Stock name: Snow crab
Latin name: *Chionoecetes opilio*
Geographical area: Barents Sea (ICES subarea 1)
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Stock Sensitivity Attributes

HABITAT SPECIFICITY: The snow crab (*Chionoecetes opilio*, Oregoniidae) is defined as subarctic species and prefers deep cold-water conditions, so the most important habitat criteria are most probably linked to temperature ranges and depths (Brêthes et al., 1987; Comeau et al., 1998; Sainte-Marie & Hazel, 1992). Therefore, availability of the right depths, bottom substrate and temperatures will restrict the distribution of the snow crab in the Barents Sea. During the life cycle, different habitats are used. Most size classes live on soft, sandy, and muddy bottoms. These substrates can act as protection for the snow crab, as it can easily burrow into the soft substrate. They are to be found at depths from relatively shallow to 450 m. Juvenile size classes (carapace width (CW) < 30 mm) can use other types of substrates as habitat before they start migrating to more soft bottom substrates.

PREY SPECIFICITY: In general, the snow crab is an omnivorous species and preys on a variety of infauna and epifauna species living in soft bottom substratum. In addition, also remnants of fish are known to be a prey item. The most frequent prey groups are bivalves, small crustaceans and polychaetes (Kolts et al., 2013; Squires & Dawe, 2003). The findings from the Barents Sea suggest that the diet resembles what is available in the Bering Sea and eastern Canada regarding prey composition (Zakharov et al., 2018).

SPECIES INTERACTION: The snow crab represents a new predatory crustacean in the Barents Sea, and it preys on a variety of infauna species living in the soft bottom sediment. It is known from the Northwest Atlantic (e.g. eastern Scotian Shelf and Newfoundland Shelf) that when the cod stock was exposed to overfishing and declined and subsequently collapsed, these periods coincided with a marked increase in snow crab abundance but also small planktivorous fish and northern shrimp (*Pandalus borealis*) (Frank et al., 2005). From the Barents Sea, we know that cod preys upon the snow crab but also haddock (*Melanogrammus aeglefinus*), wolffish (*Anarhichas spp*.), thorny (*Amblyraja radiata*, Rajidae) and Arctic skate (*Amblyraja hyperboreus*, Rajidae), long rough dab (*Hippoglossoides platessoides*), shorthorn sculpin (*Myoxocephalus scorpius*, Cottidae) and Arctic staghorn sculpin (*Gymnocanthus tricuspis*, Cottidae) may do so (Holt et al., personal communication). A recent study (Hansen et al., 2019), using the Nordic and Barents Seas Atlantis Ecosystem Model, shows that the possible future increase in the snow crab distribution has the potential to impact a larger part of the Barents Sea ecosystem. Preliminary results indicate that capelin, herring, Polar cod, redfish, and Greenland halibut benefit from present crab in the system. However, their level of response varies, but they all respond positively as predators having a large fraction of snow crab in their diet. Any other competitors would be other bottom feeding fish in the Barents Sea.

ADULT MOBILITY: It is known from the literature that adult snow crabs, both males and females, can undertake small-scale ontogenetic movements or seasonal migrations (Nichol & Somerton, 2015). The snow crab distribution in the Barents Sea is most likely restricted by bottom temperature and bottoms depth. Adult crabs can move and migrate into new areas. Recently, some authors (Mullowney et al., 2018) showed that large adult males migrated mostly westwards in the Barents Sea, while others (Orensanz et al., 2005) described that snow crab perform migration due to changes in bottom temperatures.

DISPERSAL OF EARLY LIFE STAGES: The snow crab stock has probably spread into the Barents Sea both by migrating adults and drifting larvae. As mature adults spread further west in the Barents Sea, it is expected that they also will release larvae which will drift by currents and potentially colonize new areas. The pelagic larval phase, consisting of 2 zoeal stages and 1 megalopa stage can last a total of at least 3-5 months (Lovrich et al., 1995; Ouellet & Sainte-Marie, 2018), which can be favourable if the larvae find the right environment and suitable seabed for settlement when the pelagic phase ends (Orensanz et al., 2005).

EARLY LIFE HISTORY SURVIVAL AND SETTLEMENT REQUIREMENTS: The snow crab has a complex life cycle. Eggs are hatched from April to June when the larvae become pelagic and feeding upon plankton for 3-5 months. This refers to zoea stages 1 and 2, the latter turning into a megalope. The larvae settle to the bottom substratum during autumn (September to October). In other areas the pelagic stages can have highest abundance in October, and they will then not start to settle until January. The earliest benthic stages of snow crab are apparently being the most stenothermic of all life stages (Comeau et al., 1998; Ouellet & Sainte-Marie, 2018; Sainte-Marie et al., 1995). For the Barents Sea, there is presently limited knowledge about the early life history survival of snow crab.

COMPLEXITY IN REPRODUCTIVE STRATEGY: The female can brood for up to 2 years, depending on ambient temperatures, food availability and the maturity status. For first-time breeding female, it can take up to 27 months, for the second or third breeding events up to 24 months. Also, more rapid developments of the eggs (from 12 to 18 months) have been observed (Danielsen et al., 2019; Sainte-Marie, 1993; Webb et al., 2007). The female becomes sexually mature at their last (terminal) moult when the CW reaches 35 to 100 mm (in the Barents Sea; Institute of Marine Research, IMR-data, Norway). This may happen between 4 and 6 years, or after 8 to 10 moults. Prior to mating, a male will start holding a female preparing for terminal moult and assists her through moulting. The male protects her fending off other males and predators. There can be competition for females, and females can be selective when choosing a mating partner. The male fertilizes the eggs before they are released, and the eggs are deposited on the female pleopods under the abdomen until the larvae hatch. Mainly the water temperature determines how long eggs are carried. Sperm can accumulate during the mating process, so after the larvae hatch the female can mate again or use stored sperm to fertilize future clutches of eggs.

SPAWNING CYCLE: The reproductive cycle can be annual or biennial depending on temperature, with females residing in water < 1 °C brooding their eggs for approximately 2 years, whereas females residing in warmer water complete the cycle in approximately one year (Kuhn & Choi, 2011; Moriyasu & Lanteigne, 1998). At least two features of the snow crab reproduction make our results difficult to interpret, namely the possible variation in the duration of brooding between annual and biennial cycles and the differing mating period between primiparous and multiparous females.

SENSITIVITY TO TEMPERATURE: The snow crab is characterized as a subarctic species and has a limited temperature range. The snow crab is found in temperatures between -1 to 6 °C. It is shown that when the snow crab is living in temperatures close to 6-7 °C, the metabolic costs are thought to match metabolic gains (Siikavuopio et al., 2019). Juvenile crabs are more stenothermic than adult crabs (Ouellet & Sainte-Marie, 2018).

SENSITIVITY TO OCEAN ACIDIFICATION: There are results from a study on the closely related tanner crab (*Chionoecetes bairdi*), where embryonic development, hatching success, and calcification of ovigerous females were studied. The results from this publication suggest that projected ocean pH levels within the next two centuries will likely have a pronounced impact on tanner crab populations, unless the crab are able to acclimatize or adapt to changing conditions (Long et al., 2013; Swiney et al., 2016). The snow crab is well adapted to projected ocean pH levels, in sharp contrast to the tanner crab, although ocean acidification sensitivity of juveniles still needs to be examined (Foy et al., 2018).

SNOW CRAB

POPULATION GROWTH RATE: The tabled criteria to be consulted do not apply to snow crab.

STOCK SIZE/STATUS: In the fishery for snow crab, only male crabs that meet or exceed the minimum legal size of 100 mm CW may be harvested. In the Barents Sea, the fishery started in 2012 as a trail fishery. One boat landed 2,500 tonnes the first year. The year to come, more and more boats and different nations participated. The landings increased rapidly and in the period 2014 to 2016 Norwegian, Russian and EU vessels participated in the fishery. At the most, around 37 vessels were active. The total landings from the Barents Sea have fluctuated around a mean of 14,000 tonnes with a top in the landings of 18,000 tonnes in 2015. From 2017, a total allowable catch (TAC) was established both in the Russian and Norwegian fishery. The last years, the landings have stabilized around 12,000 tonnes in total. We still lack good timeseries on the stock, but it is assumed that the fishing pressure was very high around 2015, but how it affected the stock is remains unclear. The high minimum legal size of 100 mm CW is set to protect the reproductive potential. We do not have good measurements for the biomass development in the Barents Sea.

OTHER STRESSORS: Any fishing of soft-shell crabs can be considered a significant stressor on the stock.

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 Snow crab (*Chionoecetes opilio*) in ICES subarea 1. 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.

Snow crab (*Chionoecetes opilio*) in ICES subarea 1

SENSITIVITY ATTRIBUTES	L	M	H	VH	$Mean_w$	Usage	Remark
Habitat Specificity	0	3	2	0	**2.4**		
Prey Specificity	5	0	0	0	**1.0**		
Species Interaction	0	3	2	0	**2.4**		
Adult Mobility	1	2	2	0	**2.2**		
Dispersal of Early Life Stages	5	0	0	0	**1.0**		
ELH Survival and Settlement Requirements	0	0	4	1	**3.2**		
Complexity in Reproductive Strategy	0	0	2	3	**3.6**		
Spawning Cycle	0	4	1	0	**2.2**		
Sensitivity to Temperature	0	0	1	4	**3.8**		
Sensitivity to Ocean Acidification	0	1	3	1	**3.0**		
Population Growth Rate	5	0	0	0	**1.0**		
Stock Size/Status	5	0	0	0	**1.0**		
Other Stressors	0	1	3	1	**3.0**		
Grand mean					**2.29**		
Grand mean SD					**1.02**		

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	1	3	1	0	**2.0**		-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	5	0	0	0	**1.0**		0
Sea Ice Abundance	5	0	0	0	**1.0**		1
Grand mean					**1.32**		
Grand mean SD					**0.41**		
Accumulated Directional Effect					**–**		**-1.2**

***Accumulated Directional Effect*: NEGATIVE**	**-1.2**

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