NORWEGIAN SPRING-SPAWNING HERRING

Stock name: Norwegian spring-spawning herring
Latin name: *Clupea harengus*
Geographical area: Norwegian Sea, with juveniles distributed in the Barents Sea (ICES subareas 1 and 2)
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Stock Sensitivity Attributes

HABITAT SPECIFICITY: Norwegian spring-spawning herring (NSSH, *Clupea harengus*, Clupeidae) has its main spawning off Møre during February-March, but with a historically highly dynamic utilization of spawning areas along the Norwegian coast from Siragrunnen in the south extending northwards to Vesterålen. Atlantic herring spawns at the sea floor and eggs hatch after about three weeks. During late spring and summer, the newly hatched NSSH larvae drift with the current northwards along the coast and into the Barents Sea. The herring leaves the Barents Sea after 3-4 years and migrates southward along the Norwegian coast to join the spawning stock. NSSH is a very important species in the ecosystems which preys mainly on *Calanus finmarchicus* and is itself an important prey for other species (e.g. cod, saithe and other demersal species), in addition to sea birds and whales. Large numbers of killer whales and humpback whales follow the herring during its migration (Jourdain & Vongraven, 2017). It is hence an important food source for coastal species during spring and summer. The gonads account for about 20 % of the herring weight before spawning, and large amounts of spawning products are deposited on the spawning grounds every year (Slotte, 1999). The herring spawns on gravel and rocky bottom on banks along the Norwegian coast during spring with a peak in February (Slotte, 2001). A study from overwintering habitats has shown that there is a large spread in the temperature ranges during the long overwintering period (Huse et al., 2010).

PREY SPECIFICITY: After spawning NSSH migrates into the Norwegian Sea to feed. The main prey species is the copepod *C. finmarchicus* (Dalpadado et al., 2000; Huse & Toresen, 1996; Prokopchuk & Sentyabov, 2006). Herring also prey on other copepod species, appendicularians, *Themisto* spp., euphausiids, *Limacina* sp. and others. Main feeding areas are the frontal areas between the warm Atlantic and cold Arctic water, in the central and western part of the Norwegian Sea, although sometimes extending into Arctic waters where NSSH is feeding on *C. hyperboreus* (Broms et al., 2012). In September-November the herring migrates northeastward to the main wintering areas off the coast and in fjords in northern Norway. The southward spawning migration starts in January.

SPECIES INTERACTION: NSSH may compete for food with other pelagic fish such as mackerel and blue whiting in the Norwegian Sea, as they utilize similar prey groups and species. Herring and blue whiting are potential competitors at the Arctic front, where the diet overlap can be high. Overlap in diet between herring and mackerel is varying with years and geographical location spanning from relatively high to low. These fish species utilize to some extent different prey sizes and being differently vertical distributed in the water column. Herring and mackerel have limited horizontal distributional overlap, which may reduce the competition for food. Herring may also compete in diet with carnivorous zooplankton. Juvenile herring in the Barents Sea is also well known to prey on larval capelin (Godiksen et al., 2006; Huse & Toresen, 2000) and this is likely the primary cause for the collapses seen in the capelin stock in recent decades (Gjøsæter et al., 2009; Gjøsæter & Bogstad, 1998).

ADULT MOBILITY: The juvenile NSSH grows up in coastal areas and in the Barents Sea (J. Holst & Slotte, 1998). After 3-4 years the herring leaves the nursery areas and migrates southward along the Norwegian coast to join the spawning stock. The adults have an extensive feeding migration in the Norwegian Sea during the summer (Dragesund et al., 1980, 1997; J. C. Holst et al., 2002; Huse, 2016; Huse et al., 2010; Jakobsson & Østvedt, 1999; Røttingen, 1990). NSSH is highly migratory and is able to migrate to new feeding, overwintering and spawning areas in response to changes in ocean climate and productivity (Fernö et al., 1998; J. C. Holst et al., 2002; Huse et al., 2010; Jakobsson & Østvedt, 1999).

DISPERSAL OF EARLY LIFE STAGES: NSSH spawns their eggs on coarse sand, rocks and gravel down to ca. 250 m (Runnstrøm, 1941) where the eggs hatch after about three weeks. The newly hatched larvae drift mainly with the Norwegian Coastal Current northwards along the coast either into the northern Norwegian fjords and primarily into the Barents Sea during summer (Bjørke & Rey, 1991; Dragesund et al., 1980; Sætre, Toresen, Søiland, et al., 2002; Toresen et al., 2019).

EARLY LIFE HISTORY SURVIVAL AND SETTLEMENT REQUIREMENTS: The NSSH juveniles primarily grow up in fjords and in the shelf waters of the Barents Sea (Dragesund, 1970; J. Holst & Slotte, 1998). Thereby, they use the entire water column for feeding both at the surface and close to the bottom (Huse & Toresen, 1996). Some cohorts, such as the large 2002 cohort, partly grew up in the eastern part of the deep Norwegian Sea. This indicates flexibility in herring with regards to potential nursery areas.

COMPLEXITY IN REPRODUCTIVE STRATEGY: The NSSH is an iteroparous species, matures at age 3-5 and is a single batch spawner. The male and female spawn synchronously in dense aggregations (Axelsen et al., 2000; Skaret et al., 2003) on gravel (Runnstrøm, 1941). NSSH successful spawning is dependent on particular bottom habitat (Runnstrøm, 1941) (see above).

SPAWNING CYCLE: The herring is a single batch spawner and both males and females release their spawn at a single event (Axelsen et al., 2000; Runnstrøm, 1941). This makes the NSSH vulnerable to changes in the timing of the spring bloom to which the herring spawning is adapted to. There has been some variability in the timing of the spawning/hatching (Husebø et al., 2009; Vikebø et al., 2012) but remains unclear whether adaptive capacities in NSSH allow for future climate changes affection the timing of the spring bloom.

SENSITIVITY TO TEMPERATURE: The herring occurs in a wide range of temperatures (latitude from 35 to 70 °N, spawning reported between 0-15 °C) (Blaxter, 1985; Fernö et al., 1998). The temperature during the overwintering stage for example is highly variable (Huse et al., 2010).

SENSITIVITY TO OCEAN ACIDIFICATION: This is a much-debated topic where both experimental designs and up-scaled model projections diverge. However, there is no reason to doubt that ocean acidification (OA) will reduce NSSH stock productivity if the “business-as-usual” scenario continues, with particular reference to increased early life stage mortality. However, recent studies have shown that indirect effects of OA might be positive for survival of herring larvae, and there is a need to include food web effects of OA before projections of the effect of OA can be done (Sswat et al., 2018).

POPULATION GROWTH RATE: The growth dynamics of NSSH is well understood and the length growth follows an asymptotic trajectory towards the maximum length (Toresen, 1990). There are also indications of a density dependent growth in herring (Huse et al., 2012; Toresen, 1990). The maturity ogive is well quantified and is a key part of the assessment model (Engelhard et al., 2003; Engelhard & Heino, 2004; ICES, 2018). The productivity of the NSSH is highly influenced by the recruitment dynamics which is characterized by infrequent strong year classes (Fiksen & Slotte, 2002; Huse, 2016; Sætre, Toresen, & Anker-Nilssen, 2002; Skagseth et al., 2015). This is partly related to physical variability in temperature and currents (Sætre, Toresen, & Anker-Nilssen, 2002; Skagseth et al., 2015) and also to changes in zooplankton availability for larval herring (Toresen et al., 2019).

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STOCK SIZE/STATUS: The NSSH is managed in accordance with a harvest control rule agreed by the coastal states (ICES, 2019). The agreed harvest rate is below the established fishing mortality (F) consistent with achieving maximum sustainable yield (F_{MSY}) for the stock (ICES, 2019). However, there are disagreements between the coastal states with regards to the sharing of the quota. This has resulted in an increased harvest to a level above the agreed total allowable catches (TAC) for NSSH. This is a threat to a stock that is otherwise very well managed through appropriate advice, regulations and enforcement.

OTHER STRESSORS: NSSH is experiencing two primary stressors; fishing and climate change, the latter being particularly pronounced at high latitudes.

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 Norwegian spring-spawning herring (*Clupea harengus*) 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.

Norwegian spring-spawning herring (*Clupea harengus*) in ICES subareas 1 and 2

SENSITIVITY ATTRIBUTES	L	M	H	VH	$Mean_w$	Usage	Remark
Habitat Specificity	0	1	4	0	**2.8**		
Prey Specificity	0	5	0	0	**2.0**		
Species Interaction	0	2	3	0	**2.6**		
Adult Mobility	2	3	0	0	**1.6**		
Dispersal of Early Life Stages	5	0	0	0	**1.0**		
ELH Survival and Settlement Requirements	0	1	4	0	**2.8**		
Complexity in Reproductive Strategy	2	3	0	0	**1.6**		
Spawning Cycle	0	0	0	5	**4.0**		
Sensitivity to Temperature	0	4	1	0	**2.2**		
Sensitivity to Ocean Acidification	5	0	0	0	**1.0**		
Population Growth Rate	0	0	2	3	**3.6**		
Stock Size/Status	5	0	0	0	**1.0**		
Other Stressors	0	5	0	0	**2.0**		
Grand mean					**2.17**		
Grand mean SD					**0.97**		

CLIMATE EXPOSURE	L	M	H	VH	$Mean_w$	Usage	*Directional Effect*
Surface Temperature	0	0	0	0		N/A	
Temperature 100 m	1	3	1	0	**2.0**		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**		-1
pH (Surface)	5	0	0	0	**1.0**		-1
Gross Primary Production	2	3	0	0	**1.6**		1
Gross Secondary Production	0	3	2	0	**2.4**		1
Sea Ice Abundance	3	2	0	0	**1.4**		1
Grand mean					**1.60**		
Grand mean SD					**0.52**		
Accumulated Directional Effect					**–**		**5.2**

***Accumulated Directional Effect*: POSITIVE**	**5.2**

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