Stock Annex: Sandeel (*Ammodytes* spp.) in divisions 4.b and 4.c, Sandeel Area 1r (central and southern North Sea, Dogger Bank)

Stock-specific documentation of standard assessment procedures used by ICES.

Stock: Sandeel (*Ammodytes marinus*) in the North Sea area 1 (SA1)

Working group: Herring Assessment Working Group

Created:

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Main modifications: Stock annex revised following WKSAND 2106; all sections were revised

Last updated: November 2016

Last updated by: WKSand

A. General

A.1. Stock definition

Stock identity

The area boundaries developed for WKSAN 2010 were based on the Christensen *et al.* (2008) bio-physical model of larval transport. During the 2016 benchmark process an alternative hydrodynamic model; HBM-ERGOM (Christensen et al., 2008) was used in the bio-physical model to re-assess the divisions. This new model was used to consider the 2010 divisions as well as alternative area-divisions decided upon during the WKSand data preparation workshop held in Copenhagen in June 2016 (Figure A.1.1) and a proposal made with the industry during the benchmark in November 2016.

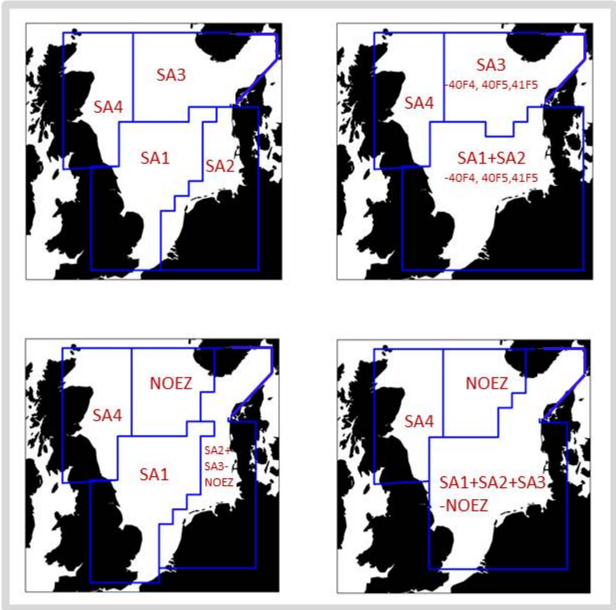


Figure A.1.1. Alternative area-divisions decided upon during the WKSAND data preparation workshop held in Copenhagen in June 2016.

An updated run of the bio-physical model (Figure. A.1.2) supports SA4 as it is today. Also the main part of SA1 (Dogger Bank) is relatively isolated from the rest of the North Sea. SA2 is also proposed as a discrete area, although inclusion of the EU part of SA3 and exclusion of the fishing grounds near the coast of Holland is suggested. With respect to the central fishing grounds (i.e. north-eastern parts of SA 1) it is less clear how they fit into the larger picture. Figures A.1.3 – A.1.6 illustrates how the Dogger bank (western part of SA1) is relatively self-sustained (i.e. high degree of retention), whereas the central parts show a much more unclear retention pattern, with larvae potentially arriving from as far away as the fishing grounds off the coast of Holland.

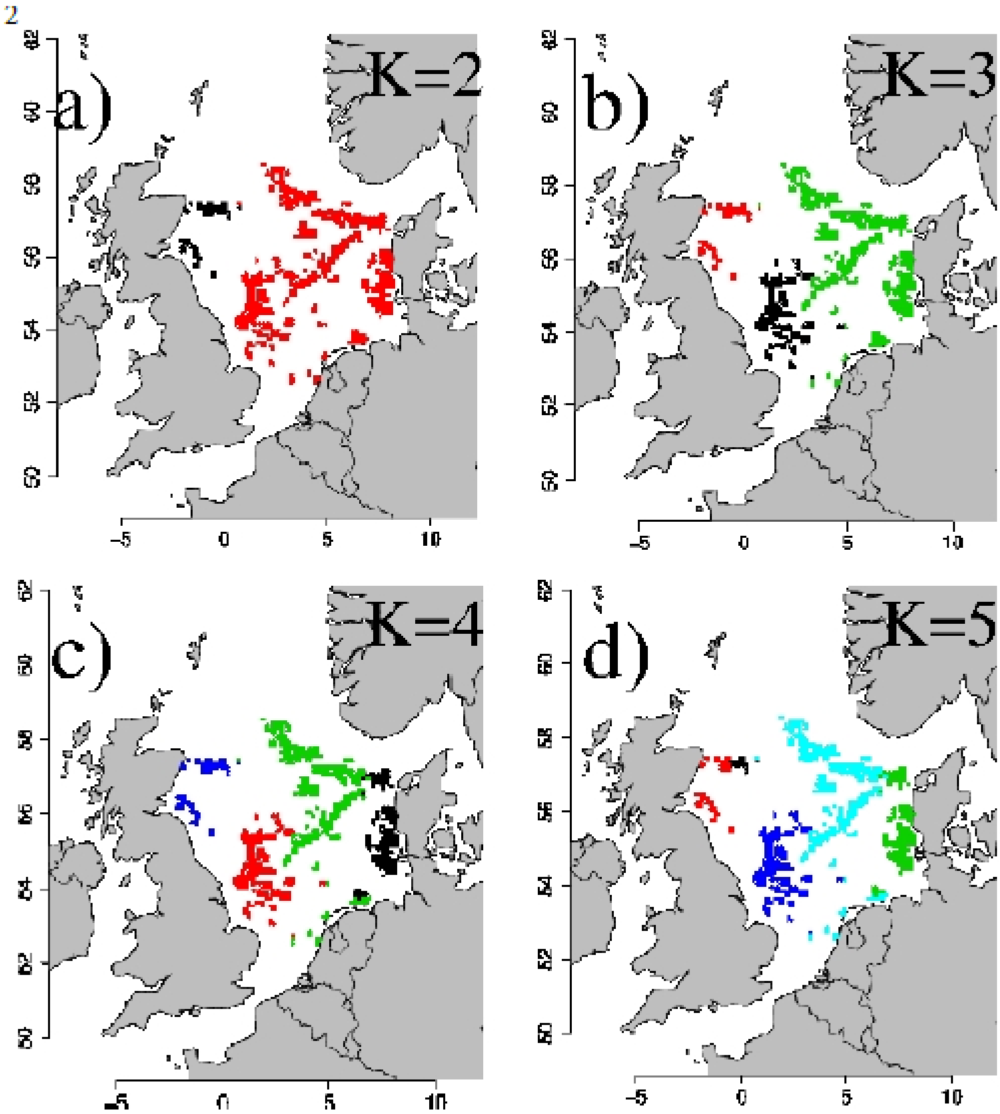


Figure A.1.2. Sandeel areas proposed by the bio-physical model. Example of an updated run of the bio-physical model (longer data time series as input to the oceanographic forcing of the larval drift patterns, although not updated all the way to 2015). The results from four different cluster scenarios are shown (2 clusters, 3 clusters, 4 clusters and 5 clusters).

As with all earlier biophysical models, the new model run supported the 2010 boundaries proposed for SA4. The main part of SA1 (Dogger Bank) was also found to be relatively isolated from the rest of the North Sea. The origin of larvae recruiting to the central fishing grounds (i.e. north-eastern parts of SA 1) were predicted to be more widespread with larvae potentially arriving from as far away as the fishing grounds off the coast of Holland in SA 2 in for example 2008 (Figure A.1.3). Output from this model was used to consider retention and export in a new proposal for area boundaries discussed during the WKSand 2016 benchmark (WKSand 2016 report).

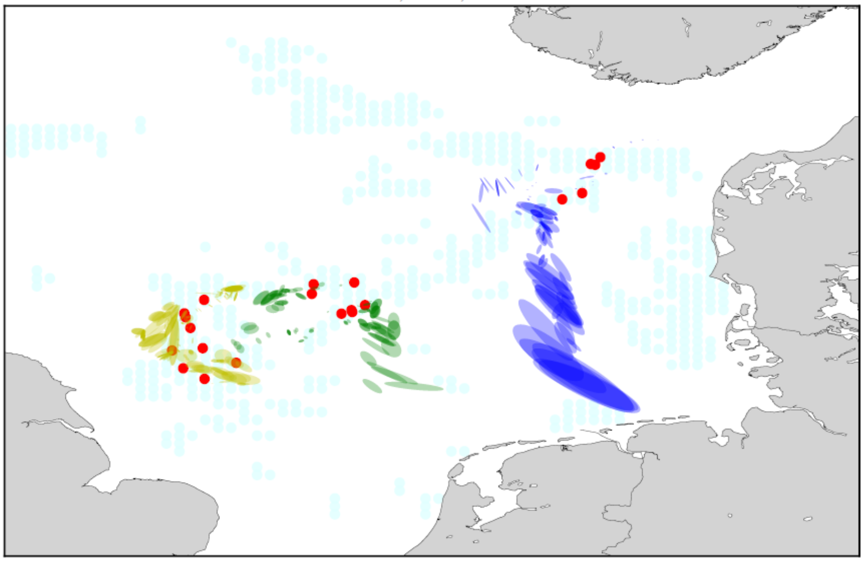


Figure A.1.3. Larvae back tracking. Larvae (n=378) sampled in 2006, 2008 and 2009 were aged (based on otoliths) and back tracked to their origins. Red dots represents where larvae were sampled. The ellipse area represents standard deviation of the Gaussian representation of possible latitude and longitude hatch position. For each ellipse the area represents approximately 70% of the probable hatch position and is cantered at the position with highest probability (Kristian Ege Nielsen).

The matrix of transport probabilities between sandeel habitat units (longitude x latitude = 0.167 x 0.1 degrees) within old and new sandeel assessment areas (SA) was analysed. The time series of both the old and the new SA divisions show relatively high retention with occasional larger outflow of larvae, were especially a flush out of 80% with the old SA2 in 2008 highlights the more variable hydrodynamics of the smaller old area compared to the larger new SA2 using the new divisions (combining old SA2+ SA3 in EU EEZ areas). There is an apparent slight change of average transport between SAs due to the introduction of new SA divisions, however none of these changes were significant (paired t-test). Assuming passive particle drift of sandeel larvae the new SA divisions appears to provide a long term spatially stable retention of the drifting sandeel larvae within areas.

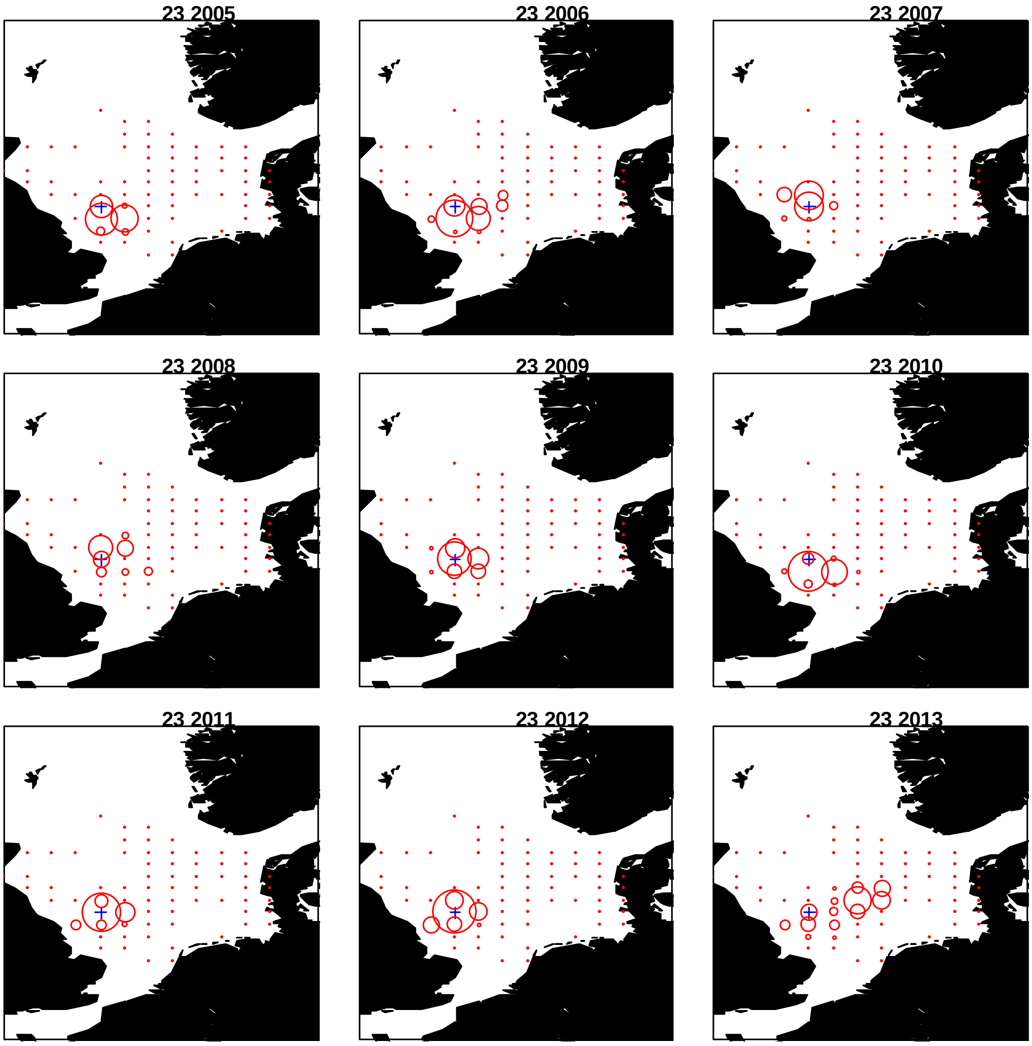


Figure A.1.4 Where does the selected square (marked with a blue cross) recruit to according to drift simulations? Bubbles indicate the relative importance of a given location as receiver of sandeel larvae. Note that the distribution of the mother population has not been taken into account. The plots are made from a connectivity matrix produced by the bio-physical model applied in Figure A.1.2.

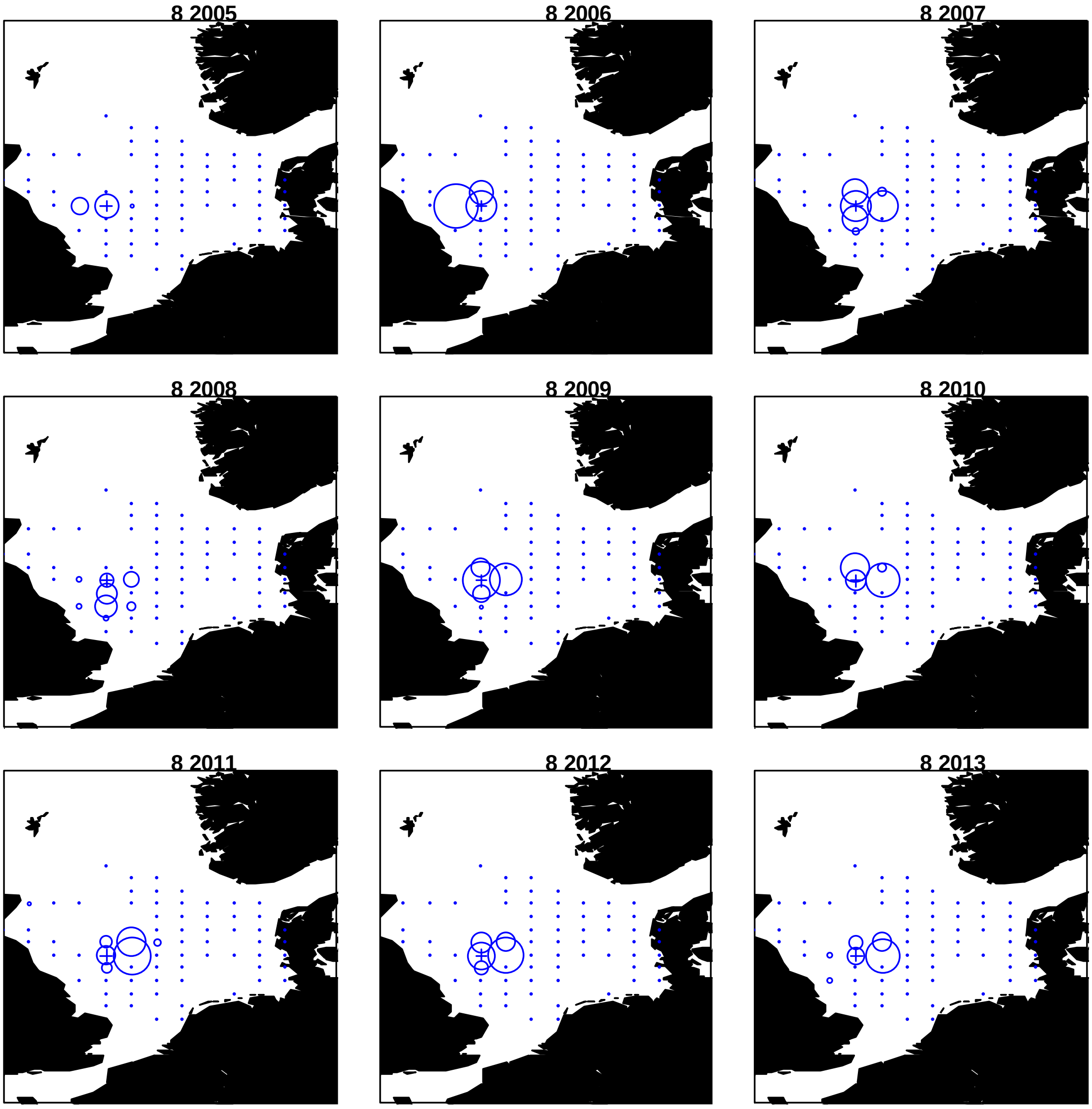


Figure A.1.5. Where does the selected square (marked with a blue cross) receive recruits from according to drift simulations? Bubbles indicate the relative importance of a given location as receiver of sandeel larvae. Note that the distribution of the mother population has not been taken into account. The plots are made from a connectivity matrix produced by the bio-physical model applied in Figure A.1.3.

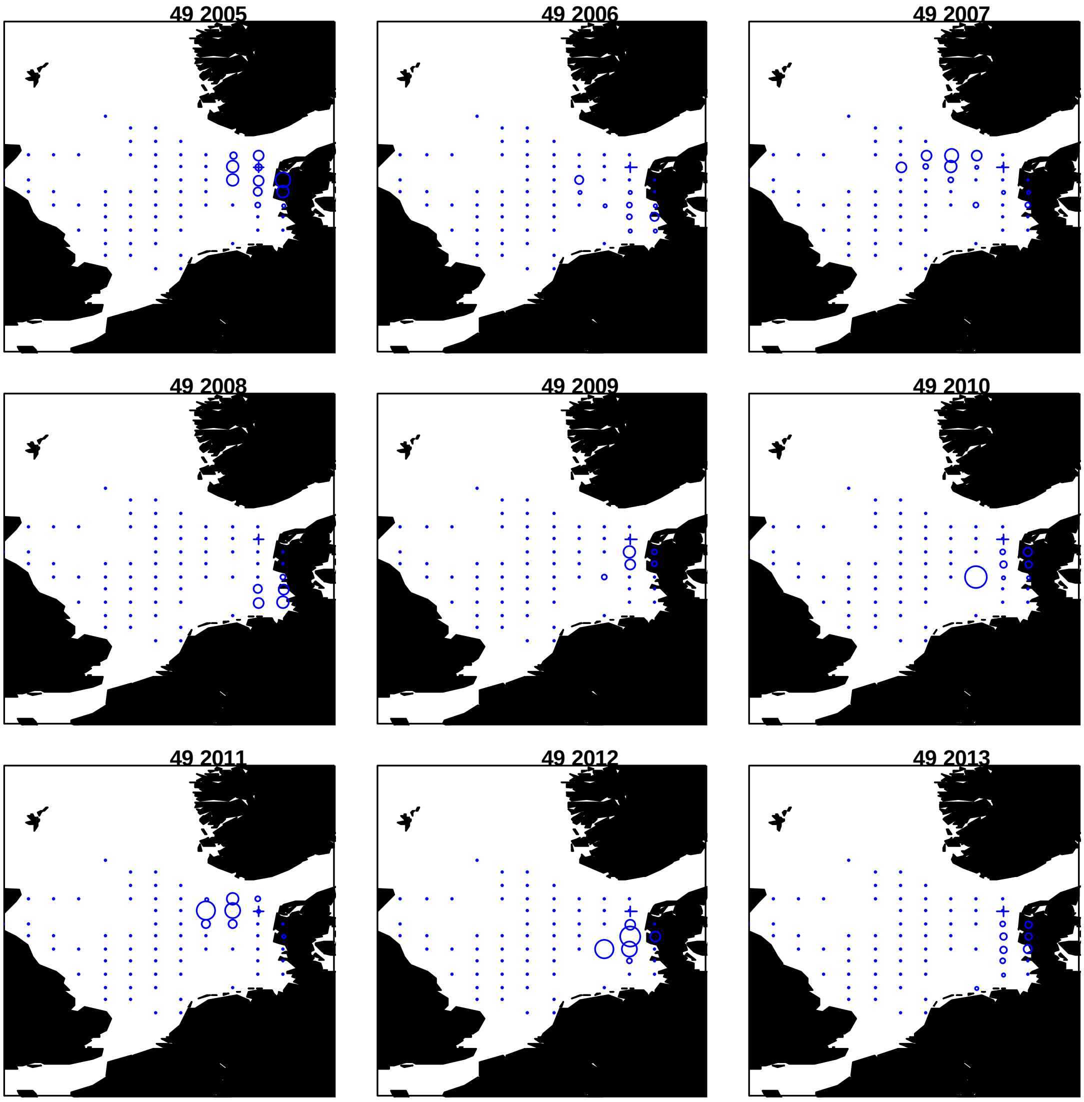


Figure A.1.6.Where does the selected square (marked with a blue cross) receive recruits from according to drift simulations? Bubbles indicate the relative importance of a given location as receiver of sandeel larvae. Note that the distribution of the mother population has not been taken into account. The plots are made from a connectivity matrix produced by the bio-physical model applied in Figure A.1.3.

Otolith microchemistry can provide a useful natural tag for studying dispersal and connectivity in regions where significant spatial differences can be detected. Gibb *et al.* (2017) investigated the natal origin of *A. marinus* in the North West North Sea and West of Scotland using an unsupervised clustering analysis of the near core region of *A. marinus* otoliths. Their analysis provided support for the proposed segregation between the Northern Isles (SA7) and SA4, predicted by an earlier biophysical model (Proctor *et al.*, 1998). Using a similar approach Wright *et al.* (WD to WKSAND 2016XX) examined variation in otolith microchemistry at grounds in SA1, 3 and 4. Clustering indicated that there were differences in juvenile otolith chemistry among sandeel assessment areas. A linear mixed model comparison of larval and recently settled otolith chemistry found differences among sandeel assessment areas but not between life stages, suggesting that larvae tended to remain within the areas they eventually settled. The largest difference in otolith chemistry was between SA4 and SA3 grounds but there were also significant differences between the otolith chemistry of SA1 grounds and the other areas. The results of the study were therefore consistent with previous biophysical model evidence for limited connectivity between the north west North Sea (SA4), the central North Sea (SA1) and the north east North Sea (SA3) (Proctor *et al.*, 1998; Christenssen *et al.*, 2008) and the new model runs.

A.1.1 Comparison of stock trends

High consistency in stock trends in terms of numbers at age among the sandeel assessment regions would not support the need for separate assessment areas. External consistency among sandeel assessment areas was considered using both commercial CPUE and dredge survey data. The external consistency between CPUE in different areas was analysed during WKSAND 2016 (WD: Rindorf 2016: External consistency between CPUE at age in different areas). No sandeel assessment area was found to be significantly correlated with the Firth of Forth (SA4). High correlations ($r2>0.5$) were found between recruitment in SA1 and 2 and between recruitment in the Norwegian and EU components of SA3. Moderate correlations ($r2>0.25<0.5$) were found between recruitment in SA1 and the EU and Norwegian component of SA3. The same pattern in significant correlations was also found for CPUE at age 2.

External consistency among and within sandeel assessment areas was examined using dredge survey indices calculated using the new method for the calculation indices. The recruitment dynamics were very different between the 2010 stock areas, although the 2009 recruitment signal was evident in all areas except for SA3. A closer look at SA3 (made by dividing SA3 into an EU and Norwegian economic zone) revealed that the recruitment signal in 2006 was driven by an increase in the EU component and the one in 2013 was driven by an increase in the Norwegian component. Further details of this analysis are given in WKSand 2016 WD_SurveyIndex) Taking the two analyses together, there is generally a low level of concordance among sandeel assessment areas although recruitment in SA1 and 2 appears correlated.

A.1.2 Demographic comparisons among stock assessment areas

As stocks are expected to reflect groups with different growth and mortality parameters we would expect that the proposed sandeel stocks should differ with respect to age and size composition. Since WKSAN 2010, further studies have examined the geographical variation in size and age composition. Rindorf *et al.* (2016) confirmed the regional variation in size at age suggested by earlier studies (Bergstad *et al.*, 2001; Boulcott *et al.*, 2007). They also found a 4 fold variation in weight at age across the North Sea with size at age being higher on the warmer, deeper central and north eastern fishing grounds and lowest in SA4.

A.1.3 Final stock definition based on WKSAND 2016

With off-set in the above research the WKSAND decided to re-draw the sandeel areas of the North Sea (Figure A.1.3). SA2 is the combined areas 2 and 3b. Obviously, other approaches may be used as well in the evaluation of proposed area divisions. One could be to look at recruitment dynamics within and between areas; see the working documents: "Co-variation between areas in dredge survey indices" and "External consistency between CPUE in different areas", and in the end any area division that does not support a robust stock assessment model is irrelevant. Elaborate description of the approaches that constituted the scientific/biological basis for the final area-division can be found in the WKSand2016 report and supplementary working documents to that report.

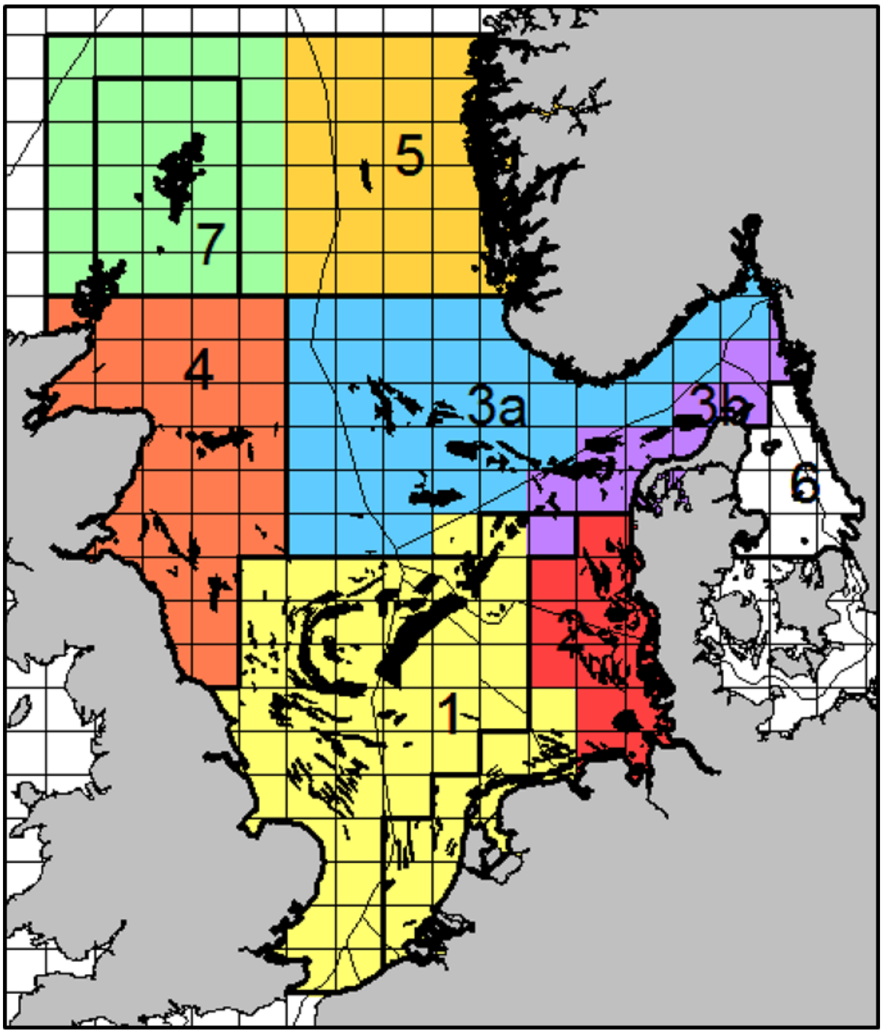


Figure A.1.3. Sandeel areas established at WKSAND 2016. Sandeel fishing banks (black areas), EEZ borders, and assessment areas: eastern area (red), northern area (blue), southern area (yellow), western area (dark orange), Shetland area (green) and Viking bank area (light orange).

A.2 Fishery

Most of the sandeel catch consists of the lesser sandeel *Ammodytes marinus*, although small quantities of other *Ammodytoidei* spp. are caught as well. There is little bycatch of protected species (ICES WGNSSK 2004).

General description

Denmark, Norway, Sweden, UK, and Germany participate in the sandeel fishery, where Denmark is the main contributor to the sandeel landings. Up to 2002 Denmark in average contributed 73% of the total landings and after 2002 73%.

The fishery is highly seasonal. The geographical distribution of the sandeel fishery varies seasonally and annually, taking place mostly in the spring and summer. In the third quarter of the year the distribution of catches generally changes from a dominance of the west Dogger Bank area back to the more easterly fishing grounds.

The sandeel fishery developed during the 1970s, and landings peaked in 1999 with 1.2 million tons. There was a significant shift in landings in 2003. The average landings of the period 1994 to 2002 was 880 000 tons whereas the average landings of the period 2003 to 2016 was 300 000 tons.

The size distribution of the Danish fleet has changed through time, with a clear tendency towards fewer and larger vessels (ICES, 2007). From 2000 there was a decline in the sandeel fishery and many Danish fishing vessels were scrapped and the quotas sold (Figure A.2.1). In 2004 an introduced ITQ led to a concentration of the fishery quotas and building of larger vessels. The investment and thereby the improvement of the vessels lead to building of large trawlers, at sizes which made it possible to use even bigger trawls and codends (Figure A.2.2). During the last ten years, the number of Danish vessels participating in the North Sea sandeel fishery has been stable with around 100 active vessels.

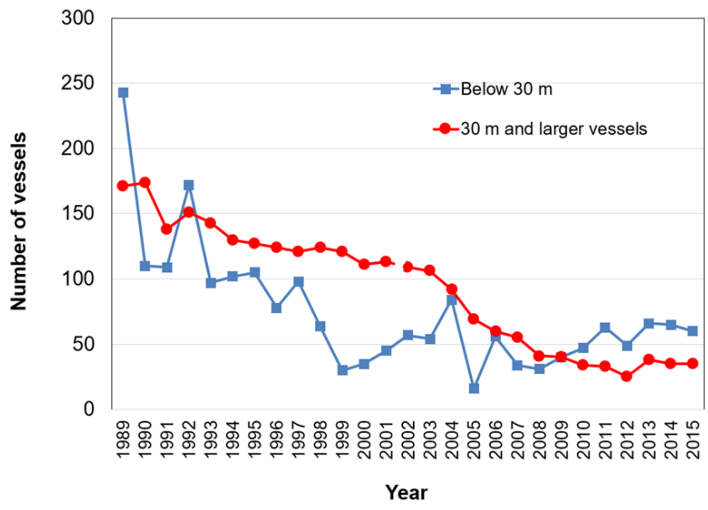


Figure A.2.1. Number of Danish vessels landing sandeel 1989-2015. (Data: Danish Agrifish Agency 2016.)

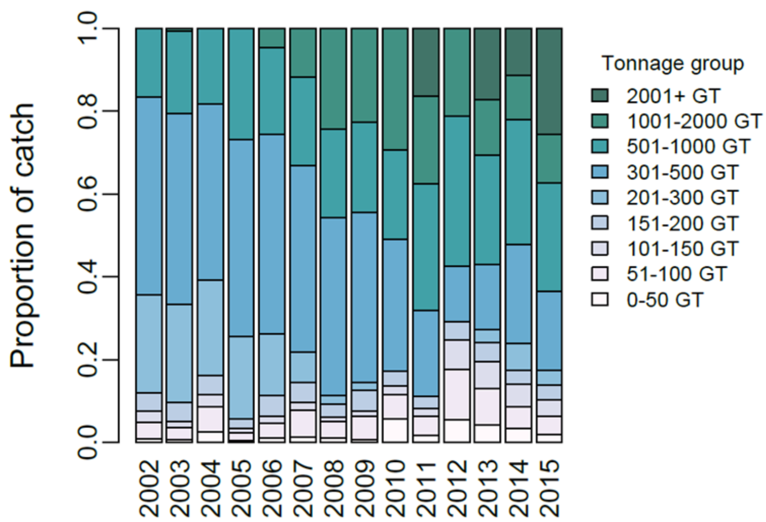


Figure A.2.2. Bar plot of proportional catch by tonnage group in each year (Ohlberger and Hilborn, 2016).

The same tendency was seen for the Norwegian vessels fishing sandeel until 2005. In 2006 only six Norwegian vessels were allowed to participate in an experimental sandeel fishery in the Norwegian EEZ compared to 53 in 2002. In 2008, 42 vessels participated in the sandeel fishery, and 29 vessels participated in 2015. From 2002 to 2014 the average GRT per trip in the Norwegian fleet increased from 269 to 1150 t.

The rapid changes of the structure of the fleet that have occurred in recent years may introduce more uncertainty in the assessment, as the fishing pattern and efficiency of the current fleet may differ from the previous fleet and the participation of fewer vessels has limited the spatial coverage of the fishery.

Fishery management regulations

Technical measures for the sandeel fishery include a minimum percentage of the target species at 95% for meshes <16 mm, or a minimum of 90% target species and maximum 5% of the mixture of cod, haddock, and saithe for 16 to 31 mm meshes.

The fishery is regulated by a TAC by area (since 2011). Since 2005, Danish vessels have not been allowed to fish sandeel before 31 March.

A.3 Ecosystem aspects

Sandeel are small, short-lived, lipid-rich, shoaling fish. They represent high quality food for many predatory fish, seabirds and marine mammals (Greenstreet *et al.*, 1997, 1998; Brown *et al.*, 2001; Stafford *et al.*, 2006; Macleod *et al.*, 2007; Daunt *et al.*, 2008). The sensitivity of the best known species is reviewed by Engelhard *et al.* (2014), who lists fish, seabird and marine mammal predators of sandeel (see section 3.2.2). Sandeel overwinter buried in sandy bottom habitats. Commercial catches show a steep decrease in catches between August and April indicating that the overwintering period for adult sandeel on average lasts for 8 months (Winslade 1974; Wright *et al.*, 2000; Høines and Bergstad 2001) interrupted only by spawning in December/January (Macer 1966; Boulcott and Wright 2008). During the period when sandeel are buried in the sandeel, they are inaccessible to many predators such as surface-feeding seabirds, though they continue to be eaten by some predatory fish, seals, and diving seabirds which apparently can dig them out of the sand (Hammond *et al.*, 1994).

Bottom-up effects on sandeel

There is strong evidence that sandeel stocks are affected by bottom-up processes involving climate and changing plankton stocks. A study of early larval survival suggested that the match between hatching and the onset of zooplankton production may be an important contributory factor to year-class variability in this species (Wright and Bailey, 1996). Frederiksen *et al.* (2005) used Continuous Plankton Recorder (CPR) data to develop an index of sandeel larval abundance for the Firth of Forth area. The sandeel larval index was strongly positively related to the abundance of phyto- and zooplankton, suggesting strong bottom-up control of sandeel larval survival (Frederiksen *et al.*, 2005). In an analysis of the underlying factors regulating recruitment and productivity of sandeel in SA 1, assessing the productivity and recovery potential of the stock under different climate and fishing scenarios using a coupled model approach, it was evident that spring sea surface temperature (SST) in the 2nd quarter was the most significant explanatory climate variable for recruitment success (Table A.3.1). Although other variables were statistically significant, SST q2 had the best fit and the highest degree of explained deviance overall (73.3%). In addition SSB, the number of 1-year-old sandeel (N1) and the abundance of *Calanus finmarchicus* were found significant. The final relationship between recruitment success, SSB and N1 were represented by non-linear decreasing functions (Figures A.3.1a and

A.3.2b), where in the latter case the negative effect on R/SSB occurs first at intermediate value of ln(N1). The functional relationship between recruitment success and SST was best described by a negative linear relationship (Figure A.3.1c), while the effect of *C. finmarchicus* was linear and positive (Figure A.3.1d). The final model explains well the long-term dynamics and inter-annual variability in recruitment success and hindcasted SSB (based on the age-structured model) throughout the period (Figure A.3.1e and f).

Table A.3.1. Summary statistics of parametric coefficients and smooth terms for the final stock-recruitment model for North Sea sandeel.

A. Intercept				
Estimate	**SE**	**t-value**	**p-value**	
-0.302	0.1	-2.97	0.007**	
B. Smooth terms				
Predictor	edf	F-value	p-value	Partial r^2 (%)
SSB	1.92	24.6	<0.001***	53.2
N1	1.89	11.5	<0.001***	23.3
SST	1.00	14.5	<0.001***	19.5
Cal. fin	1.00	4.93	0.036*	4.9

edf is the estimated degrees of freedom for the model smooth terms where edf>1 indicates a non-linear relationship. The partial r^2 refer to the percentage of the total deviance explained by each covariate separately.

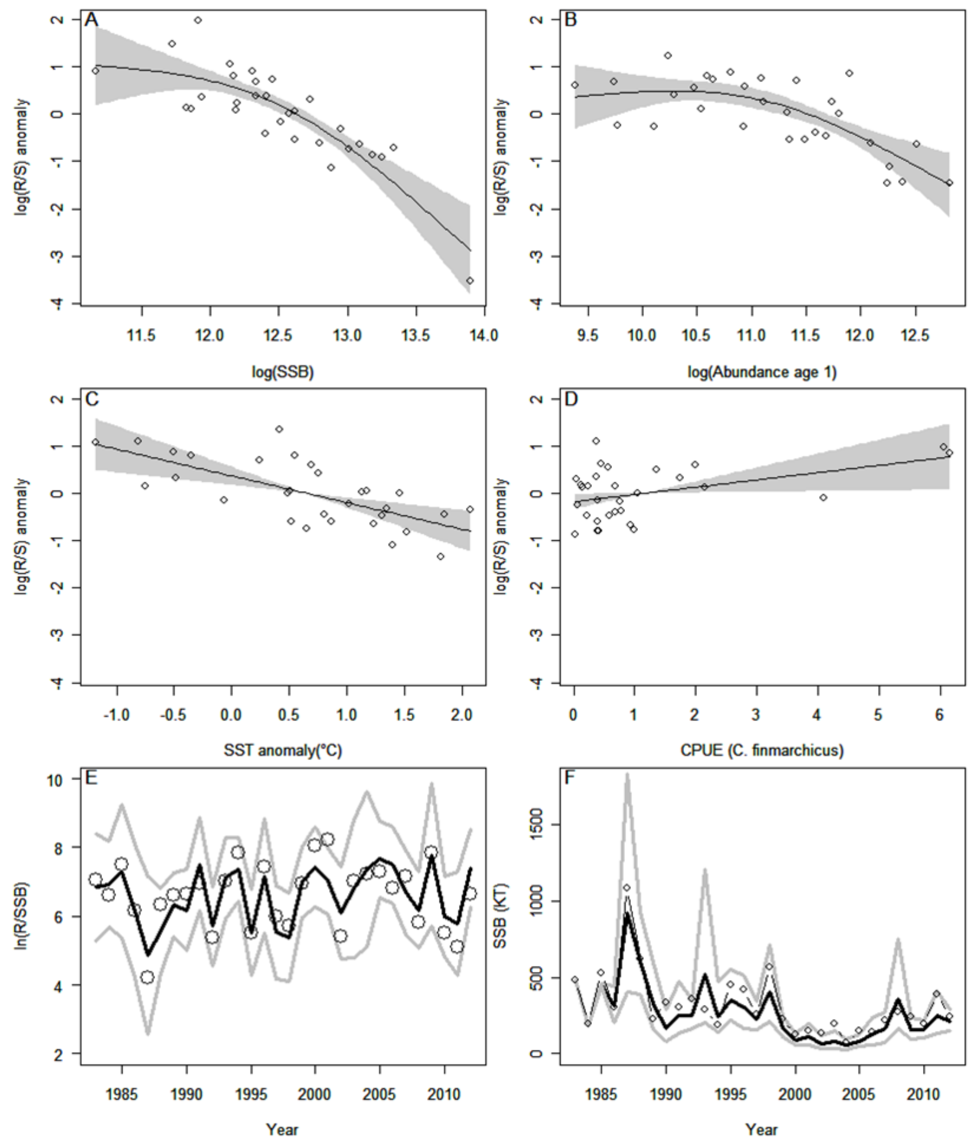


Figure A.3.1 a-f. The effects of final model predictors on sandeel recruitment success with 95% confidence intervals (grey), illustrating non-linear negative relationships with SSB (A) and abundance at age 1 (B), a negative linear relationships with SST (C), as well as positive effects of prey abundance (D; C. finmarchicus). (E) Observed (circles) and fitted values (black) of recruitment success with 95% confidence intervals (grey) based on the final GAM. (F) Observed and hindcasted estimates of spawning stock biomass (SSB; black) with 95% confidence intervals (grey) based on an age-structured population model.

Top-down effects on sandeel

Sandeel are important prey to a long list of predators. The sensitivity of the best known species is reviewed by Engelhard *et al.* (2014), who lists fish, seabird and marine mammal predators of sandeel (Extracts presented in Table A.3.2). Combining this with information of spatial distribution of the different species and the quality (size and condition) of the sandeel available gives an indication of where the biomass of sandeel is most likely to be related to predator performance.

Table A.3.2. Documented evidence on dependencies of North Sea top predators on sandeel. Table shows, for each predator species, the levels of mobility; proportion of diet made up by sandeel; and documented cases of effects of low sandeel abundance on top predators. Mobility describes the potential of the predator to relocate to different feeding areas in response to localised prey shortages: I, immobile year-round; IB, immobile during the breeding season only; M, mobile year-round. Diet proportions refer to the percentage composition by mass of a particular prey type, averaged over one year and over North Sea: note that local and seasonal percentages can be substantially higher or lower. Shading of species cells indicates high likelihood of effects of low forage fish availability, resulting from both a low potential to relocate and a high (>20%) proportion of forage fish in the diet. Shading of diet indicates >20% (light grey) or >50% (dark grey), and shading of reported effects indicates those on condition or growth (light grey) and on reproductive success (dark grey). From Engelhard *et al.* (2014); Literature sources: [1] Windsland *et al.* (2007); [2] Sharples *et al.* (2009); [3] Cunning-ham *et al.* (2004); [4] Reijnders *et al.* (2010); [5] ICES (2011); [6] Engelhard *et al.* (2014); [7] Santos *et al.* (2008); [8] MacLeod *et al.* (2007); [9] BWPi (2004); [10] Mendel *et al.* (2008); [11] Harris and Wanless (1991); [12] Stienen (2006); [13] Rindorf *et al.* (2000); [14] Furness (2007); [15] Wanless *et al.* (2005); [16] Mitchell *et al.* (2004); [17] Frederiksen *et al.* (2004); [18] Engelhard *et al.* (2013); [19] Rindorf *et al.* (2008); [20] Pomeroy *et al.* (1999); [21] Reilly *et al.* (2014).

Predator	Mobility	% Sandeel in diet	Reported effects of low forage fish abundance
Marine mammals			
Minke whale *Baleonoptera acutorostrata*	M	56%	No evidence reported for the North Sea
Grey seal *Halichoerus grypus*	IB	41%	No evidence reported, in peer reviewed literature though there is a reference in Engelhard *et al.* 2014 to an unpublished study.
Harbour seal *Phoca vitulina*	IB	37%	Later pupping dates [4], which in turn are associated with higher likelihood of breeding failure and lower pup weights [20]
Striped dolphin *Stenella coeruleoalba*	M	3%	No evidence reported
Harbour porpoise *Phocoena phocoena*	M	2%	Poor nutritional status of stranded animals reported to concur with low sandeel intake in 2002 and 2003 [8], but this does not appear to be linked to low recruitment of sandeel in the dredge survey in Firth of Forth [HAWG 2016].
Seabirds			
Sandwich tern *Sterna sandvicensis*	I	high	Highly vulnerable to changes in local food supply (especially clupeids): reproductive performance, breeding numbers and breeding distribution [12]
Arctic tern			Cury et al 2011, also papers by Monaghan's group; massive decline in breeding numbers in Shetland following collapse of sandeel stock in area 7
Shag *Phalacrocorax aristotelis*	I	high	Reproductive output probably limited by local sandeel availability at Isle of May [13] see also Cury et al 2011; massive decline in breeding numbers in Shetland following collapse of sandeel stock in area 7
Great skua *Catharacta skua*	IB	10-95%	Reproductive success influenced by local sandeel availability [14] also several papers by Votier et al, Cury et al 2011, Meek et al 2011
Arctic skua			Cury et al 2011, Phillips & Furness, Meek et al 2011; massive decline in breeding numbers in Shetland following collapse of sandeel stock in area 7

Puffin *Fratercula arctica*	IB	55%	No evidence reported for the North Sea; massive decline in breeding numbers in Shetland following collapse of sandeel stock in area 7
Guillemot *Uria aalge*	IB	42%	Provisioning of chicks influenced by local abundance and quality of sandeel and sprat [15] see also Cury et al 2011
Razorbill *Alca torda*	IB	37%	Reproductive output probably limited by local sandeel availability at Isle of May [16]
Kittiwake *Rissa tridactyla*	IB	28%	Reproductive performance strongly dependent on local sandeel availability [17] see also Cury et al 2011, Cook et al 2014; massive decline in breeding numbers in Shetland following collapse of sandeel stock in area 7
Gannet *Morus bassanus*	IB	18%	No evidence reported
Lesser black-backed gull *Larus fuscus*	M	low	No evidence reported
Northern fulmar *Fulmarus glacialis*	M	11%	Decline in breeding success with reduction in sandeel in fulmar diet, particulary around Shetland (Cury et al 2011)
Fish			
Saithe *Pollachius virens*	M	5%	No evidence reported
Horse-mackerel *Trachurus trachurus*	M	17%	No evidence reported
Whiting *Merlangius merlangus*	M	7% 85% on sandbanks [21]	Positive correlations between local sandeel abundance and condition [18]. However, [21] finds that whiting are not prey-limited in the Firth of Forth even in years of low sandeel abundance.
Starry ray *Amblyraja radiata*	M	18%	No evidence reported
Grey gurnard *Eutrigla gurnardus*	M	12%	Positive correlations between local sandeel abundance and condition [18]
Cod *Gadus morhua*	M	4%	Positive correlation between overlap with sandeel and growth in the North Sea [19]
Haddock *Melanogrammus aeglefinus*	M	15% 45% on sandbanks [21]	Haddock were not found to be prey limited during years of low sandeel abundance in the Firth of Forth [21]
Mackerel *Scomber scombrus*	M	10%	No evidence reported

Furness and Tasker (2000) reviewed the ecological characteristics of seabirds in the North Sea and ranked species from highly sensitive (e.g. terns, kittiwake, Arctic skua) to insensitive (e.g. northern gannet) to reductions in sandeel abundance. They argued that the most sensitive seabirds would be those with high foraging costs, little ability to dive below the sea surface, little ‘spare’ time in their daily activity budget, short foraging range from the breeding site, and little ability to switch diet. From their analyses, they produced a map of seabird sensitivity in the North Sea (Figure A.3.2).

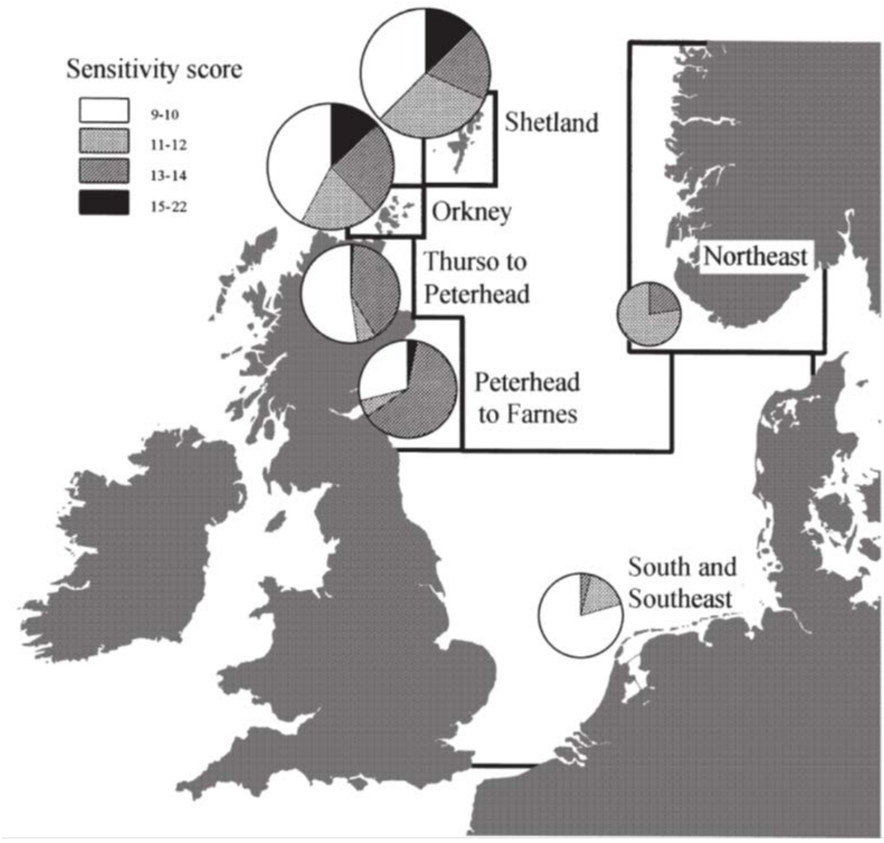
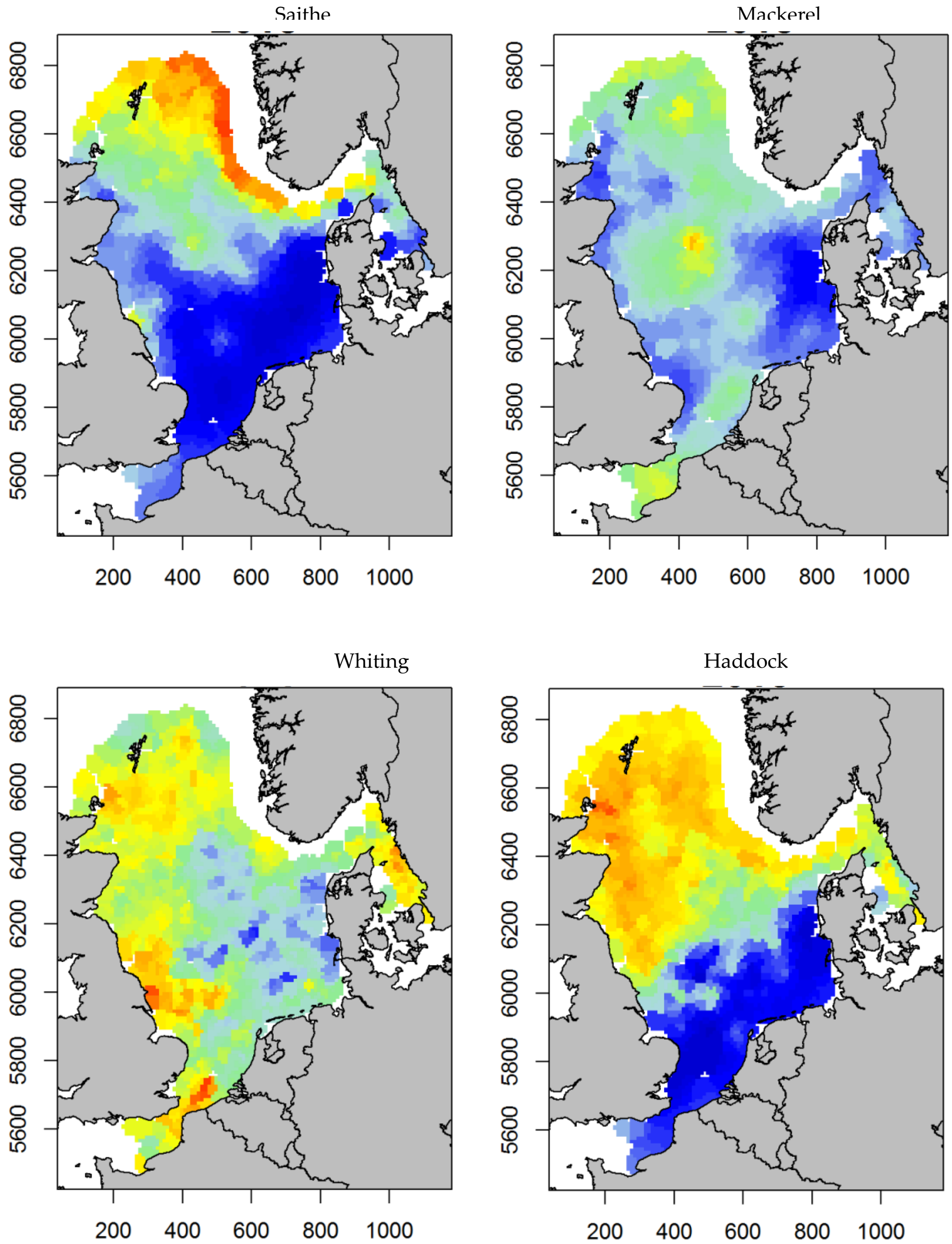


Figure A.3.2. Numbers of pairs of seabirds of high sensitivity to sandeel abundance, breeding in different parts of North Sea. Areas are defined as Shetland, Orkney, Thurso to Peterhead, Peterhead to Farnes (inclusive), southern and southeastern North Sea, and north-eastern North Sea. Size of each circle indicates size of local breeding population of seabirds of high sensitivity score. From Furness and Tasker (2000). Note that this map is now rather out of date, as many seabird populations in the northern North Sea have declined dramatically in numbers whereas populations in the south have remained more robust. The relative importance of southern areas has therefore increased since this map was produced.

Distribution of sandeel predators

Saithe and haddock tend to have a northerly distribution, whereas Gurnards, whiting and mackerel tend to be more widespread (Figure A.3.3). The abundance of fish predators is generally lower in the German bight area. Within the northern area, saithe is more abundant in the eastern areas. Seabirds and grey seals tend to be distributed close to the coast of northern Britain, with the exception of sandwich tern, which is concentrated close to the coast in the German bight (ICES 2016 WKSand report). The distribution of cetaceans seems highly variable between years (ICES 2016 WKSand report).


Saithe
Mackerel
Whiting
Haddock
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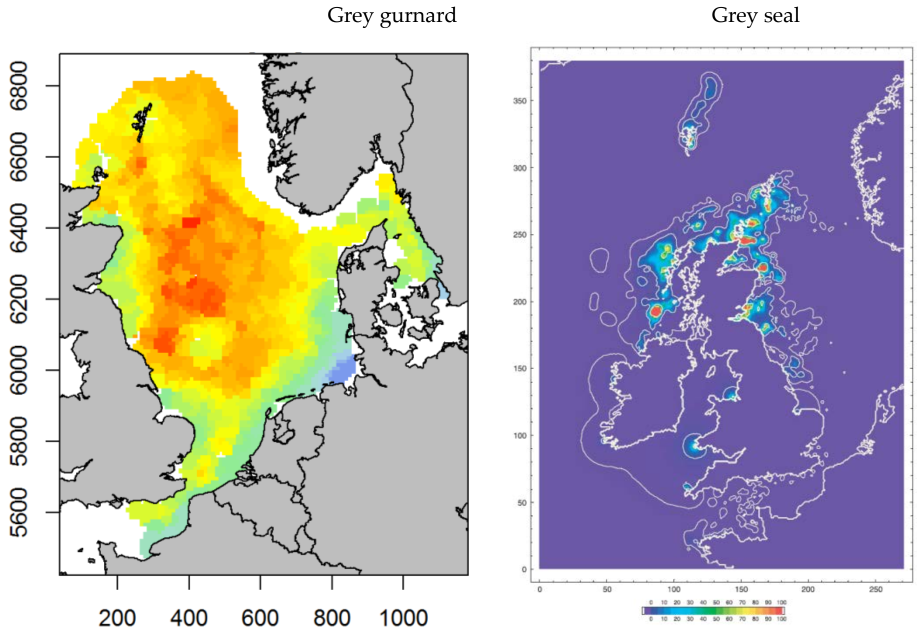

Figure A.3.3. Distribution of saithe, mackerel, whiting, haddock, grey gurnards and grey seals. Fish distributions are 2015 distributions derived from www.FishViz.org. Grey seal distribution is derived from Matthiopoulos *et al.* (2004).

Spatial patterns in sandeel size and condition

Sandeel length and weight at age varies substantially across the North Sea (Rindorf *et al.* 2016) with sandeel in the North-western and far southern parts being smaller than elsewhere and sandeel in the southern parts having a lower condition than elsewhere (Figure A.3.4). These differences produce a 4–fold difference in weight at age 2 in different regions of the North Sea (weighing between 4.6 and 19.0 g in week 21).

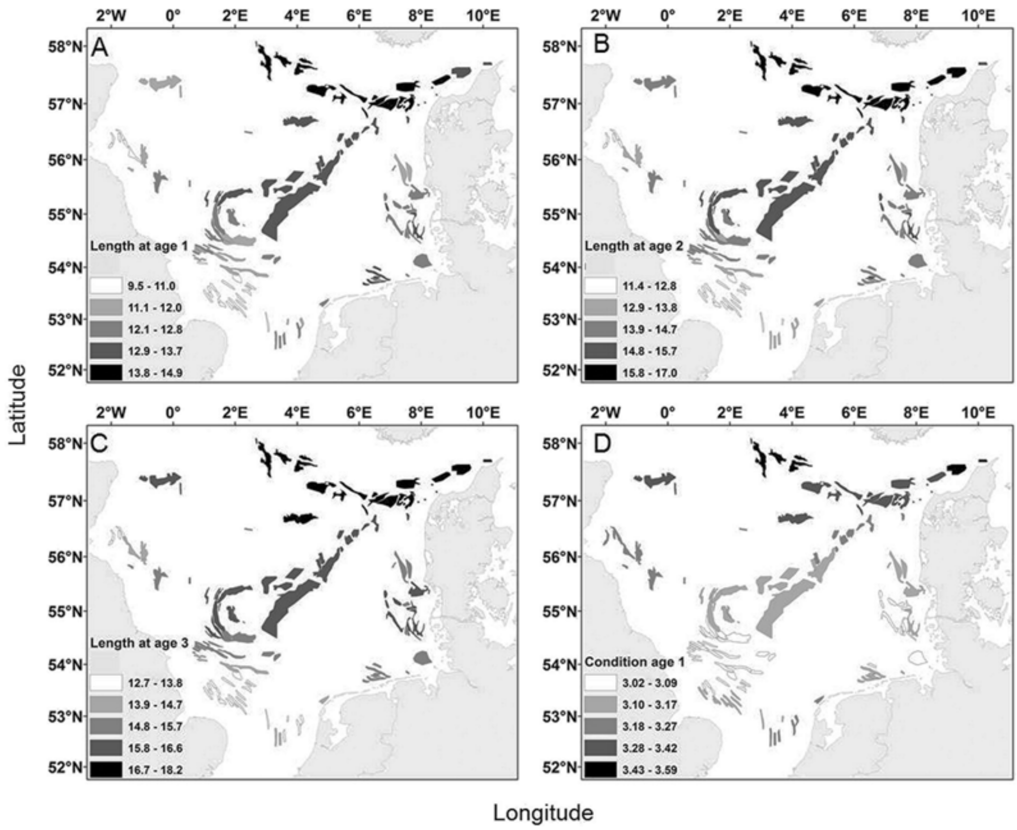

Figure A.3.4. Maps of predicted length at each ground in week 21 at ages 1 (A), 2 (B) and 3 (C) and predicted condition at age 1 in week 21 (D). Shading indicates mean length and condition, respectively, white indicating the lowest level and black the highest. Minimum length at ages 1, 2 and 3: 7.0, 12.1 and 13.1 cm, respectively. Maxi-mumlengths at ages 1, 2 and 3: 17.1, 19.5 and 21.2 cm, respectively. From Rindorf *et al.* (2016).

Implications for ecosystem-based management

The potential conflict between sandeel fisheries and other ecosystem components rely on the degree of spatial overlap between fisheries and sensitive predators and the degree of dispersal of sandeel at different life stages.

Neither potential fishing grounds (Figure A.3.4) nor the distribution of fisheries catches (Figure A.3.5) are evenly distributed. Whereas the fishing grounds are assumed to remain relatively constant over time, the actual distribution of the fishery varies greatly from year to year in response to both changes in the availability of sandeel and changes in management between areas (Figure A.3.5).

Figure A.3.5. Sandeel landings as reported to ICES. Note that the fishery was not constrained by the agreed TACs until 2006 onwards, hence catches in the period from 2000-2005 represent a free fishery. In the period 2000-2006, the area 1 and stocks were below the current agreed Blim in all years in area 3 and all but one or two years in areas 1 and 2 (2003 in area 1, 2000 and 2003 in area 2). From, 2011 onwards, the TACs have been advised on an area basis. From (HAWG 2016).

The breeding distribution of many seabirds in the North Sea is dictated by the spatial distribution of suitable breeding habitat. Recent aerial surveys of seabirds in relation to offshore wind farm development areas (Bradbury *et al.* 2014) have also shown that the Dogger Bank area is a hot spot for seabirds in summer, especially guillemots, razorbills and puffins, which feed extensively on sandeel. Distributions of harbour porpoises in UK waters have changed over decades. Whereas their numbers were once high in Shetland, the distribution in 2005shows the highest concentration on the

Dogger Bank (Figure. A.3.6). Grey seal overlap with the fishery is concentrated off the Scottish east coast.

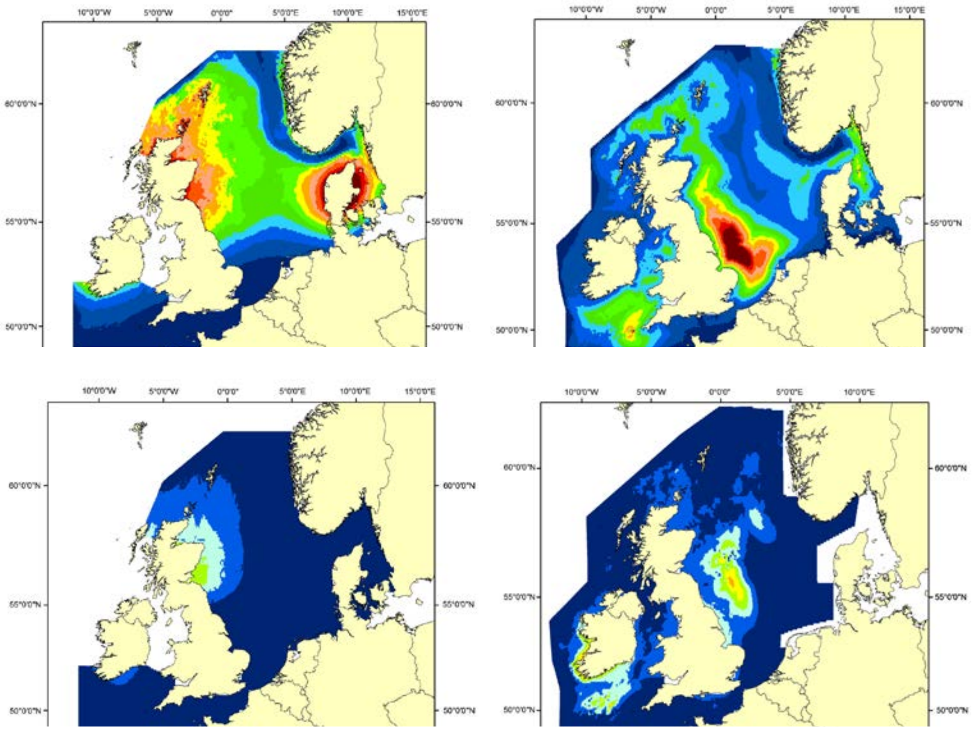

Figure. A.3.6. Distribution of harbour porpoise (top) and minke whales (bottom) based on SCANS surveys in 1994 (left) and 2005 (right). From Hammond *et al.* (2013).

B. Data

B.1 Commercial catch

Denmark, Norway, Sweden, UK, and Germany participate in the sandeel fishery, where Denmark is the main contributor to the sandeel landings. Up to 2002 Denmark in average contributed 73% of the total landings and after 2002 73%.

The fishery is highly seasonal. The geographical distribution of the sandeel fishery varies seasonally and annually, taking place mostly in the spring and summer. In the third quarter of the year the distribution of catches generally changes from a dominance of the west Dogger Bank area back to the more easterly fishing grounds. The annual patterns of the sandeel fishery between 2000 and 2015 is shown in Figure B.1.1.1

Figure B.1.1 Landings per year and square.

The sandeel fishery developed during the 1970s, and landings peaked in 1999 with 1.2 million tons. There was a significant shift in landings in 2003. The average landings of the period 1994 to 2002 was 880 000 tons whereas the average landings of the period 2003 to 2016 was 300 000 tons. Table B.1.1 shows sandeel landings by country for 1955-2015.

Table B.1.1. Sandeel. Catches ('000 t), 1955–2015. (Data provided by Working Group Members).

Year	Denmark	Germany	Faroes	Ireland	Nether-lands	Norway	Sweden	UK	Lithu-ania	Total
1955	37.6	+	-	-	-	-	-	-	-	37.6
1956	81.9	5.3	-	-	+	1.5	-	-	-	88.7
1957	73.3	25.5	-	-	3.7	3.2	-	-	-	105.7
1958	74.4	20.2	-	-	1.5	4.8	-	-	-	100.9
1959	77.1	17.4	-	-	5.1	8	-	-	-	107.6
1960	100.8	7.7	-	-	+	12.1	-	-	-	120.6
1961	73.6	4.5	-	-	+	5.1	-	-	-	83.2
1962	97.4	1.4	-	-	-	10.5	-	-	-	109.3
1963	134.4	16.4	-	-	-	11.5	-	-	-	162.3
1964	104.7	12.9	-	-	-	10.4	-	-	-	128.0
1965	123.6	2.1	-	-	-	4.9	-	-	-	130.6
1966	138.5	4.4	-	-	-	0.2	-	-	-	143.1
1967	187.4	0.3	-	-	-	1	-	-	-	188.7
1968	193.6	+	-	-	-	0.1	-	-	-	193.7
1969	112.8	+	-	-	-	-	-	0.5	-	113.3
1970	187.8	+	-	-	-	+	-	3.6	-	191.4
1971	371.6	0.1	-	-	-	2.1	-	8.3	-	382.1
1972	329.0	+	-	-	-	18.6	8.8	2.1	-	358.5
1973	282.9	-	1.4	-	-	17.2	1.1	4.2	-	306.8
1974	432.0	-	6.4	-	-	78.6	0.2	15.5	-	532.7
1975	372.0	-	4.9	-	-	54	0.2	13.6	-	444.7
1976	446.1	-	-	-	-	44.2	0.1	18.7	-	509.1
1977	680.4	-	11.4	-	-	78.7	6.1	25.5	-	802.1
1978	669.2	-	12.1	-	-	93.5	2.3	32.5	-	809.7
1979	483.1	-	13.2	-	-	101.4	-	13.4	-	611.1
1980	581.6	-	7.2	-	-	144.8	-	34.3	-	767.9
1981	523.8	-	4.9	-	-	52.6	-	46.7	-	628.1
1982	528.4	-	4.9	-	-	46.5	0.4	52.2	-	632.4
1983	515.2	-	2	-	-	12.2	0.2	37	-	566.8
1984	618.9	-	11.3	-	-	28.3	-	32.6	-	691.1
1985	601.7	-	3.9	-	-	13.1	-	17.2	-	635.9
1986	832.7	-	1.2	-	-	82.1	-	12	-	928.0
1987	609.2	-	18.6	-	-	193.4	-	7.2	-	828.4
1988	708.8	-	15.5	-	-	185.1	-	5.8	-	915.3
1989	841.6	-	16.6	-	-	186.8	-	11.5	-	1056.3
1990	512.1	-	2.2	-	0.3	88.9	-	3.9	-	607.5
1991	726.5	-	11.2	-	-	128.8	-	1.2	-	867.7
1992	803.7	-	9.1	-	-	89.3	0.6	4.9	-	907.6
1993	533.4	-	0.3	-	-	95.5	-	1.5	-	630.8
1994	688.6	-	10.3	-	-	165.8	-	5.9	-	870.7
1995	672.6	-	-	-	-	263.4	-	6.7	-	942.8
1996	649.5	-	5	-	-	160.7	-	9.7	-	824.8
1997	831.8	-	11.2	-	-	350.1	-	24.6	-	1217.8
1998	628.2	-	11	-	+	343.3	8.6	23.8	-	1014.8

Year	Denmark	Germany	Faroes	Ireland	Nether-lands	Norway	Sweden	UK	Lithu-ania	Total
1999	511.3	-	13.2	0.4	+	187.6	23.2	11.5	-	747.1
2000	557.3	-	-	-	+	119	28.6	10.8	-	715.7
2001	650.0	-	-	-	-	183	50	1.3	-	884.3
2002	659.5	-	-	-	-	176	19.2	4.9	-	859.6
2003	282.8	-	-	-	-	29.6	21.8	0.5	-	334.7
2004	288.8	2.7	-	-	-	48.5	33.3	+	-	373.3
2005	158.9	-	-	-	-	17.3	0.5	-	-	176.6
2006	255.4	3.2	-	-	-	5.6	27.9	-	-	292.8
2007	166.9	1	2	-	-	51.1	7.9	1	-	229.9
2008	246.9	4.4	2.4	-	-	81.6	12.5	-	-	347.8
2009	293.0	12.2	2.5	-	1.8	27.4	12.4	3.6	2	352.9
2010	285.9	13	-	-	-	78	32.7	4	0.6	414.2
2011	278.5	9.8	-	-	-	109	32.7	6.1	1.7	437.8
2012	51.5	1.7	-	-	-	42.5	5.7	-	-	101.4
2013	208.7	7.9	-	-	0.4	30.446	26.8	2.436	1.3	278.0
2014	156.3	5.1	-	-	-	82.5	18.8	+	0.8	263.8
2015	162.9	9.1	-	-	-	100.9	32.9	1.6	-	307.3

B.1.1 Landings data

Landings are reported from all countries, however, only Danish and Norwegian catches are sampled for biological parameters (see section B.2). All landings are used for reduction purposes.

B.1.2 Data coverage and quality

Sampling activity for commercial catches is shown in Figure B.1.2.1. Over time, the initiation of a self-sampling programme for the Danish fishery in 2001 and scientific sampling from landings have given a better coverage of the catch since the early 2000's. Norwegian catches are sampled either from the landing sites or from on-board samples where 100 individuals in a haul are frozen and sent to IMR.

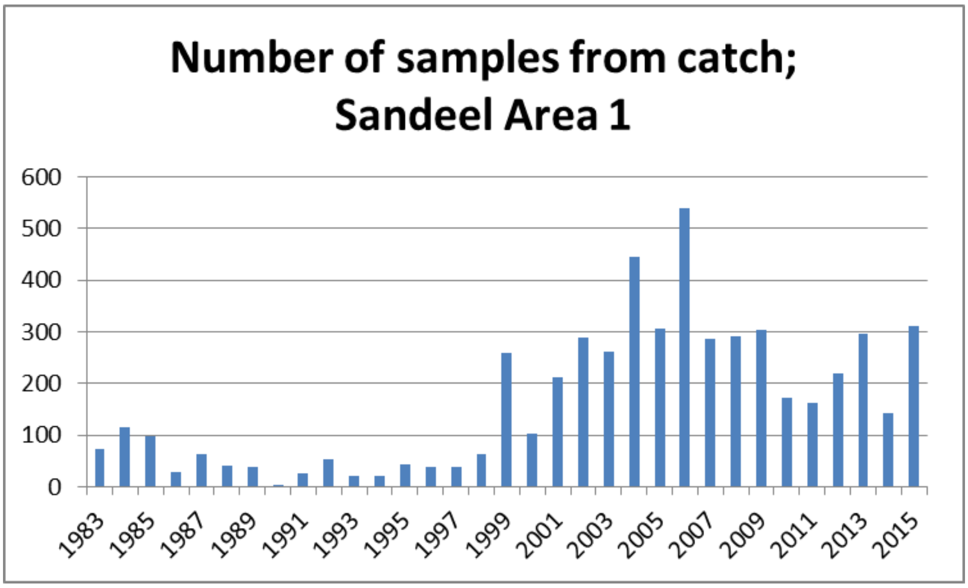

Figure B.1.2.1. Number of samples taken by both self-sampling (since 2001) and scientific samples of catches of sandeel in SA1 per year.

B.1.3 Discards estimates

No discards have been reported or observed in the sandeel fishery in SA1 and there is not historical time series of data available.

B.1.4 Recreational catches

Not relevant for this stock

B.2 Biological sampling

Self-sampling and scientific sampling from landings have given a rather high number of samples. Samples thus included Danish and Norwegian samples from harbour sampling and Danish samples taken by skippers on board vessels and frozen immediately (available from 1999 onwards). The Danish samples cover both age and length distributions whereas the Norwegian samples cover only length distribution prior to 1997 and both age and length samples after 1997.

B.2.1Maturity

Maturity estimates from 2005 onwards are obtained from the Danish dredge survey in December. During WKSAND 2016 it was decided to use average maturities as no trends were observed in maturity in any of the sandeel areas and no analyses documented relationships between maturity and stock size or weight at age.

Age 1	Age 2	Age 3	Age 4
0.02	0.80	0.99	1.00

B.2.2 Natural mortality

Predation rates are estimated by WGSAM every three years, and on these occasions, the general settings of the model are also updated if deemed necessary. As a result, the estimates of natural mortality of each species may change somewhat back in time.

However, the temporal patterns tend to be relatively stable between updates (Figure. B.2.2.1, Table B.2.2.1).

Table B.2.2.1. Correlations between time series of natural mortality based on the 2008, 2011 and 2015 key runs (WGSAM 2008, 2011 and 2015).

Key runs compared	Age 1	Age 2
2015 vs 2011	0.825	0.708
2011 vs 2008	0.943	0.928
2015 vs 2008	0.841	0.697

In the 2010 benchmark, the natural mortalities presented to the group were based on the total number of sandeel in the North Sea. Based on this, WKSAN 2010 decided that it was inappropriate to use temporally variable natural mortalities as the temporal development may be different in different sandeel assessment areas. Since then, the multispecies model has been adjusted to estimate natural mortalities of sandeel in the southern (current assessment areas 1 and 2) and northern (current sandeel areas 3 and 4) separately. As suggested in the 2010 benchmark, the natural mortalities differ substantially between areas.

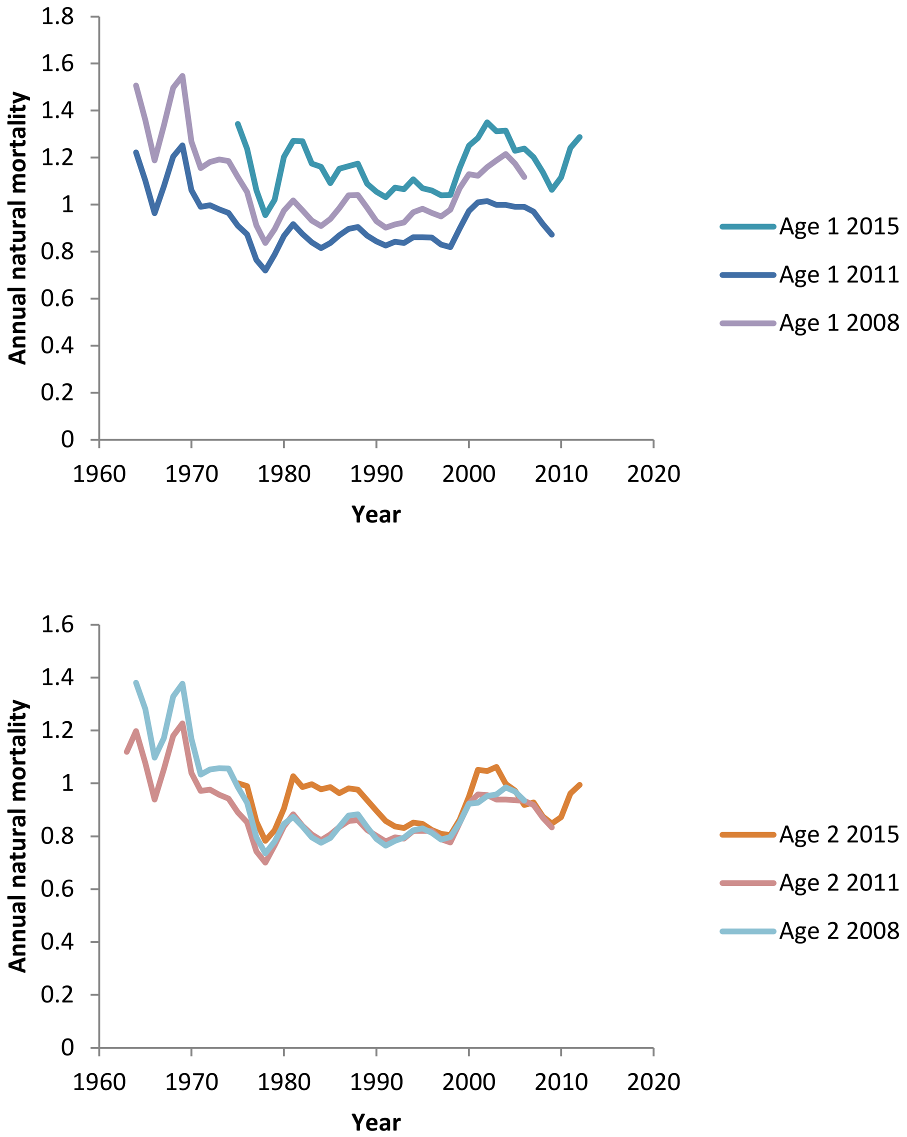

Figure. B.2.2.1. Estimates of annual natural mortality based on 2008, 2011 and 2015 key runs of the multispecies model SMS (WGSAM 2008, 2011, 2014 and 2015). The values of the 2015 key run are derived as the average of northern area (upper panel) and southern area (lower panel), weighted by the abundance of the age group in the beginning of the year.

B.2.2.1 Natural mortalities modified for inclusion in assessment

Given all this information, it was decided to use 3-year average values of natural mortality at age in sandeel area 1 (ICES 2016, WKSand report). WGSAM recommends using a smoothed version, for example 3-year averages before including natural mortalities in annual stock assessments. They also recommend not using trends to extrapolate the time series, but instead using the terminal year value for subsequent years. Further, they recommend considering the effects of new key runs on stock-recruitment relationships before updating time series outside benchmarks. If the effect on the stock recruitment plot (shape rather than level) is minor, the time series can be updated to use the new time series even outside a benchmark. Finally, to be used in assessments, the quarterly values of M must be combined to provide M by half year. Figure. B.2.2.1.1 shows the half-yearly 3-year average M's for southern and northern sandeel together with the long term average and the estimated trend.

The 2010 WKSAN group considered that 'since there were updated estimates of half-yearly natural mortality available from WGSAM, these should be used in the assessment. As the trends in natural mortality were only apparent in the end of the time period where the uncertainty is greatest, it was decided not to use annual estimates of M. Instead, the average over the period 1982 to 2007 for each age and half-year was used. However, the group considered it unfortunate that spatially explicit natural mortalities were not available as it is unlikely that natural mortality is constant across the assessment areas.' (WKSAN 2010). On the latter point, southern and northern estimates are now available and indeed show substantial differences in temporal patterns. On the presence or absence of a temporal pattern, there seems to have been changes of up to -29% to +48% of the average over the entire time series (Table B.2.2.1.1). Further, there has been a marked increase in the estimated M values in the period with low stock size in the northern area and in the southern area a steady increase has been seen since around 1995.

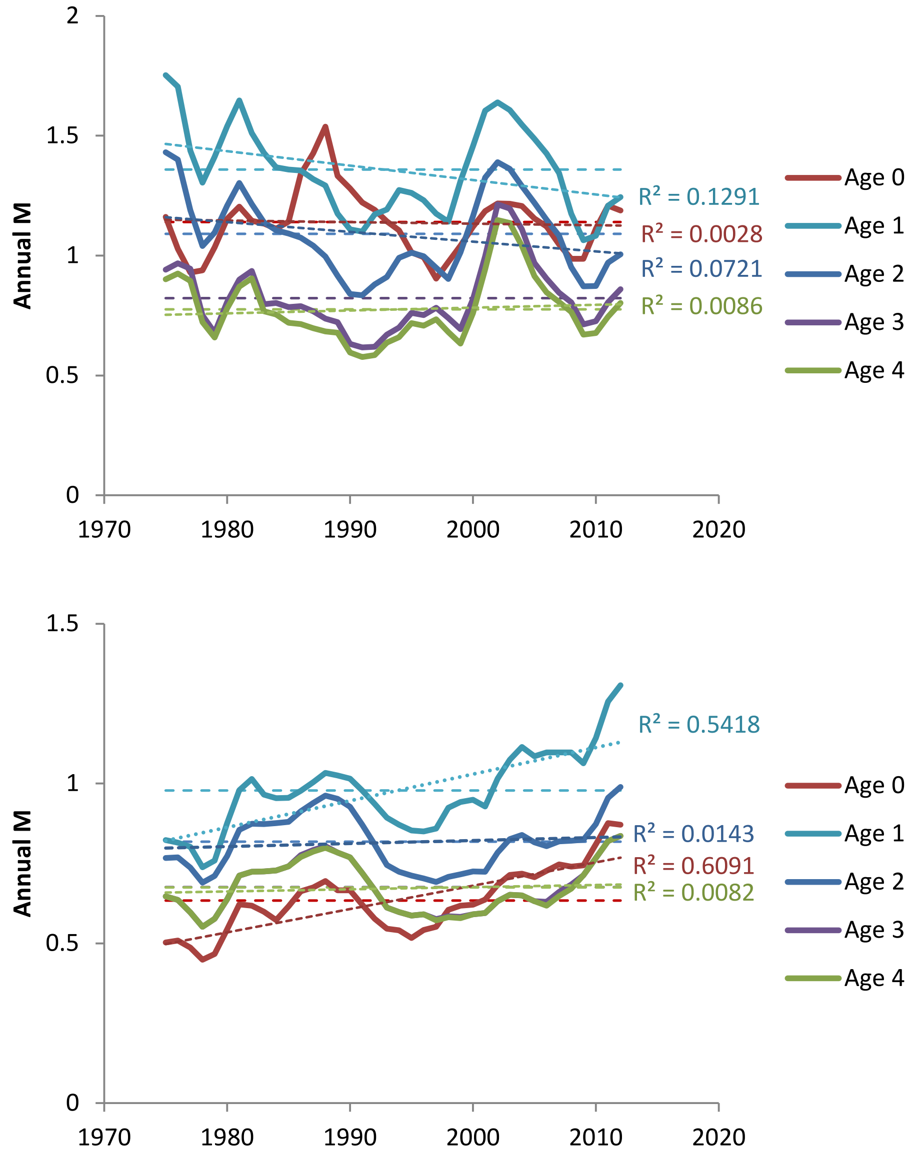

Figure. B.2.2.1.1. Estimated annual M in the northern (top) and southern (bottom) sandeel stock. Averages over the entire time period are shown at broken lines, trends as dotted lines.

Table B.2.2.1.1 Minimum and maximum annual estimates in % of the average M for specific ages and areas.

Age	Northern		Southern	
	Min	Max	Min	Max
0	79%	135%	71%	138%
1	79%	129%	76%	134%
2	77%	132%	85%	121%
3	75%	148%	82%	124%
4	75%	148%	82%	125%

Thus WKSAND 2016 decided to apply a 3-year average values of natural mortality at age in sandeel area 1 (ICES 2016, WKSAND report). 3-year averages of natural mortality at age from multispecies modelling of southern sandeel (SMS, WGSAM 2015) were used. The last value provided is used for all years following the latest data point. Tables B.2.2.1.2a and B.2.2.1.2b show natural mortality pr. Year age for Season 1 (a) and 2 (b).

Table B.2.2.1.2a; Natural mortality in SA1 by age and year in Season 1

Year	Season	M0	M1	M2	M3	M4
1983	1	0	0.385	0.346	0.254	0.254
1984	1	0	0.377	0.343	0.249	0.249
1985	1	0	0.364	0.332	0.243	0.243
1986	1	0	0.358	0.332	0.244	0.243
1987	1	0	0.374	0.347	0.25	0.249
1988	1	0	0.381	0.352	0.25	0.249
1989	1	0	0.4	0.368	0.257	0.257
1990	1	0	0.386	0.349	0.248	0.248
1991	1	0	0.38	0.335	0.239	0.239
1992	1	0	0.369	0.315	0.224	0.224
1993	1	0	0.367	0.302	0.216	0.216
1994	1	0	0.351	0.288	0.21	0.21
1995	1	0	0.352	0.288	0.209	0.209
1996	1	0	0.326	0.269	0.201	0.201
1997	1	0	0.341	0.269	0.2	0.199
1998	1	0	0.376	0.279	0.205	0.204
1999	1	0	0.398	0.29	0.207	0.206
2000	1	0	0.404	0.298	0.21	0.21
2001	1	0	0.362	0.279	0.203	0.203
2002	1	0	0.399	0.302	0.214	0.214
2003	1	0	0.418	0.319	0.216	0.216
2004	1	0	0.45	0.33	0.213	0.213
2005	1	0	0.433	0.318	0.202	0.202
2006	1	0	0.436	0.305	0.198	0.195
2007	1	0	0.42	0.3	0.202	0.199
2008	1	0	0.417	0.293	0.207	0.204
2009	1	0	0.373	0.277	0.208	0.208

2010	1	0	0.391	0.277	0.215	0.215
2011	1	0	0.443	0.31	0.229	0.229
2012	1	0	0.489	0.339	0.241	0.241
2013	1	0	0.489	0.339	0.241	0.241
2014	1	0	0.489	0.339	0.241	0.241
2015	1	0	0.489	0.339	0.241	0.241
2016	1	0	0.489	0.339	0.241	0.241
2017	1	0	0.489	0.339	0.241	0.241

Table B.2.2.1.2b; Natural mortality in SA1 by age and year in Season 2

Year	Season	M0	M1	M2	M3	M4
1983	2	0.599	0.58	0.527	0.472	0.472
1984	2	0.573	0.577	0.533	0.479	0.479
1985	2	0.615	0.592	0.548	0.498	0.498
1986	2	0.663	0.619	0.582	0.531	0.527
1987	2	0.675	0.63	0.592	0.542	0.538
1988	2	0.695	0.652	0.61	0.554	0.55
1989	2	0.666	0.625	0.584	0.527	0.527
1990	2	0.666	0.629	0.578	0.521	0.521
1991	2	0.621	0.598	0.536	0.482	0.482
1992	2	0.577	0.567	0.495	0.443	0.443
1993	2	0.545	0.526	0.443	0.396	0.396
1994	2	0.54	0.52	0.436	0.388	0.388
1995	2	0.517	0.501	0.423	0.377	0.377
1996	2	0.542	0.524	0.434	0.389	0.389
1997	2	0.552	0.518	0.422	0.375	0.373
1998	2	0.605	0.548	0.429	0.381	0.378
1999	2	0.618	0.544	0.425	0.375	0.373
2000	2	0.621	0.545	0.427	0.38	0.38
2001	2	0.637	0.567	0.445	0.392	0.392
2002	2	0.683	0.616	0.482	0.418	0.418
2003	2	0.714	0.656	0.507	0.436	0.436
2004	2	0.717	0.664	0.509	0.436	0.436
2005	2	0.707	0.653	0.498	0.429	0.429
2006	2	0.727	0.662	0.499	0.432	0.422
2007	2	0.747	0.677	0.519	0.459	0.449
2008	2	0.74	0.681	0.528	0.477	0.467
2009	2	0.744	0.69	0.548	0.506	0.506
2010	2	0.81	0.752	0.596	0.552	0.552
2011	2	0.876	0.814	0.645	0.592	0.592
2012	2	0.871	0.819	0.65	0.596	0.596
2013	2	0.871	0.819	0.65	0.596	0.596
2014	2	0.871	0.819	0.65	0.596	0.596
2015	2	0.871	0.819	0.65	0.596	0.596
2016	2	0.871	0.819	0.65	0.596	0.596
2017	2	0.871	0.819	0.65	0.596	0.596

B.2.3 Length and age composition of landed and discarded fish in commercial fisheries

Sandeel measured for length distribution were weighed in the Danish samples whereas only aged sandeel were weighed from the Norwegian samples. To obtain weight-at-length for Norwegian samples, the parameters of the weight–length relationship (per month year and old Sandeel sampling area).

$W = aL^b$

were estimated using the sandeel weighed in the Norwegian age samples after 1997 and Danish length-weight relationships before 1997 and weight-at-length estimated for sandeel which were not weighed. All data are combined in the analyses, corresponding to the assumption that the composition of catches taken in a given year and month did not differ between countries. No differences in age-reading was evident (Coad 2016, WDX to WKSand 2016).

B.2.3.1 Estimating age length keys

Only age readings of Ammodytes marinus and unidentified sandeel *Ammodytes* spp. are used. The method suggested by Rindorf and Lewy (2001) is used to assure that the estimation is optimized when sampling is sparse. This method is used to estimate an age–length-key for each combination of year, time and area (Table B.2.3.1). When the number of fish aged is too low to allow a reliable estimation on rectangle level (confidence limits of the estimate exceeds +/- 25%), higher aggregation levels are used (Table B.2.3.1). When a given age is not observed in an age sample, this is assumed to reflect an absence of this age only if the number of fish sampled of this age or older exceeds 10. Otherwise, the absence of the particular age is assumed to be a result of low sampling efforts, and the probability of being of the particular age compared to the probability of being older taken from a higher aggregation level. The probability of being of a given age is set to zero at lengths outside the interval of lengths observed for this age +/- 2 length groups (1 cm groups from 6 to 20 cm, 2 cm groups between 20 and 30 cm). Overdispersion (Rindorf and Lewy, 2001) was not estimated.

Table B.2.3.1. Aggregation levels for age length keys and length distributions

Level	Space	Time
3	Square	Jan-feb, march, April (1-15), april (16-30), may (1-15), may (16-31), june (1-15), june (16-30), july, aug, sep-oct, nov-dec
4	Sandeel sampling areas within asessment areas(Figure. 1)	Jan-feb, march, april (1-15), april (16-30), may (1-15), may (16-31), june (1-15), june (16-30), july, aug, sep-oct, nov-dec
5	Aggregated sandeel sampling areas within assessment areas: 1A+1B, 1C, 2A+6, 2B+3, 4+5, 3AS+3AN	Jan-feb, march, april (1-15), april (16-30), may (1-15), may (16-31), june (1-15), june (16-30), july, aug, sep-oct, nov-dec
6	Aggregated sandeel sampling areas within assessment areas: 1A+1B, 1C, 2A+6, 2B+3, 4+5, 3AS+3AN	Jan-mar, april-may, june-aug, sep-dec
7	Sandeel assessment areas	Jan-mar, april-may, june-aug, sep-dec
8	Sandeel assessment areas	Jan- june, july-dec
9	All areas together	Jan- june, july-dec

10	All areas together	Jan- dec

B.2.3.2 Estimating age distributions and mean weight-at-age

The number of *A. marinus* of each age (0 to 4+) per kg and the mean weight per individual of each age in each length distribution sample was estimated by combining the age–length key and the length distribution specific to that square and period (periods given in Table B.2.3.1). The average number of sandeel per age per kg and their mean weight in a given rectangle in each month was estimated as the average of that recorded in individual samples when at least five samples were available. Mean weight was only estimated when the total catch of a given age in the square exceeded ten. If the total North Sea sampling resulted in less than ten sandeel of a particular age, the mean weight for that age from the North Sea as a whole was used. When less than five length samples were taken, the next aggregation level (Table B.2.3.2), was used. Hence, for each rectangle, month and year, the average number of *A. marinus* per age and kg caught was estimated and the level noted. No correction was made for differences in condition between on-board samples and harbour samples.

After estimating age composition of the catches, it became clear that the historical age compositions in years prior to 1993 from working group reports could not be reproduced based on the current database. For example, in some years no 3 or 4+ aged sandeel were recorded in the database whereas these were recorded in previous working group reports. Because of this, it was decided by WKSAN 2010 to use age compositions and weights at age historically reported for catches prior to 1993.

Table B.2.3.2. Aggregation levels for estimating the number of sandeel per age per kg.

LEVEL	SPACE	TIME
3	Square	Jan-feb, march, april, may, june, july, aug, sep-oct, nov-dec
4	Sandeel sampling areas within asessment areas(Figure. 1)	Jan-feb, march, april, may, june, july, aug, sep-oct, nov-dec
5	Aggregated sandeel sampling areas within assessment areas: 1A+1B, 1C, 2A+6, 2B+3, 4+5, 3AS+3AN	Jan-feb, march, april, may, june, july, aug, sep-oct, nov-dec
6	Aggregated sandeel sampling areas within assessment areas: 1A+1B, 1C, 2A+6, 2B+3, 4+5, 3AS+3AN	Jan-mar, april-may, june-aug, sep-dec
7	Sandeel assessment areas	Jan-mar, april-may, june-aug, sep-dec
8	Sandeel assessment areas	Jan- june, july-dec
9	All areas together	Jan- june, july-dec
10	All areas together	Jan- dec

B.2.3.3 Estimating catch in ton per rectangle per month

Before 1989, only logbook information stating the catch in directed Danish sandeel fishery is known. As the large majority of the catch in the sandeel fishery consists of sandeel, the distribution of catches in the directed sandeel fishery on rectangle and months were assumed to represent the distribution of sandeel catches. The total catch in tones was derived from the report of the working group on the assessment of Norway pout and sandeel (ICES 1995) and distributed on rectangles and month in the particular year according to the distribution of catches derived from Danish logbooks. From 1989 to 1993, the landings of sandeel per rectangle and month from the Danish fishery are available at DTU-AQUA. These were used to distribute total landings to rectangle and month. From 1994 to 1998, international sandeel catches in ton per rectangle per year are available. These catches were distributed to months according to the monthly distribution of Danish catches in the rectangle in the given year. If no Danish catches were recorded from the rectangle, the monthly distribution of the total catches in the ICES division was used. After 1999, international sandeel catches in ton per rectangle per month and year are available.

All catches were scaled in order to sum to official ICES landing statistics. Total catches per area are seen in Figure 2.3.3.1

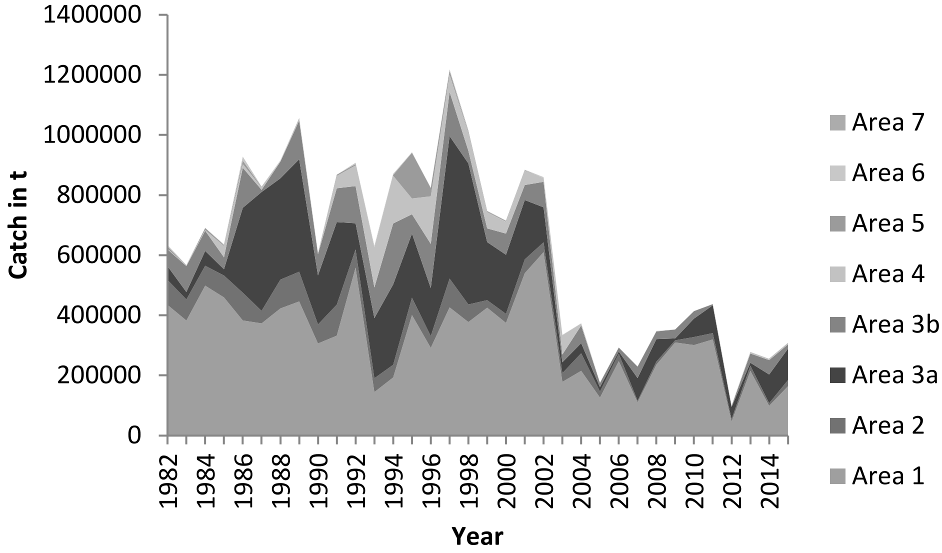

Figure B.2.3.3.1. Total catches pr. Sandeel area.

B.2.3.4 Estimating catch in numbers and mean weight

The catch in numbers per age (1000s), month and rectangle of sandeel was estimated as the product of sandeel catches in kg and the number-at-age of sandeel per kg in the particular rectangle. The total number in a larger area and longer time period is estimated as the sum over individual rectangles and months in this area. The mean weight is estimated as the weighted average mean weight (weighted by catch in numbers of the age group in the rectangle and month). Mean weight is given in kg.

B.2.3.5 Number of samples taken in each area

The number of biological samples taken was insufficient (<10 for two or more consecutive years) to conduct analytical assessments for areas 5, 6 and 7 and for area 4 prior to 1993 (Table B.2.3.5.1).

Table B.2.3.5.1 Number of samples taken in each area and suggested combined areas. Years with less than 10 samples are coloured orange

Yearly	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 3a	Area 3b	Area 2+3b
1983	79	15	34	0	0	0	0	0	34	49
1984	116	15	44	0	2	3	0	13	31	46
1985	101	20	13	19	2	3	0	1	12	32
1986	26	2	42	1	0	1	0	27	15	17
1987	62	6	66	1	0	1	0	60	6	12
1988	42	2	80	0	0	1	0	67	13	15
1989	40	5	47	0	0	1	0	43	4	9
1990	1	1	40	0	0	2	0	37	3	4
1991	25	8	54	1	0	0	0	30	24	32
1992	56	17	49	4	0	7	0	24	25	42
1993	23	16	111	15	0	7	0	64	47	63
1994	20	8	80	15	0	4	0	50	30	38
1995	41	15	75	7	7	2	0	58	17	32
1996	43	12	163	27	19	1	0	113	50	62
1997	41	23	177	25	8	3	0	116	61	84
1998	70	10	200	7	0	2	0	176	24	34
1999	263	24	68	44	0	1	0	42	26	50
2000	102	12	83	59	0	2	0	47	36	48
2001	213	9	66	90	1	1	0	33	33	42
2002	288	28	121	62	0	1	0	50	71	99
2003	281	45	64	160	0	2	0	30	34	79
2004	451	60	183	47	0	1	0	26	157	217
2005	320	20	56	30	0	1	0	34	22	42
2006	550	13	115	2	0	2	0	72	43	56
2007	295	13	261	0	0	1	0	108	153	166
2008	290	9	167	1	0	0	0	49	118	127
2009	302	7	127	0	0	1	0	12	115	122
2010	169	28	282	1	0	3	0	40	242	270
2011	167	42	29	4	0	4	0	17	12	54
2012	220	64	79	21	0	12	0	31	48	112
2013	292	21	240	5	0	3	0	41	199	220
2014	143	52	110	18	0	5	0	29	81	133
2015	309	62	103	38	0	4	0	48	55	117

B.3 Surveys

B.3.1 Survey design and analysis

Smooth age length keys are estimated using the methodology described in [ref1]. The ALKs are assumed constant within years and assessment area. Numbers-at-age are then calculated using the observed numbers-at-length and the estimated ALKs. The method provides an objective fill-in procedure for missing length groups. The methodology has been implemented in the DATRAS package with full source code available [ref3].

Survey indices by age and area are calculated using the methodology similar to what is described in [ref2], that is a Delta-Lognormal model which consists of a binomial presence/absence model and a lognormal model for strictly positive responses. Once the parameters in the model are estimated, a standardized survey index is obtained by predicting and adding up the abundances in a fine meshed grid of points that is the same in all years. This can be thought of as performing a virtual experiment where the experimental conditions such as the haul positions and time of day are exactly the same in each year. The grid is created based on information about the sandeel banks. Only sandeel banks that have been sampled at least 3 times are included in the grid.

The following equation describes the model considered for both the presence-absence and the positive parts of the model for the *i*th haul:

$$g(\mu_i) = \alpha(\mathrm{Year}_i, \mathrm{SP\ ID}_i) + \beta(\mathrm{SubArea}_i) + U(\mathrm{Year}_i, \mathrm{SubArea}_i) + f_1(\mathrm{time}_i)$$

Where SP_ID is a categorical variable for assessment area. SubArea is a categorical variable for sub area (see those sub areas in Figure B.3.1.1). Time is time of day. μ is the expectation on the appropriate scale (i.e. probabilities and log abundances). The levels of α and β are estimated as fixed effects, f_1 is a cyclic cubic regression spline on the time of day (i.e. with same start end end point), and $U \sim N(0, \sigma_u^2)$ are random effects for each combination of year and sub area. Parameters are estimated independently by age group.

More information is provided in the Survey Index working document (WD_SurveyIndex).

Casper W Berg and Kasper Kristensen. Spatial age-length key modelling using continuation ratio logits. *Fisheries Research*, 129:119–126, 2012.

Casper W Berg, Anders Nielsen, and Kasper Kristensen. Evaluation of alternative age-based methods for estimating relative abundance from survey data in relation to assessment models. *Fisheries Research*, 151:91–99, 2014.

Kasper Kristensen and Casper W. Berg. Datras package for r. http://rforge.net/DATRAS/, 2012.

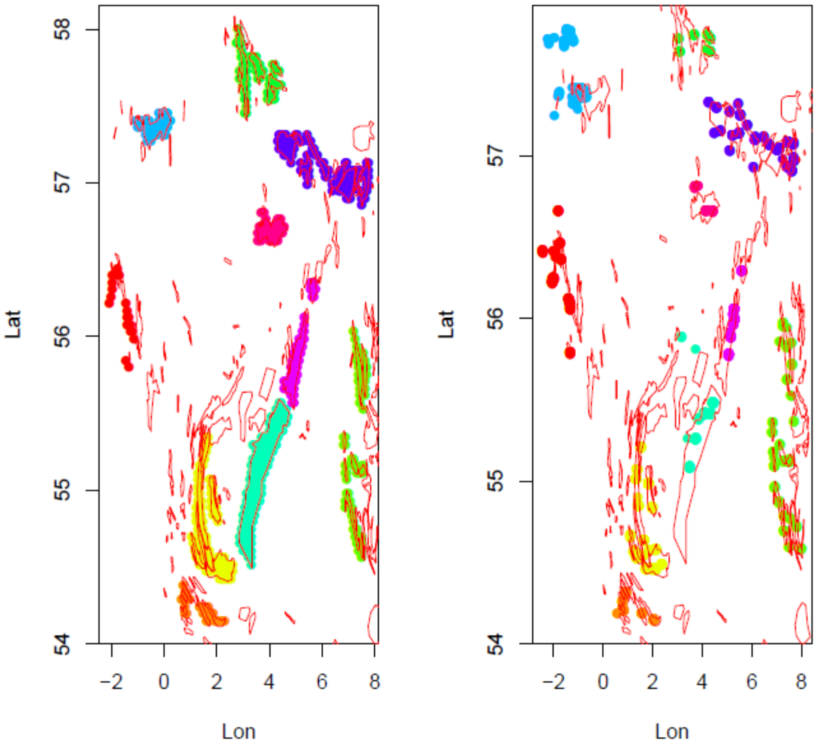

Figure B.3.1.1: Right: Survey index grid. Each colored dot represents a virtual haul, colors represents sub areas where abundance is assumed constant for a given year. Left: Actual haul positions colored by sub area. Red polygons are sandeel banks. Hauls outside the polygons are assigned a sub area based on the nearest neighbor.

B.4 Commercial CPUE

The 2010 sandeel benchmark commented that Real time monitoring (RTM) could be a way to increase the certainty in catch forecasts in by stating that ‘Although this’ (referring to the dredge) ‘relationship appears to be robust it may be prudent to continue some level of real-time monitoring in years where the dredge survey result is outside the bounds of the current observations particularly at the lower bound. It is further specified that the method seems to be useful in area 1, but not in areas 2, 3 and 4. Since then, RTM has been conducted in 2012 and 2016 using the method described below. In 2012, catch rates of all age groups were used whereas only 1-year olds were included in 2016 and the sampling period was furthermore changed slightly.

The purpose of the RTM is to make an in-season estimate of stock abundance of sandeel from observations of catch per unit effort (CPUE) from the fishery early in the season (April or from mid-April to beginning of May), allowing for an in-year TAC prediction and a thereby a revision of the initially forecasted TAC. To minimize the problems introduced from potential technical creep in the data series, the RTM time series is included as a moving window of only ten years. The difference in the hindcasted stock dynamics and model diagnostics in a model with and without inclusion of the RTM time-series were negligible.

RTM based Stock abundance (the RTM time-series) is measured as CPUE in number per age class. Effort is measured as number days absent from harbour for the individual fishing trips, standardised to an average vessel size of 200 GT: $\overline{CPUE} = \frac{\sum_{1}^{N} Catch_i}{\sum_{1}^{N} Daysabsent_i * \left(\frac{GT_i}{200}\right)^{0.449}}$

Where N is the number of trips, Catch is the catch in tonnes on a given trip, Days absent is the number of days absent on a given trip, GT is the gross tonnage of the vessel and 0.449 is the average effect of vessel size as measured over the previous 10 years using data from all months and the method described in ICES (ICES 2010, WD for the 2016 benchmark). Effort (days absent), vessel GT and total catch weight of sandeel by trip are obtained from log book data extracted from the Danish Garfish Agency's database. Age distribution of the catch is obtained from samples taken by the Danish AgriFish Agency; ideally one sample from each landing. Samples taken at sea by the industry from every third haul, with detailed information on catch position and time are also be used when available.

The RTM CPUE is highly correlated with the dredge index and shows a reasonable consistency between years. There is no trend in the relationship between dredge and RTM recruitment estimates (see also working document).

As the RTM time-series has been implemented, the assessment model is now more operational in relation to making the decision to perform an RTM (and in-season update of advice). Note also that with the current setup, it is optional whether or not RTM should be performed. However, it is important to stretch, that guide lines should be formulated to avoid introducing a bias in the advice when not using RTM every year. For example, carrying out RTMs only in years where the initial advised TAC is low, or vice versa, could potentially introduce a bias.

B.5 Other relevant data

None

C. Assessment methods and settings

C.1 Choice of stock assess model

The SMS model, presently used for the ICES assessment of blue whiting (WGWIDE), and for the North Sea and Baltic Sea multispecies (WGSAM), was modified slightly to estimate fishing mortality from observed effort. In the original SMS version, fishing mortality, $F_{y,q,a}$ was modelled as an extended separable model including a seasonal, age and year effect. The new version substitutes the year effect by observed effort.

$F_{y,q,a}$ = SesonEffect(Y,A1) * AgeEffect(Y,A2,q) * $YearEffect_y$ (1, original version)

$F_{y,q,a}$ = SesonEffect(Y,A1) * AgeEffect(Y,A2,q) * $Effort_{y,q}$ (2, new version)

where

indices A*1* and *A2* are groups of ages, (e.g. ages 0, 1–2, 3–4) and *Y* is grouping of years (e.g. 1983–1998, 1999–2009). The SMS-effort defines that the years included in the model can be grouped into a number of period clusters (*Y*), for which the age selection and seasonal selection are assumed constant. Fishing mortality is assumed proportional to effort. The grouping of ages for age selection, *A1*, and season selection, *A1*, can be defined independently. During benchmark assessments, new period clusters are added if neccessary. Period clusters are selected based on (1) changes in fleet composition and spatial coverage, (2) the AIC for model comparison, and (3) Chi-square method for testing if any improvement in model neg. log likelihood values were statistically significant (alpha=0.01). The break points sometimes caused distinct jumps in the exploitation patterns between blocks.

There are two additional options for the SMS-effort version (none of which is currently used), where technical creeping is taken into account.

$F_{y,q,a}$ = SesonEffect(Y,A1) * AgeEffect(Y,A2,q) * $Effort_{y,q}$ * $(y\text{-}firstYear)^{commonCreep(Y)}$ (3)

$F_{y,q,a}$ = SesonEffect(Y,A1) * AgeEffect(Y,A2,q) * $Effort_{y,q}$ * $(y\text{-}firstYear)^{ageCreep(Y,A1)}$ (4)

Equation (3) uses a common creeping exponent for all ages by one or more year clusters (Y), e.g. the efficient increase by 3.8% per year in the first year range, and 2.8% per year in the second. Equation (4) is more flexible as it allows an age dependent creeping exponent. If we assume that we only use one year cluster (the whole year range) an example could be that the technical creep for age 1 is 5.5% per year, while age 2 has a negative exponent, -2.7% (equivalent to parameter=0.973). As the product of effort and “technical creep” express both the fishing power and the directivity towards a specific age group, such an example indicates that there has been an overall increase in (standardised) fishing power, but the fishery has been less directed towards older sandeel in recent years.

SMS is a statistical model where three types of observations are considered: Total international catch-at-age; research survey cpue (and stomach content observations, which are not used here). For each type a stochastic model is formulated and the likelihood function is calculated. As the three types of observations are independent the total log likelihood is the sum of the contributions from three types of observations. A stock–recruitment (penalty) function is added as a fourth contribution.

Catch-at-age

Catch-at-age observations are considered stochastic variables subject to sampling and process variation. Catch-at-age is assumed to be lognormal distributed with log mean equal to log of the standard catch equation The variance is assumed to depend on age and season and to be constant over years. To reduce the number of parameters, ages and seasons can be grouped, e.g. assuming the same variance for age 3 and age 4 in one or all seasons. Thus, the likelihood function, L_C, associated with the catches is

$$L_{CATCH} = \prod_{a,y,q} \frac{1}{\sigma_{CATCH\ a,q}\sqrt{2\pi}} \exp\left(-\frac{(\log(C_{a,y,q}) - E(\log(C_{a,y,q})))^2}{2\sigma^2_{CATCH\ a,q}} \right)$$

Where

$$E(\log(C_{a,y,q})) = \log\left(\frac{F_{a,y,q}}{Z_{a,y,q}} N_{a,y,q}(1 - e^{-Z_{a,y,q}}) \right)$$

Leaving out the constant term, the negative log-likelihood of catches then becomes:

$$l_{CATCH} = -\log(L_{CATCH}) \propto NOY \sum_{a,q} \log(\sigma_{CATCH\ a,q}) + \sum_{a,y,q} (\log(C_{a,y,q}) - E(\log(C_{a,y,q})))^2 / (2\sigma^2_{CATCH\ a,q}))$$

Survey indices

Similarly, the survey indices, *cpue(survey,a,y,q),* are assumed to be log-normally distributed with mean

$$E(\log(CPUE_{survey,a,y,q})) = \log(Q_{survey,a} \overline{N}_{SURVEY\ a,y,q})$$

where Q denotes catchability by survey and $\overline{N}_{SURVEY}$ mean stock number during the survey period. Catchability may depend on a single age or groups of ages. Similarly, the variance of log *cpue*, $\sigma(survey,a)$, may be estimated individually by age or by clusters of age groups. The negative log likelihood is on the same form as for catch observations:

$$l_{SURVEY} = -\log(L_{SURVEY}) \propto \sum_{survey,a} NOY_{survey} \sum_{survey,a} \log(\sigma_{SURVEY\,survey,a}) + \sum_{survey,a,y} (\log(CPUE_{survey,a,y}) - E(\log(CPUE_{survey,a,y}))^2 / (2\sigma^2_{SURVEY\,survey,a}))$$

Stock–recruitment

In order to enable estimation of recruitment in the last year for cases where survey cpue and catch from the recruitment age is missing (e.g. saithe) a stock–recruitment relationship $R_y = R(SSB_y \mid \alpha, \beta)$ penalty function is included in the likelihood function. Assuming that recruitment takes place at the beginning of the third quarter of the year and that recruitment is lognormal distributed the parameters the log penalty contribution, l_{SR}, equals

$$l_{SR} = -\log(L_{SR}) \propto NOY\ \log(\sigma_{SR}) + \sum_{y} ((\log(N_{a=0,y,q=3}) - E(\log(R_y)))^2 / 2\sigma^2_{SR})$$

where

$E(\ln(R_y)) = \ln(\alpha\ SSB_y \exp(-\beta\ SSB_y))$ for the Ricker case. Other stock–recruitment relations (Beverton and Holt and "Hockey stick") and stock-independent geometric mean recruitment have also been implemented. As indicated in equation (26) recruitment-at-age zero in the beginning of the third quarter was considered.

Total likelihood function and parameterisation

The total negative log likelihood function, l_{TOTAL}, is found as the sum of the four terms:

$$l_{TOTAL} = l_{CATCH} + l_{SURVEY} + l_{STOM} + l_{SR}$$

Initial stock size, i.e. the stock numbers in the first year and recruitment over years are used as parameters in the model while the remaining stock sizes are considered as functions of the parameters.

The parameters are estimated using maximum likelihood (ML) i.e. by minimizing the negative log likelihood, l_{TOTAL}. The variance/covariance matrix is approximated by the inverse Hessian matrix. The variance of functions of the estimated parameters (such as biomass and mean fishing mortality) has been calculated using the delta method.

The SMS model was implemented using the AD Model Builder (ADMB Project 2009), freely available from ADMB Foundation (www.admb-project.org). ADMB is an efficient tool including automatic differentiation for Maximum likelihood estimation of many parameters in nonlinear models.

Settings of the SMS model is implicated in Table C.3.1.1.

C.2 Model used of basis for advice

C.3. Assessment model configuration

Table C.3.1.1. Model Configurations

Type	Name	Year range	Age range	Variable from year to year Yes/No
Caton	Catch in tonnes	Is not used as input		
Canum	Catch at age in numbers	1983-	0-4+	Yes
Weca	Weight at age in the commercial catch	1983-	0-4+	Yes
West	Weight at age of the spawning stock at spawning time.	Same values as Weca		
Mprop	Proportion of natural mortality before spawning	1983-	0-4+	No
Fprop	Proportion of fishing mortality before spawning	Is assumed to be 0		
Matprop	Proportion mature at age	Is assumed to be 0		
Natmor	Natural mortality	1983-	0-4+	Yes (sliding three year average)

The SMS model estimates exploitation patterns and the relationship between F and effort with predefined period clusters of years (the seperability assumption of the model; see also method description above). For example, prior to the benchmark assessment, the model for SA1 applied 1989 and 1999 as the breakpoints between period clusters. During the benchmark assessment, additional breakpoints were added in 2005 and 2010. Break points were (1) selected based on changes in fleet composition and spatial coverage, (2) the AIC for model comparison, and (3) Chi-square method for testing if any improvement in model neg. log likelihood values were statistically significant (alpha=0.01). The break points sometimes caused distinct jumps in the exploitation patterns between period clusters. The SESAM model, which was run exploratively for SA1 prior to the 2016 benchmark meeting, confirmed stock dynamics and the dynamic exploitation patterns emerging from the SESAM model to some extent mimicked the discrete changes in exploitation pattern in the SMS model.

D. Short-term prediction

Model used: Deterministic forecast

Software used*:* R

Initial stock size: Numbers at age projected by the assessment model. The majority of catches consist of age-1 fish in most years. The forecast is therefore highly reliant on the survey index for age-0 fish, which provide information about the size of the age-1 year class in the forecasted fishing season.

Maturity: Same as used in the input for the assessment model (assumed constant between years)

F and M before spawning: Assumed to be 0

M: Natural mortality is taken from the final year, which is already a 3 year average

Weight at age in the stock: 5 year average

Weight at age in the catch: 5 year average

Exploitation pattern: Taken from the last year in the assessment model (which is constant for the last cluster period in the model (see, description of assessment model above)

Intermediate year assumptions: None

Stock recruitment model used: None. Instead the long-term geometric mean recruitment is assumed

Procedures used for splitting projected catches: None

Other: During MYREF2 it was evaluated to what extent the Bescapement approach (using Bpa as target) is sustainable according to the criteria put forward by ICES. The conclusion was that the approach is only sustainable if an upper level on F is applied (Fcap). This upper level is needed to ensure that the stock is not overexploited in years where the log-normal uncertainty of the incoming years class is not fully accounted for by the Bpa buffer (for example in years, where the dredge survey indicate a very large recruitment). Until now an Fcap of 0.6 has been applied to SA1. However, this value should be re-estimated to take into account the changes made for the new SA1.

E. Medium-term prediction

Not produced for this stock

F. Long-term prediction

Not produced for this stock

G. Biological reference points

	Type	Value	Technical basis
MSY	MSY Btrigger	145 000 t	Equal to Bpa (B-escapement strategy)
Approach	FMSY	Not defined	B-escapement strategy
	Blim	110 000 t	From stock recruitment relationship
Precautionary	Bpa	145 000 t	From Blim and CV of SSB in the final assesment year
Approach	Flim	Not defined	
	Fpa	Not defined	

H. Other issues – This section will be completed during HAWG 2017

H.1 Biology of species

H.2 Stock dynamics, regulations in 20th century – historic overview

Year (Y)	2007	2008	2009	2010	2011	2012
Assessment Model						
Software						
Catch data range						
CPUE Series 1 (years)						
CPUE Series 2 (years)						
Index of Biomass (years)						
Error Type						
Number of bootstrap						
Maximum F						
Statistical weight B1/K						
Statistical weight for fisheries						
B1-ratio (starting guess)						
MSY (starting guess)						
K (starting guess)						
q1 (starting guess)						
q2 (starting guess)						
q3 (starting guess)						
Estimated parameter						
Min and Max allowable MSY						

Min and Max K	
Random Number Seed	

Data	2006	2007	2008	2009
Catch data				
Survey: A_Q1				
Survey: B_Q4				
Survey: C				

H.3 Current fisheries

See section A.2.1

H.4 Management and advice

See section A.2.2

H.5 Others (e.g. age terminology)

None.

H.6 References

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