasing temperatures (Richards et al., 2012) and has led to closure of the fishery (ASMFC, 2015). In Greenland, warming temperatures has led to an increase in the area occupied by the species (Wieland, 2005). In experiments, larval survival was not affected by CO_2 levels expected by 2100, but development rates were lower than in a control group (Bechmann et al., 2011; Arnberg et al., 2013). However, effects of warming temperature are likely greater on survival than decreasing pH (Arnberg et al., 2013). Decreasing pH may also decrease the quality of Northern Shrimp to consumers raising the possibility of a socio-economic interaction (decreased value at lower pH) (Dupont et al., 2014).

Life History Synopsis**:** Northern Shrimp is a boreal crustacean that occurs in cold waters of the North Pacific and Arctic Oceans and from the Atlantic Ocean as far south as the Gulf of Maine (NEFSC, 2014). Northern Shrimp are hermaphroditic, maturing first as males at 2.5 years, then as females at 3.5 years, and only a small portion of the population lives to spawn more than once as a female (ASMFC, 2014). Spawning occurs in offshore waters during summer and early fall (NEFSC, 2014). Eggs are extruded onto the abdomen of the females during fall and are carried until hatching (NEFSC, 2014). During late fall, egg-bearing females migrate inshore where the eggs hatch in spring (NEFSC, 2014). On the Newfoundland-Labrador Shelf, incubation times averaged approximately 7 months (Fuentes-Yaco et al., 2007). Larvae develop through 6 larval stages over an approximately 3 month pelagic period (NEFSC, 2014). Cooler temperatures support higher recruitment (NEFSC, 2014), and the timing of hatching in relation to the onset and duration of the spring plankton bloom may be important to the growth of early life history stages (Fuentes-Yaco et al., 2007). Larvae consume phytoplankton, copepod eggs, and nauplii while pelagic, but become increasingly associated with the benthos and increasingly consume larger copepodites and detritus at later stages (Fuentes-Yaco et al., 2007). After metamorphosis, juveniles settle to the bottom and remain in inshore waters for a year or more before migrating to deeper offshore waters to complete maturation (NEFSC, 2014). Juveniles and young males are found farther inshore than older males and non-ovigerous females (NEFSC, 2014). Growth requires molting of the exoskeleton and males undergo a series of transitional stages before maturing into females (ASMFC, 2014). Distribution is limited by temperature, salinity, depth, and substrate type (NEFSC, 2014). Organic-rich mud bottom is the preferred habitat, but rocky substrate and structure such as boulders and anemones are also used by the species (NEFSC, 2014). As the southern limit of their distribution, Northern Shrimp in the Gulf of Maine are further restricted to cooler parts of the Gulf and deep basins where temperatures remain in the 0-5 ^{o}C range (NEFSC, 2014). Adults prey on plankton and benthic invertebrates, occurring near the bottom during the day, but moving up in the water column at night to feed (NEFSC, 2014). Many commercially important species feed on Northern Shrimp, including: Atlantic Cod, Redfish, Silver Hake, and White Hake, and Pollock (NEFSC, 2014). Commercial fisheries target female Northern Shrimp (ASMFC, 2014). The Atlantic States Marine Fisheries Commission manages these fisheries through an interstate fishery management plan for Northern Shrimp including Maine, New Hampshire, and Massachusetts. The most recent assessment did not provide acceptable models for the stock, but a moratorium on fishing was enacted due to record low abundance, biomass, and recruitment indices and a record low estimate of an index of current fishable biomass (ASMFC, 2014).

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