Stock name: Lesser sandeel
Latin name: *Ammodytes marinus*
Geographical area: North Sea (ICES subarea 4)
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Stock Sensitivity Attributes

HABITAT SPECIFICITY: The lesser sandeel (*Ammodytes marinus*, Ammodytidae) fishery is the largest single-species fishery in the North Sea (P. Wright et al., 2000). During the period 1970-2010, 20% of the total fishery landings from the North Sea are accounted by this species (Sundby et al., 2017). With its association to specific benthic habitats, it is distributed in patches throughout most of the North Sea (Sparholt, 2015) with low abundances in the northeast. A small and important spawning ground is found in the northwestern North Sea, at the Tampen area (Sundby et al., 2017). Sandeel is buried most of the time in sandy seabeds of medium to coarse grain sizes 0.25-2.0 mm (Holland et al., 2005; P. Wright et al., 2000) with low proportion of silt and clay (Macer, 1966; P. Wright et al., 2000). These habitats are normally well ventilated and well oxygenated. Larger individuals seem to prefer coarser sand than young ones. Due to these habitat requirements changes in the habitat may impact sandeel populations substantially. Fishing grounds for sandeel are a fine scaled and patchy throughout the North Sea (Jensen et al., 2011; P. Wright & Bailey, 1996). Sandeel has a distinct diel vertical migration behaviour. It hides in the sandy bottom at night and ascends during the day towards the surface to feed in the pelagic layer. During cloudy or dark summer days sandeel may skip ascending from the bottom (Hassel et al., 2003).

PREY SPECIFICITY: Sandeel forage in schools on a range of zooplankton including copepods (*Calanus*, *Pseudocalanus*, and *Temora*), Annelida and Larvacea (Macer, 1966; van Deurs et al., 2014). Larger specimens tend to target larger food items. The species is zooplanktivorous throughout its life. Cannibalism has been reported on later larval stages and juveniles (Eigaard et al., 2014) increasing with the size of the adults.

SPECIES INTERACTION: The species is an important prey for fish, seabirds, and sea mammals (Furness, 2002). There is a number of studies indicating the importance of sandeel availability to breeding success in seabird colonies (Lahoz-Monfort et al., 2011; Lewis et al., 2001; Wanless et al., 1998). Recently, it has been found that high kittiwake breeding success at the southeast coast of England is associated with a high sandeel spawning stock biomass (SSB) and lower sandeel fishing mortality two years previously (Carroll et al., 2017). A major part of seabird species along the east coasts of Scotland and England have decreased in biomasses and breeding success after 1999 (Daunt & Mitchell, 2013). Indeed, increasing winter temperature are assumed to reduce zooplankton production, which reduces sandeel biomass, negatively impacting seabird populations. Sandeel is also a forage fish to other fishes. A study at the Dogger Bank (Engelhard et al., 2013) revealed that haddock, whiting, lesser weever, grey gurnard, and plaice constituted a high body condition factors in years and regions of high abundances of sandeel.

ADULT MOBILITY: The lesser sandeel remains burrowed for long periods in the seabed in sandy areas within certain depth ranges (30-70m) (Holland et al., 2005; P. Wright et al., 2000). Their diel feeding migration includes 20 to 40 m vertical swimming (Johnsen et al., 2017). Sandeels, are, considered quite sessile being mostly exposed to extended horizontal movement during the pelagic larval and early juvenile stages.

DISPERSAL OF EARLY LIFE STAGES: Due to its habitat speciality, i.e. burying in sediment of specific characteristics within certain depth ranges (Holland et al., 2005; P. Wright et al., 2000) sandeel has, compared to other mobile fish species, limited opportunities for migrating to other areas in response to environmental changes. Lesser sandeel develops large schools forming bridges structures (including several million individuals), which act as natural anchors, likely play an important role in lesser sandeel ecology, preventing post-settled individuals from being detached from suitable bottom substrate (Johnsen et al., 2017). Reduced density increases the vulnerability of lesser sandeel to fishery and other anthropogenic impacts. The larvae are found pelagically from March to May (Macer, 1967; Munk & Nielsen, 2005). The larval pelagic drift may transport them as far as 300 km from the spawning grounds but normally less than 100 km (Christensen et al., 2008). Even within this distance of transport there would be many unsuitable habitats for settling, since the bottom substrate quality is highly specific (Jensen et al., 2011; P. Wright & Bailey, 1996). It must, therefore, be concluded that sandeel is the most sessile of all fish species considered in this report.

EARLY LIFE HISTORY SURVIVAL AND SETTLEMENT REQUIREMENTS: The eggs of lesser sandeel stick to the sediment, whereas the larvae drift before they settle during their first summer (P. Wright & Bailey, 1996). Based on larval drift models (Christensen et al., 2008) sandeel larvae could at best populate neighbouring habitats implying that change of habitats in response to climate change would be slower than for most other marine fish species.

COMPLEXITY IN REPRODUCTIVE STRATEGY: Sandeel is a capital breeder (P. J. Wright et al., 2017) implying that the adults accumulate lipid reserves during the short planktivorous feeding season in order to have energy reserves for gonad production in early spring subsequent to overwintering. This is a rather seldom life cycle and reproductive strategy in North Sea fish stocks, but similar to another major high-latitude planktivorous fish stock, the Norwegian spring-spawning herring (NSSH) in the Norwegian and Barents Seas. However, sandeel does not overwinter in the deeper water masses, like the NSSH, but buried in the sand (van Deurs et al., 2010). The cause of this overwintering strategy is similar to NSSH. Shortage of sufficient amounts of zooplankton prey during winter induced an adaptational life cycle with intensive feeding during the limited period of zooplankton production to accumulate lipid reserves for overwintering and a subsequent spawning in early spring (MacDonald et al., 2018; van Deurs et al., 2011). Sandeel eggs spawned during early spring are demersal and the larvae are pelagic for 50-90 days – prior to the appearance of strong density-driven currents (Christensen et al., 2008), i.e. at a time where there is generally little exchange across the entire North Sea. Model simulations of larval transport suggest that aggregations on banks at scales 50-300 kms apart can be connected by the annual dispersal and advection of larvae. The recruitment is to some extent correlated to SSB, except in years with high abundances of 1-group sandeel where this positive effect did not contribute significantly to stock size growth (van Deurs et al., 2009). Increasing temperature during overwintering will likely change the reproductive potential due to increasing metabolic costs (P. J. Wright et al., 2017). However, it does not seem to impact survival of the overwintering adults. It implies that climate change would have the potential to reduce the reproductive potential of sandeel in the North Sea. However, as a capital breeder it has a life cycle that is well adapted to be displaced poleward with climate change (Sundby et al., 2016).

SPAWNING CYCLE: Various spawning periods are reported for lesser sandeel. This is probably because spawning cycles may vary across the many different spawning areas in the North Sea, and that time for appearance of food for the larvae may vary at the various spawning areas. In the northeastern North Sea near the coast of western Norway, spawning occurs from December to January (O. A. Bergstad et al., 2001) whereas in the entire North Sea from November to February (Sparholt, 2015). An early egg production of *Calanus finmarchicus* supports the survival of lesser sandeel larvae. A shift in the *Calanus* species composition due to climate changes may lead to a mismatch in timing between food availability and the early life history of lesser sandeel (van Deurs et al., 2009).

SENSITIVITY TO TEMPERATURE: Sandeel recruitment versus temperature, *Calanus* abundance and SSB was analysed in two different regions of the North Sea, one southwestern region between 51 and 56

°N covering mainly British waters and one northeastern region between 55.5 and 59 °N covering mainly Danish and Norwegian waters (Arnott & Ruxton, 2002). The period studied was 1983-1999. SSB was only weakly correlated with recruitment in both regions. Only in the southern British region, the southernmost fringe region of sandeel abundance, temperature and *Calanus* abundance were significantly correlated with sandeel recruitment in the way that high temperature and low *Calanus* abundance were negatively correlated to recruitment. Some authors (van Deurs et al., 2009) did not distinguish among various regions but made a similar analysis as others (Arnott & Ruxton, 2002) for the entire sandeel population in the North Sea with extended timeseries to 2006. They found partly similar results but pointed out that the correlation between recruitment and SSB was decoupled in years with high abundance of 1-group sandeel. Moreover, they found that sandeel recruitment was specifically correlated with *C. finmarchicus* and not *Calanus helgolandicus*. They suggested the mechanistic link to *C. finmarchicus* to be due to the longer-term climate-generated shift from the spring-spawning *C. finmarchicus* to *C. helgolandicus*, the latter which does not have its spawning synchronized with sandeel spawning. Hence, their explanation of the mechanism is the same as suggested for North Sea cod recruitment (Sundby, 2000) where the impacts of temperature on North Sea cod is a proxy for the influx of *C. finmarchicus* to the North Sea ecosystem. A recent study on sandeel at Doggerbank, the southernmost area of distribution (Lindegren et al., 2018), were in line with the results on impacts of zooplankton and temperature on sandeel recruitment and added that the important zooplankton species are *C. finmarchicus* but also *Temora longicornis* (Temoridae).

SENSITIVITY TO OCEAN ACIDIFICATION: Fin-fish species are most sensitive to ocean acidification (OA) during their early life stages, although experiments on North Sea species (such as cod and herring) have so far shown that they are relatively robust (Franke & Clemmesen, 2011; Pinnegar et al., 2016). It is generally reported that more work is needed before any definitive conclusions about the impact of OA on finfish in the North Sea can be made.

POPULATION GROWTH RATE: Lesser sandeel is a relatively short-lived species in the southern part of the North Sea (Sparholt, 2015). In the northernmost regions at the Norwegian coast, where the species is unfished, it may reach 10 years (O. A. Bergstad et al., 2001). The various descriptors of lesser sandeel growth rate show highly various scores: maximum length (25 cm): <u>low score</u>; maximum age (12 years): <u>moderate score</u>; age-at-maturity (1-2 years): <u>moderate score;</u> von Bertalanffy K (0.16-0.25): <u>moderate score</u> (ICES, 2017).

STOCK SIZE/STATUS: Several of the subpopulation have undergone large changes in stock size over time, which partly are explained by high fishing pressure. In the northeastern part of the North Sea (Vikingbank area) the stock is small, which may compromise the adaptive capacity (ICES, 2017). Clear seasonal variations have been found in individual growth as well as in condition factor up to the oldest individuals (8 years) in the Norwegian sector (O. Bergstad et al., 2002). The authors discussed that the cause of this pronounced seasonal growth could be linked to the abundance of *C. finmarchicus*.

OTHER STRESSORS: The nearshore sandeel habitats around the Danish coasts are more exposed to oxygen deficiency than the more offshore habitats. Future climate change with increasing temperature, higher oxygen demand and decreasing saturation concentration of oxygen in the ambient water cause increasing stress on sandeel (Behrens et al., 2009).

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 Lesser sandeel (*Ammodytes marinus*) in ICES subarea 4. 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.

Lesser sandeel (*Ammodytes marinus*) in ICES subarea 4

SENSITIVITY ATTRIBUTES	L	M	H	VH	$Mean_w$	Usage	Remark
Habitat Specificity	0	0	5	0	**3.0**		
Prey Specificity	0	5	0	0	**2.0**		
Species Interaction	0	0	3	2	**3.4**		
Adult Mobility	0	0	5	0	**3.0**		
Dispersal of Early Life Stages	0	0	5	0	**3.0**		
ELH Survival and Settlement Requirements	0	2	3	0	**2.6**		
Complexity in Reproductive Strategy	0	2	3	0	**2.6**		
Spawning Cycle	0	2	3	0	**2.6**		
Sensitivity to Temperature	0	0	5	0	**3.0**		
Sensitivity to Ocean Acidification	0	5	0	0	**2.0**		
Population Growth Rate	4	1	0	0	**1.2**		
Stock Size/Status	0	5	0	0	**2.0**		
Other Stressors	0	5	0	0	**2.0**		
Grand mean					**2.49**		
Grand mean SD					**0.61**		

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 tTemperature	1	3	1	0	**2.0**	3	-1
O_2 (Surface)	4	1	0	0	**1.2**	1	-1
pH (Surface)	3	2	0	0	**1.4**	2	-1
Gross Primary Production	3	2	0	0	**1.4**	1	1
Gross Secondary Production	0	3	2	0	**2.4**	2	-1
Sea Ice Abundance	0	0	0	0		N/A	
Grand mean					**1.68**		
Grand mean SD					**0.50**		
Accumulated Directional Effect					**–**		**-5.6**

***Accumulated Directional Effect*: NEGATIVE**	**-5.6**

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