NORTH EAST ARCTIC HADDOCK

Stock name: North east Arctic haddock
Latin name: *Melanogrammus aeglefinus*
Geographical area: Barents Sea (ICES subareas 1 and 2)
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Stock Sensitivity Attributes

HABITAT SPECIFICITY: Northeast Arctic haddock (*Melanogrammus aeglefinus*, Gadidae) has a somewhat more westerly distribution in the Barents Sea than the Northeast Arctic cod (Olsen et al., 2010). Therefore, it also inhabits somewhat higher temperatures during the adult stages as well as during 0-group stage (Eriksen et al., 2012; Ottersen & Loeng, 2000). Haddock is generally spawning along the shelf edge off the coast of northern Norway (Bergstad et al., 1987; Castaño-Primo et al., 2014; Russkikh & Dingsør, 2011).

PREY SPECIFICITY: All main haddock stocks include a large proportion of benthic invertebrates, mainly echinoderms, in their diet after bottom settling, but also feed on other food including fishes. After bottom settling, the degree of piscivory does not increase with age, but varies seasonally, inter-annually and between stocks (Tam et al., 2016). Northeast Arctic haddock has largely a benthic diet after the pelagic 0-group stages (Dolgov et al., 2011). It has been found that 60% of the stomach content by weight were Crustacea and Echinodermata (Jiang & Jørgensen, 1996). Only 20% were fish. Among the crustaceans, Euphasiidae, Amphipoda, Hyperiidae and *Pandalus borealis* (Pandalidae) dominated. Among the fishes, redfish (*Sebastes* sp.), capelin and sandeel dominated. In addition, echinoderms (22%) are the most common prey group, followed by euphausiids (21%), less than 13% were fish (Dolgov et al., 2011).

SPECIES INTERACTION: With respect to fish prey, the diet of Northeast Arctic haddock overlaps to a minor degree with the one of Northeast Arctic cod (Jiang & Jørgensen, 1996). 0-group haddock and cod show highly overlapping diets, consisting mainly of *Calanus finmarchicus* and *Thysanoessa inermis* (Dalpadado et al., 2009).

ADULT MOBILITY: During cool periods in the Barents Sea, cod as well as haddock are found in the western and warmest parts of the Barents Sea. During warm periods with large stock size haddock has been expanding towards east and north (Landa et al., 2014). It remains unknown how far north and east haddock will expand under future global warming. The northernmost limit is the continental shelf edge in the Polar Ocean, north of Svalbard (Stenevik & Sundby, 2007).

DISPERSAL OF EARLY LIFE STAGES: Haddock has highly dispersed eggs and larvae, with long lasting planktonic stages (Castaño-Primo et al., 2014; Russkikh & Dingsør, 2011).

EARLY LIFE HISTORY SURVIVAL AND SETTLEMENT REQUIREMENTS: Both cod and haddock tend to form strong year classes in warm periods. However, Northeast Arctic haddock recruitment is much more variable than Northeast Arctic cod recruitment; this is common to sympatric cod and haddock stocks from several regions (Fogarty et al., 2001). 0-group haddock settles in the more westerly part of the Barents Sea compared to cod. This is a result of haddock spawned farther west than cod, i.e. along the shelf edge of the northern Norwegian continental shelf at the border between the Norwegian Coastal Current and the Atlantic Current (Castaño-Primo et al., 2014). It has been hypothesized that a fraction of haddock offspring is lost in the deep Norwegian Sea (Castaño-Primo et al., 2014) when dispersal conditions allow for such advection. With a period of several cold winters, there is high mortality the first winter, and the distributional centres shift west and southwards from age 0 to age 1 due to spatial variation in mortality (Bogstad et al., 2013; Filin & Russkikh, 2019).

COMPLEXITY IN REPRODUCTIVE STRATEGY: Haddock is spawning along the edge between the Norwegian Coastal Current and the Atlantic Current off northern Norway. The southernmost spawning areas are at around 67 °N (Sundby et al., 2013). The northernmost spawning area is northeast of Tromsøflaket. Whether the spawning areas are shifting northwards and southwards with warming and cooling periods, respectively, as shown for Northeast Arctic cod (Sundby & Nakken, 2008), is not documented.

SPAWNING CYCLE: Nearly the entire spawning at high latitudes have spawning confined seasons during spring, typically during March and April (Sundby et al., 2013, 2016). Boreal species at high latitudes are generally adapted to the spring-spawning dynamics (Sundby et al., 2016), because of their spawning season must be synchronized with the spring bloom and the subsequent production of zooplankton prey. This is an adaptation to the light cycle and not to the temperature (Sundby et al., 2016). Therefore, it is assumed that climate change is not disrupting spawning seasons for species adapted to high latitudes. However, temperate species adapted to lower latitude with extended spawning seasons might face difficulties when they are displaced towards high latitude by climate change.

SENSITIVITY TO TEMPERATURE: Haddock is found mainly between 4-10 °C (Mecklenburg et al., 2018). In the Barents Sea, Northeast Arctic haddock is living at its lower temperature range. Increased temperatures in the Barents Sea are supposed to further increase habitat extent as well as stock abundances both because ambient temperatures approach optimal conditions and because the ice retreat increases the habitat extent (Landa et al., 2014).

SENSITIVITY TO OCEAN ACIDIFICATION: The effects of ocean acidification on haddock eggs and larvae are so far unstudied.

POPULATION GROWTH RATE: Northeast Arctic haddock has experienced large increase in stock size since the early 2000s, with biomass peaking in 2010. The stock is still at a high level but is now declining (ICES, 2019).

STOCK SIZE/STATUS: Haddock has increased in stock size and distribution area during the recent decades of warming in the Barents Sea (Landa et al., 2014), a development which has been much in parallel to Northeast Arctic cod. The spawning stock biomass (SSB) has been above maximum sustainable yield (MSY) $B_{trigger}$ since 1989 (ICES, 2019). Between 2008-2016, the mortality (F) was well below the F giving maximum sustainable yield (F_{MSY}). Very strong recruitment from the year classes 2005-2006, in combination with a reduced fishing pressure, and suitable growth conditions (food, temperature, feeding area) are the likely explanations of the stock increase. However, despite record high SSB and very warm temperatures, the year classes between 2006-2015 were only moderate. The current large stock should be robust against fishing.

OTHER STRESSORS: Stock is experiencing no stress other than fishing. Haddock has moved its habitat towards northeast in the Barents Sea during the recent decades of warming and large stock size. There are still potential areas for expansion along the shelf edge toward east (Landa et al., 2014).

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 Northeast Arctic haddock (*Melanogrammus aeglefinus*) in ICES subareas 1 and 2. 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.

Northeast Arctic haddock (*Melanogrammus aeglefinus*) in ICES subareas 1 and 2

SENSITIVITY ATTRIBUTES	L	M	H	VH	$Mean_w$	Usage	Remark
Habitat Specificity	0	5	0	0	**2.0**		
Prey Specificity	0	5	0	0	**2.0**		
Species Interaction	0	5	0	0	**2.0**		
Adult Mobility	4	1	0	0	**1.2**		
Dispersal of Early Life Stages	5	0	0	0	**1.0**		
ELH Survival and Settlement Requirements	0	4	1	0	**2.2**		
Complexity in Reproductive Strategy	0	4	1	0	**2.2**		
Spawning Cycle	3	2	0	0	**1.4**		
Sensitivity to Temperature	4	1	0	0	**1.2**		
Sensitivity to Ocean Acidification	0	3	2	0	**2.4**		
Population Growth Rate	0	3	2	0	**2.4**		
Stock Size/Status	0	4	1	0	**2.2**		
Other Stressors	3	2	0	0	**1.4**		
Grand mean					**1.82**		
Grand mean SD					**0.50**		

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	0	0	1	4	**3.8**	3	1
O_2 (Surface)	3	2	0	0	**1.4**	2	-1
pH (Surface)	2	2	1	0	**1.8**	1	-1
Gross Primary Production	1	2	2	0	**2.2**	2	1
Gross Secondary Production	1	2	2	0	**2.2**	2	1
Sea Ice Abundance	2	2	1	0	**1.8**	2	1
Grand mean					**2.20**		
Grand mean SD					**0.84**		
Accumulated Directional Effect					**–**		**6.8**

***Accumulated Directional Effect*: POSITIVE**	**6.8**

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