Stock name: North Sea haddock
Latin name: *Melanogrammus aeglefinus*
Geographical area: North Sea, West of Scotland and Skagerrak (ICES subareas 4, 6 and division 3.a)
Expert: Yves Reecht, Svein Sundby (based on NEA haddock narrative by Edda Johannesen and Svein Sundby)
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Stock Sensitivity Attributes

HABITAT SPECIFICITY: North Sea (NS) haddock (*Melanogrammus aeglefinus*, Gadidae) is mostly present in the Northern NS and Shetland area. Adults occur mainly at depths ranging from 75-200m (Albert, 1994; Hedger et al., 2004) and prefer winter temperatures >6 °C and salinity >34.5 ppt (Hedger et al., 2004). Although the highest densities occur at temperatures between 6.5 and 8 °C, no effects of temperatures shifts on the NS population distribution is observed (Hedger et al., 2004). Juveniles prefer somewhat colder and less saline waters forming strong aggregations in the North-East parts of the area, at Viking, Norwegian Trench, Skagerrak (Asjes et al., 2016), becoming more abundant in the West (North-East of Scotland, Shetland) at the age 1 (Asjes et al., 2016; Rogers & Stocks, 2001). Historical reports indicate main spawning grounds in the central northern NS and areas north and west of Cape Wrath and Butt of Lewis (González-Irusta & Wright, 2016; Rogers & Stocks, 2001) and to a lesser extent on the south-western slope of the Norwegian Trench, Ling Bank to Eigersund Bank (Sundby et al., 2017). A southward shift in the main spawning aggregations observed in recent decades (since the early 2000s) are comparable to those historical records, and was suggested to be link to an increased inflow of warm Atlantic water from northwest to the study area (González-Irusta & Wright, 2016). However, it is unclear whether this is part of a long-term change or whether it is caused by short-term variability.

PREY SPECIFICITY: All main haddock stocks include a large proportion of benthic invertebrates, mainly echinoderms (Schückel et al., 2010), in their diet after bottom settling, but also feed on other prey including fishes. After bottom settling, the degree of piscivorous behaviour does not usually increase with age, but varies seasonally, inter-annually and between stocks (Tam et al., 2016). North Sea haddock has a largely opportunistic benthic diet after settlement of the 0-group following a pelagic phase. However, unlike other haddock populations, there is evidence that NS haddock increases piscivore diets with individual size in the NS (Adlerstein et al., 2002; Albert, 1994; Tam et al., 2016).

SPECIES INTERACTION: The adult NS haddock population overlaps, at least seasonally, with cod, saithe and whiting (Hedger et al., 2004; Knijn et al., 1993). While the diet overlap may be minor in other stocks, e.g. with Northeast Arctic cod (Jiang & Jørgensen, 1996), increasing piscivorous feeding of NS haddock with size (Adlerstein et al., 2002; Albert, 1994) may induce stronger competition for food with other piscivorous gadoid species in the NS. This may however be mitigated by the opportunistic feeding strategy of haddock (Schückel et al., 2010; Tam et al., 2016). Young stages of haddock experience predation pressure from other gadoids, such as cod (Rogers & Stocks, 2001), saithe (Nedreaas, 1987) and whiting (Knijn et al., 1993; Pope & Macer, 1996). As for the 0-groups, inter-specific competition may be relatively strong among gadoids during the pelagic phase, feeding mostly on copepods (Bromley et al., 1997), but divergence in the development timing and segregation in space (Bastrikin et al., 2014), development of distinct feeding niches (Demain et al., 2011) and feeding plasticity (Bromley et al., 1997) are all mechanisms thought to minimize the potential for inter-specific competition after the settlement phase among gadoid species.

ADULT MOBILITY: Adult haddock (age 2+) aggregate in February to April on the spawning grounds, mainly in the central northern NS and east of Scotland. After spawning, they disperse and migrate southward to the central NS or westward (Shetland, Orkney, West Scotland) for feeding (Knijn et al., 1993; Rogers & Stocks, 2001).

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). In the NS, eggs, larvae and young juveniles are subject to advection from the east and northeast of Scotland, and northern NS to the southwestern part of northern NS and Skagerrak (Munk et al., 1999).

EARLY LIFE HISTORY SURVIVAL AND SETTLEMENT REQUIREMENTS: Gadoid species in the North Sea live near their upper thermal boundaries, opposite of the conditions for gadoid stocks in the Barents Sea where they live near (but still well above) the lower thermal range (Sundby, 2000). In response, as demonstrated for cod (Planque & Frédou, 1999), this implies that higher-than-normal temperatures in the Barents Sea is beneficial for recruitment, while in the North Sea lower-than-normal temperatures are beneficial. Since the cool interdecadal period of the 1960s and 1970s where the so-called "gadoid outburst" occurred in the North Sea (Cushing, 1984), abundance of all the major gadoid stocks in the North Sea has declined as temperature has increased. However, NS haddock recruitment is much more variable than NS cod recruitment; this is common to sympatric cod and haddock stocks from several regions and is likely driven by the short peak spawning season of haddock and lower tolerance of its larval stages to variations in salinity and temperature (Fogarty et al., 2001). During its pelagic phase, the 0-group feeds mainly on decapod larvae, copepods and small fish before settling at about 7 month (5 cm total length) (Rogers & Stocks, 2001) and is found in mostly in the northern NS in the following winter (Asjes et al., 2016; Knijn et al., 1993). During late summer, juveniles are most abundant the north and east of Scotland (Asjes et al., 2016; Rogers & Stocks, 2001). Except for quarter 3, juvenile haddock exhibit a marked preference for depths around 100-120 m (Asjes et al., 2016). Relative contributions of migration and differential mortality (as may happen during cold winters in the Northeast Arctic (Bogstad et al., 2013; Filin & Russkikh, 2019) to this observed shift in distribution are however unclear. Seasonal patterns in the persistence of aggregations (Asjes et al., 2016) nevertheless indicate some degree of juvenile mobility.

COMPLEXITY IN REPRODUCTIVE STRATEGY: Haddock in the NS is spawning on the northern NS plateau (Viking to Shetlands), the southwestern slope of the Norwegian Trench and around Scotland (González-Irusta & Wright, 2016; Rogers & Stocks, 2001; Sundby et al., 2017). In this region, haddock has an optimum temperature for spawning of 7 °C and prefers high salinity, and gravel over muddy grounds (González-Irusta & Wright, 2016). The length (age) at 50% maturity is about 30 cm (<1 year) for males and 35 cm (<1 year) for females. There is little evidence of a temperature effect on reproductive investment (Wright et al., 2011) and timing (Morgan et al., 2013) but a steady decrease in both age and length at maturity has been linked to increased fishing pressure (Marty et al., 2014).

SPAWNING CYCLE: Haddock in the NS spawns from February through May, with a peak season from mid-March to early April (González-Irusta & Wright, 2016; Rogers & Stocks, 2001; Sundby et al., 2017). The first-time spawners (Age-2) spawn later than the older age classes (Morgan et al., 2013; Wright & Gibb, 2005). Boreal species at high latitudes are generally adapted to the spring-spawning dynamics (Sundby et al., 2016), because of the 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 the spawning seasons for species adapted to high latitudes.

SENSITIVITY TO TEMPERATURE: Haddock is considered a boreal species like saithe, cod (Dulvy et al., 2008) and is typically found at temperatures between 4-10 °C (Mecklenburg et al., 2018). Within the range of suitable temperatures, however, this seems not to be the predominant driver of adult distribution (Hedger et al., 2004). The Age-0 group, on the other hand, appears more constrained by temperature, with a preference for areas with summer temperature <11 °C (Asjes et al., 2016) and is therefore expected to be more sensitive to future temperature increase and associated northward shift of the preferential habitat. Faster initial growth and lower asymptotic size of haddock may be associated with higher temperatures in the North Sea (Baudron et al., 2011).

SENSITIVITY TO OCEAN ACIDIFICATION: The effect of ocean acidification (OA) on haddock eggs and larvae are so far unstudied. Diet of haddock includes a range of crustaceans (Adlerstein et al., 2002; Albert, 1994; Schückel et al., 2010), which may be negatively affected, i.e. experience reduced growth, by a decrease in marine pH (Whiteley, 2011), and consequently negatively impact growth of fish (van Deurs et al., 2015). The opportunistic feeding habits of NS haddock may however help compensating potential effects of OA.

POPULATION GROWTH RATE: With a high variability in the success of recruitment (Fogarty et al., 2001), the stock dynamics of NS haddock rely on strong year-classes (ICES, 2020b, 2020a).

STOCK SIZE/STATUS: Fishing pressure is the main driver of the NS haddock stock (Pope & Macer, 1996). Haddock in the NS, West of Scotland and Skagerrak (divisions 4, 6a and 20) is managed as one stock following a maximum sustainable yield (MSY) approach since 2015 (ICES, 2020b). Over the last 20 years, and following a sharp drop in fishing pressure around 2000, the spawning stock biomass (SSB) has mostly remained over MSY $B_{trigger}$, despite a fishing mortality (F) often above F_{MSY} (ICES, 2020b, 2020a). This fishery is supported by strong year classes (e.g. 1999, 2005, 2009, 2019) which explains the strong variability in SSB. Recent advice (ICES, 2020a) reveals an SSB at the beginning of 2020 73% over and a fishing mortality in 2019 below precautionary limits.

OTHER STRESSORS: No other major stressor evidenced to the best of the author's knowledge.

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 North Sea haddock (*Melanogrammus aeglefinus*) in ICES subareas 4, 6, division 3.a. 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.

North Sea haddock (*Melanogrammus aeglefinus*) in ICES subareas 4, 6, division 3.a

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	2	3	0	**2.6**		
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	3	2	0	0	**1.4**		
Other Stressors	5	0	0	0	**1.0**		
Grand mean					**1.77**		
Grand mean SD					**0.58**		

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		3	
Temperature 500 m	0	0	0	0		N/A	
Bottom Temperature	0	0	2	3	**3.6**	N/A	-1
O_2 (Surface)	3	2	0	0	**1.4**	2	0
pH (Surface)	4	1	0	0	**1.2**	2	-1
Gross Primary Production	4	1	0	0	**1.2**	1	1
Gross Secondary Production	2	2	1	0	**1.8**		-1
Sea Ice Abundance	0	0	0	0		N/A	
Grand mean					**1.84**		
Grand mean SD					**1.01**		
Accumulated Directional Effect					**–**		**-5.4**

***Accumulated Directional Effect*: NEGATIVE**	**-5.4**

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