Stock name: Northern shrimp
Latin name: *Pandalus borealis*
Geographical area: Skagerrak, Kattegat and northern North Sea in the Norwegian Deep (ICES divisions 3.a and 4.a East)
Experts: Guldborg Søvik, Fabian Zimmermann
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Stock Sensitivity Attributes

HABITAT SPECIFICITY: Although northern shrimp (*Pandalus borealis*, Pandalidae) can be found on rocky substrate, the species occurs mostly on soft, muddy substrate with a high organic content (Shumway et al., 1985; Zimmermann et al., 2019). Such habitats are very common in offshore areas in the Norwegian Deep and Skagerrak (www.mareano.no). Along the Skagerrak coast, the coast of western Norway, and in fjords, suitable habitats for the species is found in irregular patches of large and small soft bottom areas (Hjort & Ruud, 1938; Strøm & Øynes, 1974) (https://www.fiskeridir.no/Kart).

PREY SPECIFICITY: Northern shrimp is omnivore feeding on detritus, plankton and invertebrates (Shumway et al., 1985).

SPECIES INTERACTION: There is no evidence of significant interspecific competition. Northern shrimp utilizes a broad prey spectrum (Shumway et al., 1985) increasing competition capacities on food resources. Other shrimp species partially overlap in distribution with northern shrimp, but typically occur in much lower densities. This implies that intraspecific competition predominantly regulates population dynamics whereas interspecific competition is most likely not relevant. Northern shrimp is preyed upon by many demersal fish species, particularly young cod (Holt et al., 2019). In the Skagerrak and Norwegian Deep, it is found in the stomachs of cod, anglerfish, saithe, velvet belly, roundnose grenadier, whiting, and blue whiting (Bergstad et al., 2003; Skorda, 2018). A strong negative relationship between abundance indices of northern shrimp and cod have been shown for several ocean regions, but this relationship seems to be less strong for the southernmost stocks, like the Skagerrak and Norwegian Deep stock (Worm & Myers, 2003).

ADULT MOBILITY: Northern shrimps are mobile, and observations of hatching migrations of egg-bearing females as well as seasonal spatial shifts in the stock distribution underline the ability to migrate between sites (Shumway et al., 1985). The mobility may be high in respect to their small sizes, but it is somewhat limited compared to widely distributed fish species that are not constrained to muddy benthic habitats.

DISPERSAL OF EARLY LIFE STAGES: Larval planktonic stages have a duration of 2-3 months depending on water temperature (Shumway et al., 1985). During this period, currents in respect to hatching locations can cause advection and result in substantial transport distances of larvae (Jorde et al., 2015; Pedersen et al., 2003). The dispersal potential of the stock is high, suggesting a high ability to colonize new (suitable) habitats. The connectivity between inner, isolated fjord populations and shrimps along the coast is dependent on current systems and is presently unknown.

EARLY LIFE HISTORY SURVIVAL AND SETTLEMENT REQUIREMENTS: During the pelagic drift (Shumway et al., 1985) northern shrimp depends on food availability being sensitive to environmental changes, notably temperature (Arnberg et al., 2013). Although the mechanisms are not well understood, recruitment success is highly variable. The frequency of good year classes in the Skagerrak and Norwegian Deep stock is presently low compared with years before 2006 (ICES, 2020). This indicates that there is a high sensitivity of early life stages to environmental changes (Koeller et al., 2009).

COMPLEXITY IN REPRODUCTIVE STRATEGY: Northern shrimp in the Skagerrak and Norwegian Deep exhibits several characteristics that indicates a complex reproductive strategy (Shumway et al., 1985): 1. Northern shrimps are hermaphrodites, developing from immature juveniles to mature males to immature females to mature females. 2. Females moult before mating and spawning. 3. Primarily females (shrimp developing directly into females) are found in southern areas. The dependence of these characteristics and, thus, the reproductive strategy, on specific environmental conditions is considered low.
SPAWNING CYCLE: Northern shrimp eggs are carried by the females for several months after spawning until females migrate to shallower areas where the eggs hatch (Shumway et al., 1985). Spawning and mating occur once a year in a relatively short period, and local stocks are adapted to the time the eggs develop to match hatching with the spring bloom (Koeller et al., 2009). Climate change induced shifts of the spring bloom may result in an increased risk of a mismatch between hatching time and the spring bloom. Specifically, increased climate variability may therefore be problematic. It is unknown if or how fast the species could adapt the timing of spawning, incubation and hatching to changing environmental conditions.

SENSITIVITY TO TEMPERATURE: Northern shrimp has a continuous distribution from Skagerrak and the North Sea to north of Spitsbergen (Bergström, 2000; Shumway et al., 1985). It is further distributed in Icelandic waters, and along the coast of Greenland and eastern North America south to the Gulf of Maine. The species may be found at depths between 50 and 500 m. In Skagerrak and the Norwegian Deep, northern shrimp is found between 100 and 500 m (Søvik & Thangstad, 2019). Northern shrimp seem to thrive within a large temperature range (from below 0 to 10-12°C) (Shumway et al., 1985). This suggests that the species has a high temperature tolerance and can adapt to increasing temperatures, particularly at its northern range limit. However, local stocks seem to be adapted to narrower temperature ranges (Jorde et al., 2015). Northern shrimp in the Skagerrak and Norwegian Deep are found at temperatures between 5 and 9 °C (Søvik & Thangstad, 2019). Distinct genetic populations along the Norwegian coast and in the Barents Sea indicate that larvae from the coastal stock drifting into the Barents Sea die, possibly because of temperatures outside tolerance levels (Jorde et al., 2015). The sensitivity of the species is considered low, whereas the sensitivity of local shrimp stocks may possibly be high. As the Skagerrak and Norwegian Deep stock is found at the species' southernmost limit of the distribution in the Northeast Atlantic, it is likely sensitive to rising temperatures.

SENSITIVITY TO OCEAN ACIDIFICATION: As a crustacean, northern shrimp may be directly affected by ocean acidification (OA), specifically during early life stages and molting. Experimental evidence suggests a slower development of early life stages under OA conditions (Arnberg et al., 2013; Bechmann et al., 2011). It is unknown whether adult shrimp will be affected by the levels of OA.

POPULATION GROWTH RATE: Northern shrimp is a relatively short-lived species with high productivity (Shumway et al., 1985) that falls into the low vulnerability bin. Direct age determination is not possible, and age is determined using length frequency distributions from the Skagerrak and Norwegian Deep stock. For this stock, maximum age is around 4-5 years (Søvik & Thangstad, 2019). Estimates of growth parameters exist for the Skagerrak and Norwegian Deep stock ($K = 0.43$, $L_{infinity} = 28.1$ mm) (ICES, 2016). In this stock, males mature at an age of 1.5 years, while most females mature at an age of 2.5 years. However, the life history of northern shrimp cannot easily be compared to the standard categories used for fish, e.g. northern shrimps are hermaphrodites that subsequently undergo maturation for each sex (Shumway et al., 1985). Furthermore, the short life cycle, especially in the southern part of its distribution range, and therefore the dependency on good recruitment at relatively short intervals may increase the vulnerability to sudden shifts in climate that may cause several consecutive years of recruitment failure.

STOCK SIZE/STATUS: Spawning stock biomass (SSB) of the Skagerrak and Norwegian Deep stock was estimated to be between the limit reference point for SSB (B_{lim}) and the value of SSB that triggers a specific management action ($B_{trigger}$) in the beginning of 2020 (ICES, 2020). SSB declined after 2008 and has fluctuated at a lower level since then, slightly above B_{lim}. Instantaneous rate of fishing mortality (F) has been around F consistent with achieving maximum sustainable yield (F_{MSY}) since 2011 and is below F_{MSY} in 2019. Recruitment has been below average since 2008, except for the 2013-year class. $B_{2020}/B_{trigger}$ = 0.84.

OTHER STRESSORS: The distribution of northern shrimp in the Norwegian Deep has decreased since 2013 (Søvik & Thangstad, 2019). The species is currently found only in southern parts of the area and along the coast. It is unknown if external stressors are causing this shift in the distribution of the Skagerrak and Norwegian Deep stock or whether it is due to the smaller stock size. F has been above F_{MSY} in all years since 2011, except in 2015, 2018 and 2019 (ICES, 2020). The coastal part of the stock is subject to multiple stressors that may have adverse effects on coastal shrimp populations. The stressors are mostly caused by human alterations of coastal habitats that result in habitat degradation (organic enrichment from fish farms, dumping of mining waste), changes in fjord hydrography due to hydropower plants changing river runoffs (Myksvoll et al., 2014), and direct adverse impacts, e.g. chemical delousing agents used in salmon farms (Grefsrud et al., 2019). In addition, an increase in hypoxic areas has been observed, potentially caused by aquaculture and/or changes in water mixing. Thus, impact of stressors on the entire stock is low, but anthropogenic stressors may have substantially negative effects locally.

Scoring of the considered sensitivity attributes

Sensitivity attributes, climate exposure based on climate projections allowing the evaluations of impacts of climate change, and accumulated directional effect scoring for Northern shrimp (*Pandalus borealis*) in ICES divisions 3.a and 4.a East. L: low; M: moderate; H: high; VH: very high, $Mean_w$: weighted mean; N/A: not applicable. Usage: this column was used to make ad hoc notes, including considerations about the amount of relevant data available: 1 = low, 2 = moderate; 3 = high. N/A = not applicable.

Northern shrimp (*Pandalus borealis*) in ICES divisions 3.a and 4.a East

SENSITIVITY ATTRIBUTES	L	M	H	VH	$Mean_w$	Usage	Remark
Habitat Specificity	0	1	4	0	**2.8**		
Prey Specificity	5	0	0	0	**1.0**		
Species Interaction	4	1	0	0	**1.2**		
Adult Mobility	0	3	2	0	**2.4**		
Dispersal of Early Life Stages	4	1	0	0	**1.2**		
ELH Survival and Settlement Requirements	0	0	3	2	**3.4**		
Complexity in Reproductive Strategy	1	3	1	0	**2.0**		
Spawning Cycle	0	0	1	4	**3.8**		
Sensitivity to Temperature	0	3	2	0	**2.4**		
Sensitivity to Ocean Acidification	0	0	3	2	**3.4**		
Population Growth Rate	4	0	0	1	**1.6**		
Stock Size/Status	0	1	3	1	**3.0**		
Other Stressors	4	0	0	1	**1.6**		
Grand mean					**2.29**		
Grand mean SD					**0.94**		

CLIMATE EXPOSURE	L	M	H	VH	$Mean_w$	Usage	*Directional Effect*
Surface Temperature	0	0	0	0		N/A	
Temperature 100 m	0	0	0	0		N/A	
Temperature 500 m	0	0	0	0		N/A	
Bottom Temperature	3	2	0	0	**1.4**		-1
O_2 (Surface)	0	0	0	0		N/A	
pH (Surface)	3	2	0	0	**1.4**		-1
Gross Primary Production	4	1	0	0	**1.2**		1
Gross Secondary Production	0	0	0	0		N/A	
Sea Ice Abundance	0	0	0	0		N/A	
Grand mean					**1.33**		
Grand mean SD					**0.12**		
Accumulated Directional Effect					**–**		**-1.6**

***Accumulated Directional Effect*: NEUTRAL**	**-1.6**

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