COASTAL COD – NORTH OF STADT (62°N)

Stock name: Coastal cod North
Latin name: *Gadus morhua*
Geographical area: North Norway, north of Stad (62 °N) (ICES subarea 2a)
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Stock Sensitivity Attributes

HABITAT SPECIFICITY: Coastal cod (*Gadus morhua*, Gadidae) North (North Norway, north of Stad) comprise local, coastal cod stocks typically from inner coastal regions. Although the local stocks are confined to small areas, their general habitat is continuously distributed along the Norwegian coast from Stad to Varanger. Modelling the drift of the offspring, particularly pelagic eggs, shows that fjord populations (Myksvoll et al., 2011) as well as coastal populations (Myksvoll, Jung, et al., 2014) have distinct and separated spawning areas. The dispersal of the offspring shows significant retention, quite differently from the neighbouring Northeast Arctic cod where the offspring is subjected to a very long transport from the outer coastal spawning areas to the Barents Sea settling after 5 months of pelagic drift. Tagging experiments indicate, though, that adult coastal cod populations undertake local seasonal migrations (Berg & Albert, 2003), and they may leave the local fjord habitat (Jakobsen, 1987) migrating occasionally to adjacent offshore location along the shelf (Godø, 1995). Some of the coastal cods are also inhabiting the offshore areas on a permanent basis (Nedreaas, 2006) but without utilizing the Barents Sea proper as habitat. An enigma is that some of the coastal cod is also spawning at the same spawning sites as the Northeast Arctic cod in Lofoten. However, it has been suggested that the spawning fish from the two stocks do not interbreed (Nordeide & Båmstedt, 1998; Nordeide & Folstad, 2000). Whether or how the pelagic offspring of the two different stocks will have differential drift pattern from the same spawning sites is unclear. It has been shown that the two stocks spawned at the same sites in Lofoten had different morphometric characteristics (Hylen, 1964). Moreover, the coastal cod matures 4 years earlier than the Northeast Arctic cod. In the same study (Hylen, 1964), the author concluded that Northeast Arctic cod migrates back to the Barents Sea after spawning in March-April, while the coastal component spawning in Lofoten is limited to areas north of 70 °N. Hence, one possibility is that the more permanently offshore components of coastal cod that do not migrate into the Barents Sea proper could be the coastal component that utilize the same spawning areas as Northeast Arctic cod. In conclusion, the major parts of Coastal cod and Northeast Arctic cod, including the early life stages, are spatially separated in coastal-fjord regions and the Barents Sea, respectively. However, a certain fraction of the two stocks have overlapping spawning areas in Lofoten during spring, most probably without interbreeding. It is still unclear how and whether the pelagic offspring from these common spawning sites have differential drift pattern and subsequent settling of the 0-group fish. In the Barents Sea the 0-group fish is settling above bottom depth of 150-300 m, while in coastal regions the 0-group is settling much shallower and partly in the littoral zone.

PREY SPECIFICITY: As Atlantic cod in general, The coastal cod is a diet generalist and opportunist clearly demonstrated by a large variety in prey that shifts with the local habitat (Mortensen, 2007). The mature part of the stock is on top of coastal food webs. Similar to most other cod stocks cannibalism is also important factor for coastal cod in northern Norway (Kanapathippillai et al., 1994). In the Ullsfjord system in Troms invertebrates are the dominant prey species for small and medium size cod, while larger cod increasingly prey on herring, other gadoid and long rough dab (Pedersen & Pope, 2003). For the largest cod cannibalism is a major fraction of the diet. In Balsfjord farther south in Troms the diet is dominated by shrimp, krill and capelin (Klemetsen, 1982). In comparison, studies from Western Norway show preference of wrasses and gobies for smaller individuals, while various species of crabs are important in the fjords of Salten adjacent to Vestfjorden (Svåsand et al., 2000). The early life stages (ELS) of cod, similar to other cod stocks, are planktivorous first feeding on small copepods and nauplii stages and later switching to larger species like krill while advancing to pelagic juveniles.

SPECIES INTERACTION: Most coastal cod stocks of North Norway are spatially separated from the Northeast Arctic cod, particularly during the early life stages (Myksvoll et al., 2011; Myksvoll, Jung, et al., 2014). However, a certain fraction of the coastal cod interacts strongly with Northeast Arctic cod as they share similar spawning areas at the same time in Lofoten. It is, however, unclear whether the two stocks interbreed at these common spawning sites. In several studies, authors argue that no interbreeding occurs (Nordeide & Båmstedt, 1998; Nordeide & Folstad, 2000). There are clear morphometric differences between the two stocks. Coastal cod matures much earlier (Hylen, 1964) indicating that the coastal cod occupies a habitat with higher temperatures than Northeast Arctic cod in the Barents Sea. Also, the structure of otoliths differs, which is assumed to be shaped by environmental rather than genetic constraints (Stransky et al., 2008). In a comprehensive review of 54 studies on population distinction between Northeast Arctic cod and coastal cod, the authors found in 70% of cases genetical isolation (Nordeide et al., 2011). However, they stated that the major part of these works is based on measurements of non-neutral loci and concluded (in 2011) that "we are still far from a proper understanding of the population genetic structure of Atlantic cod in these waters.". They suggest improved methodologies for future research. Presently (2020), the question is still open. Concerning competition for food, cod is to a certain extent competing with other gadoids like haddock and saithe (*Pollachius virens*, Gadidae). However, these species are also fed on by larger cod (Pedersen & Pope, 2003).

ADULT MOBILITY: The adult mobility varies strongly among the sub-populations. The fjord populations have the lowest degree of mobility (Nedreaas, 2006), and these populations also have the strongest retention of the pelagic offspring (Myksvoll et al., 2011; Myksvoll, Jung, et al., 2014). Hence fjord populations are considered the most isolated and separated of the coastal cod populations. The populations spawning at the inner coastal locations seems to take somewhat longer migrations along the coast, while those populations taking the longest migrations are also those that are commonly termed "bank cod" (Nedreaas, 2006). They migrate offshore wards on the continental shelf and limited to the southernmost near-coastal parts of the Barents Sea. These populations seem to share spawning areas with the Northeast Arctic cod at Møre and in Lofoten (Johansen et al., 2018).

DISPERSAL OF EARLY LIFE STAGES: Egg and larval dispersal depend strongly on spawning areas. The fjord populations spawn generally at the mouth of the fjords. Here, the combined effect of egg buoyancy, salinity stratification and estuarine circulation dynamics can exert strong retention inside the fjords (Myksvoll et al., 2011). Densities of coastal cod eggs have been shown to be slightly higher than the eggs of Northeast Arctic cod (Stenevik et al., 2008). This increases the potential for a deeper distribution in fjords. However, it remains unclarified whether the densities are significantly higher than those of Northeast Arctic cod eggs (Jung et al., 2012). The coastal metapopulations are more dispersed from their spawning areas than the ones in the fjords, but they still seem to have limited their transport along the inner coast region (Myksvoll, Jung, et al., 2014). The coastal populations that share spawning areas with the Northeast Arctic cod (Johansen et al., 2018) have the most extensive transport routes. However, for still unknown reasons, they seem to have more limited ELS transport compared to Northeast Arctic cod that settle as 0-group inside the Barents Sea.

EARLY LIFE HISTORY SURVIVAL AND SETTLEMENT REQUIREMENTS: The coastal cod stocks settle along the coastline at shallow depths after a short period of pelagic drift. The pelagic stages start feeding on small copepods and nauplii stages switching to larger prey as they grow. Subsequent to settlement they grow and recruit into the populations across a wide range of environmental gradients along the coast (Aglen et al., 2016). Invertebrate diet dominates for all small cod (Pedersen & Pope, 2003).

COMPLEXITY IN REPRODUCTIVE STRATEGY: Skipped spawning is known for Northeast Arctic cod in the Barents Sea under poor food conditions, but requires, yet absent, investigations along the coast. Northern populations of coastal cod have a higher fecundity than southern cod populations (Blom &

Kennedy, 2016). It is expected that spawning temperature conditions for northern coastal cod will not reach critical levels of 9.5 °C as a potential threat for North Sea cod under future climate change.

SPAWNING CYCLE: Northern coastal cod has an extended spawning period from March to May and matures at age 5-7 (Hylen, 1964). There are indications that peak spawning of coastal cod occurs towards the end of April (Kjesbu, 1988).

SENSITIVITY TO TEMPERATURE: The stocks are distributed along the coast of Norway north of 62 °N across a wide depth range (5-400m). The sensitivity to temperature is assumed to be approximately similar to other Northeast Arctic cod stocks which implies a spawning temperature ranging from 1 to 9.5 °C with an optimal temperature of about 6 °C. Pelagic juveniles and young cod, on the other hand, have a much wider temperature tolerance. The optimal growth rate is observed at around 13 °C (Otterlei et al., 1999), and declines rapidly at temperatures >18 °C. Adult coastal cod experience warmer conditions than Northeast Arctic cod, particularly during summer when the Northeast Arctic cod inhabits the polar Front in the Barents Sea at 0 °C and even below. During the life cycle of ELS in spring, however, coastal cod is exposed to somewhat lower temperatures than the Northeast Arctic cod, because upper-layer temperatures during spring is lower in fjords and inner coastal regions compared to the outer coastal regions where Northeast Arctic cod spawns.

SENSITIVITY TO OCEAN ACIDIFICATION: Ocean acidification (OA) will occur first in deeper layers. The pelagic surface layer will be less influenced by OA. However, it is assumed that the early larval stages are more vulnerable to OA than the adults, assumable due to undeveloped gills that in adult allow ion-regulation (Frommel et al., 2013). Experiments with cod larvae from the Baltic Sea and the Barents Sea showed increased mortality of both stocks under the IPCC RCP8.5 scenario (comparing to atmospheric CO_2 of 1,100 ppm by the end of 21st century) (Stiasny et al., 2016), although less impact on Baltic cod as larvae from the Baltic Sea naturally are exposed to very high OA due to low salinity and sub-oxic conditions. In fact, Baltic cod larvae were resilient to OA (Frommel et al., 2013). It is expected that North Sea cod has similar degree of vulnerability to OA as the Barents Sea cod. Also, Norwegian coastal cod larvae were observed to suffer tissue damages under high OA (Frommel et al., 2012). High OA was observed to negatively influence calcification in larval otoliths of Barents Sea cod (Maneja et al., 2013). The RCP8.5 scenario seem devastating for the coastal cod stock. It is unclear how the RCP4.5 scenario would impact larval cod. Coastal cod is expected to be impacted to a larger extent to OA and reduction in oxygen than the oceanic populations in the Barents Sea and the North Sea. This is because many of the coastal cod stocks inhabit deep fjord with sill where deep water is more exposed to OA due to weak currents and low-oxygen water.

POPULATION GROWTH RATE: Population growth is negative, and the fjord population, that shows the lowest exchange with other coastal cod stocks, display the most negative trend (Nedreaas, 2006). ICES recommended a rebuilding plan for Norwegian coastal cod (ICES, 2018) over the recent 15 years. Total allowable catch (TAC) of 21,000 tonnes has been included as a part of the quotas for Northeast Arctic cod since 2005. However, ICES' estimates of the commercial catches of the coastal cod are increasing since 2014 exceeding 50,000 tonnes in 2017.

STOCK SIZE/STATUS: According to Nedreaas (Nedreaas, 2006) the population was reduced by 50-80 % between 1985 and 2005, because of a lack of efficient measures to reduce fishing pressure, and weak recruitment. ICES fails to implement a biomass maximum sustainable yield (B_{MSY}) for coastal cod north of 62 °N, but their advice is not to exploit the populations. However, in addition to the commercial fisheries, these stocks are uncontrolled exploited by non-commercial fishing and tourist fishing. Presently, the age structure indicates that the mortality is moderate but might be increasing. It is the most isolated fjord populations that is under the highest pressure.

OTHER STRESSORS: The development of hydroelectric power plants in Norway during the 20th century has influenced the natural seasonal runoff to the Norwegian fjords resulting in various impacts on the ecological responses (Skreslet, 1986). In Northern Norway fjords, the consequence of increased runoff during early spring causes an earlier stratification than in unregulated fjord systems, changing in the estuarine circulation during spring. This causes aberrant transport of coastal cod eggs spawned within such fjords (Myksvoll, Sandvik, et al., 2014) negatively influencing connectivity among various local fjord stocks of coastal cod. Another stressor in fjords and coastal waters is pollution by river run-off termed “murky waters” due to increasing modern land-use. It reaches the euphotic depth which possibly inhibits primary production growth, particularly during the onset of the spring bloom (Aksnes, 2015). In addition, increased activity in salmon farming, raises concern among fishermen of uncontrolled expelling effects of sea lice, pathogens, pollutants and others affecting natural occurring fish populations, particularly during spawning. An experiment indicated absence of spawning cod in a fjord in Northern Norway with intensive salmon farming (Bjørn et al., 2009) . The effects of the changes in water cycle in the Norwegian fjords, including changes in the seasonal fluxes and in water quality are still unclear. However, it becomes apparent that fish populations in Norwegian fjords and near-coastal regions are stronger negatively impacted by anthropogenic stressors than their oceanic counterparts.

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 Coastal cod (*Gadus morhua*) stock in ICES subarea 2a. 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.

Coastal cod (*Gadus morhua*) North in ICES subarea 2a

SENSITIVITY ATTRIBUTES	L	M	H	VH	$Mean_w$	Usage	Remark
Habitat Specificity	1	3	1	0	**2.0**		
Prey Specificity	1	3	1	0	**2.0**		
Species Interaction	2	2	1	0	**1.8**		
Adult Mobility	1	3	1	0	**2.0**		
Dispersal of Early Life Stages	1	3	1	0	**2.0**		
ELH Survival and Settlement Requirements	1	3	1	0	**2.0**		
Complexity in Reproductive Strategy	0	1	3	1	**3.0**		
Spawning Cycle	0	1	3	1	**3.0**		
Sensitivity to Temperature	0	1	3	1	**3.0**		
Sensitivity to Ocean Acidification	5	0	0	0	**1.0**		
Population Growth Rate	0	1	3	1	**3.0**		
Stock Size/Status	1	1	2	1	**2.6**		
Other Stressors	5	0	0	0	**1.0**		
Grand mean					**2.18**		
Grand mean SD					**0.70**		

CLIMATE EXPOSURE	L	M	H	VH	$Mean_w$	Usage	*Directional Effect*
Surface Temperature	0	0	0	0		N/A	
Temperature 100 m	1	2	2	0	**2.2**	3	1
Temperature 500 m	0	0	0	0		N/A	
Bottom Temperature	0	0	0	0		N/A	
O_2 (Surface)	4	1	0	0	**1.2**	2	-1
pH (Surface)	5	0	0	0	**1.0**	2	-1
Gross Primary Production	4	1	0	0	**1.2**	1	1
Gross Secondary Production	1	2	1	1	**2.4**	1	1
Sea Ice Abundance	4	1	0	0	**1.2**	1	1
Grand mean					**1.53**		
Grand mean SD					**0.60**		
Accumulated Directional Effect					**–**		**4.8**

***Accumulated Directional Effect*: POSITIVE**	**4.8**

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