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Report of the Benchmark Workshop on Sandeel (WKSand 2016)

31 October – 4 November 2016

Bergen, Norway

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

H. C. Andersens Boulevard 44–46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

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Executive summary

The Benchmark Workshop on Sandeel Stocks (WKSand) 2016 met in Bergen, Norway, from 31 October to 4 November 2016, following data assessment and web conference meetings earlier in the year. Its remit was to review the definition of sandeel stocks and appropriate stock assessment methods for sandeels in the North Sea.

27 people participated including stakeholders. An External Expert and an External Chair from outside the ICES community took part in the process. See participants list in Annex 1. The outputs of the workshop are this report, and the new stock annexes to be used for the assessment of the stocks in the ICES advisory process.

The main outcomes of the workshop were:

Agreement that larval drift in relation to hydrography, otolith chemistry, and independent dynamics justify definition of 7 separate stocks of sandeels in the North Sea. There was agreement that boundaries between these 7 stocks should be adjusted to reflect new information on hydro-dynamics, differences in management and in behaviour of the fishing fleet between areas. The main changes were primarily advocated by fishermen and their representatives, and it was agreed to split area 3, with the EU part of area 3 merged with area 2, rationalise the boundary between areas 5 and 7, and 4 and 7, and make small adjustments to the boundary of area 1, making the areas better fit the underpinning science while also being appropriate for practical concerns of the fishing industry.

It was agreed that the SMS model should be used for stocks in areas SA1, SA2, SA3 and SA4 but that data were inadequate for an analytical assessment for areas 5, 6 or 7. However, the External Experts identified a problem with the SMS model that needs to be addressed: the model is not designed to provide reliable estimates of variance, and the variance estimate derived from the model is a critical component of the escapement strategy TAC setting process. Much variance in the real world is not included in the SMS model (an obvious example being uncertainty in sandeel consumption by predators, and hence the variance around the estimate of M) and so variance is underestimated by the model, which results in the TAC being set at a higher level than should be the case to achieve the desired metric of less than a 0.05 risk of SSB falling below the reference point threshold.

It was agreed that the SESAM model seems to be valuable as an exploratory tool. It is possible that SESAM may provide a way to estimate variance with a more comprehensive coverage of input parameter variability and uncertainty.

In view of evidence derived from analysis of kittiwake breeding success, it was agreed that assessments in SA1 and SA4 should at least take note of total stock biomass thresholds recommended by recent published reviews to avoid depletion of the stock below levels likely to have adverse effects on dependent predators.

A number of recommendations and further research needs were listed for consideration.

1 Description of the Benchmark Process

1.1 Stock ID and sub-stock structure

1.1.1 Stock delineation

A fish "stock" can be defined as a sub-set of a species having the same growth and mortality parameters, and inhabiting a particular geographical area, with little mixing with adjacent groups (Gulland, 1968). At the last sandeel benchmark in 2010, the North Sea sandeel stock was delineated into seven stocks (Figure. 1.1.1.1a) based on predicted larval mixing among fishing grounds using a biophysical model of larval exchange. Larval mixing was used for delineation because this planktonic phase of the life history appears to account for most exchange among areas of habitat. Biophysical model simulations of larval transport suggest that aggregations of banks at scales from 50 – 300 kms apart can be connected by the annual dispersal and advection of larvae (Proctor *et al*., 1998; Christensen *et al*., 2008). In contrast, the maximum distance travelled by tagged individuals displaced from grounds was only 64 km over 1 – 3 years (Gauld, 1990). Following settlement sandeels are rarely found further than 15 km away from known habitat (Wright, 1996; Engelhard *et al*., 2008) which is characterised by sand with a low silt and clay content (Macer, 1966; Reay, 1970; Wright *et al*., 2000; Holland *et al*., 2005). Due to the limited availability of such substrate (Wright *et al*., 1998), the distribution of post-settled sandeels is highly patchy (Jensen *et al*., 2011) which, together with the local hydrographic regime, leads to areas of low connectivity (Wright & Bailey, 1996; Proctor *et al*., 1998; Jensen, 2001; Munk *et al*., 2002; Christensen *et al*., 2008).

At WKSAND the fishing industry requested an end to the area based management but, as is made clear in the following sections, there was no scientific support for such a request. However, the industry did highlight important concerns about the utilization of certain banks with respect to fleet métier and differences in local management and so there was a debate as to whether some areas should be altered to reflect this, which led to a new industry proposal shown in Figure 1.1.1.1b. The main reasons for proposing the new altered areas are explained below.

According to information from sandeel fishers participating in WKSAND, the non-coastal fishery had in earlier periods prior to 2002 been characterized by a southern movement. This fishery started at the Northern Dogger early in the season and then as the season progressed the fishery moved south. In some seasons this fishery continued down to the southern part of Area 2 near the Dutch coast (red on the old map Figure 1.1.1.1a and yellow on the new map right Figure 1.1.1.1b). The fleet that carried out this fishery mainly consisted of larger vessels. Coastal and smaller vessels predominantly operate along the coast of Jutland and did not show the same southern movement trend in the fishing pattern as the season progressed. It was also the fishermen's belief that the sandeel population dynamics would be more connected by moving the southern area 2 squares to be part of area 1. Based upon these views a proposal to move some of the southern squares located previously in area 2 into area 1 was made (Figure 1.1.1.1b) and reviewed below.

There was also concern from both fishermen and scientists about the present Area 3, as the EU component and Norwegian EEZ involve quite different management approaches. Furthermore, all the sandeel banks in the Skagerrak area are coastal whereas the sandeel banks in the Norwegian EEZ are located offshore. In addition the fleets operating in the two areas are different, one being Norwegian and one being mainly Danish.

The proposal to amalgamate the EU part of the original area 3 into area 2 was suggested to be sensible because the resulting area would give an area wherein a relative homogenous fleet operated. Further it would cover the area where the Jyllandstream going from South to North has a large effect on larval drift and productivity. Both area 2 and area 3b contain coastal sandeel banks and both areas have a relatively similar depth (Figure 1.1.1.1b). Given the suggested changes WKSAND 2016 examined the biological evidence to support both the current and proposed changes.

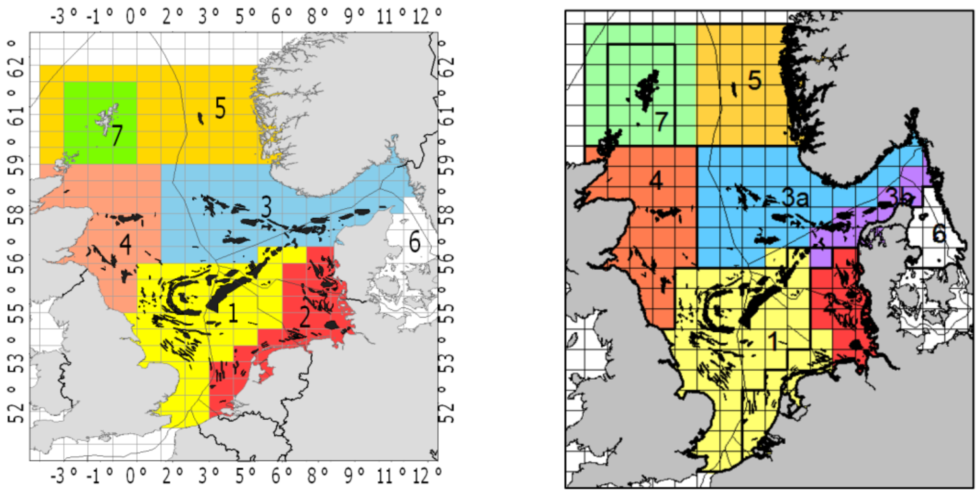

Figure 1.1.1.1a) WKSAND 2010 sandeel areas (left) and b) new proposed sandeel areas (right).

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; POLCOMS-ERSEM was used in the bio-physical model to re-assess the divisions (Christensen, in prep.) 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 and a proposal made with the industry during the benchmark in November 2016. 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. However, the origin of larvae recruiting to the central fishing grounds (i.e. northeastern parts of SA1) were predicted to be more widespread with larvae potentially arriving from as far away as the fishing grounds off the coast of Holland in SA2 (Figure 1.1.1.2). Output from this model was used to consider retention and export in the new industry proposal for area boundaries discussed during the WKSAND 2016 benchmark. Table 1.1.1.1 shows the percentage retained and exported based on the 2010 and proposed boundaries. There was no significant change in retention and export between the 2010 and new proposed boundaries between areas.

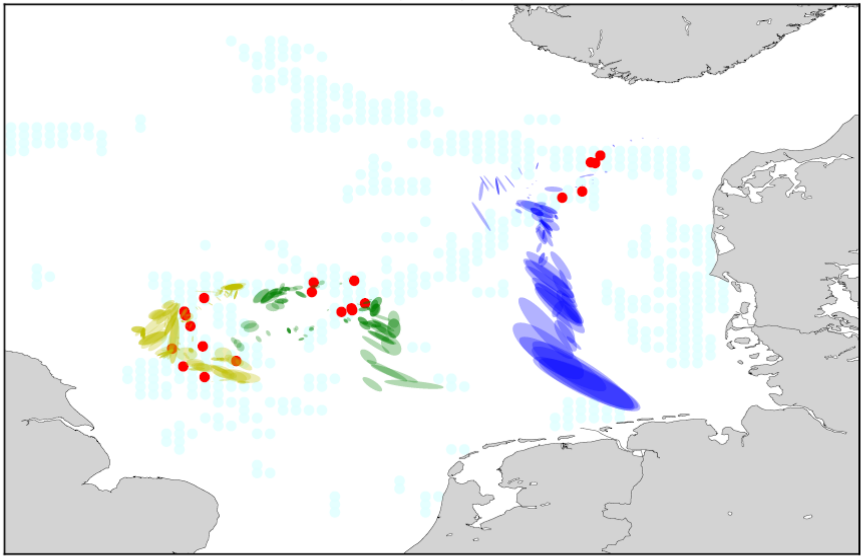

Figure 1.1.1.2 Larvae back tracking. Larvae (n=378) sampled in 2006, 2008 and 2009 were aged (based on otoliths) and back tracked to their origins. Red dots represents where larvae were sampled. The ellipse area represents standard deviation of the Gaussian representation of possible latitude and longitude hatch position. For each ellipse the area represents approximately 70% of the probable hatch position and is centered at the position with highest probability.

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 areas 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 SA2r using the new divisions (combining old SA2+ SA3 in EU EEZ areas).

Table 1.1.1.1 Average annual transport percentages between SAs. Left panels: import of drift particles into a specific SA. Right panels: export of drift particles from a specific SA. Upper panels: old SA divisions. Lower panels: new SA divisions.

% transport	to Area				
from Area	1	2	3	4	Grand Total
1	98%	1%	13%	0%	48%
2	1%	94%	6%	0%	20%
3	1%	5%	80%	0%	27%
4	0%	0%	1%	100%	5%
Grand Total	100%	100%	100%	100%	100%

% transport	to New				
from New	1	2	3	4	Grand Total
1	99%	15%	7%	0%	51%
2	0%	77%	2%	0%	21%
3	0%	8%	89%	0%	24%
4	0%	0%	1%	100%	5%
Grand Total	100%	100%	100%	100%	100%

Import:

% of what is transported into Area X (a column) coming from Area 1, 2, 3, or 4

% transport	to Area				
from Area	1	2	3	4	Grand Total
1	91%	0%	9%	0%	100%
2	2%	88%	10%	0%	100%
3	1%	3%	96%	0%	100%
4	0%	0%	5%	95%	100%
Grand Total	45%	19%	32%	4%	100%

% transport	to New				
from New	1	2	3	4	Grand Total
1	89%	7%	3%	0%	100%
2	1%	96%	3%	0%	100%
3	0%	9%	91%	0%	100%
4	0%	0%	5%	95%	100%
Grand Total	46%	26%	24%	4%	100%

Export:

% of what comes from Area X (a row) is transported into Area 1, 2, 3, or 4

There is an apparent slight change of average transport between SAs due to the introduction of new SA areas, 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.

Although biophysical models provide broadly consistent results, uncertainty due to the resolution of the underpinning hydrodynamic models and the behaviour of larvae and pre-settled juveniles makes independent verification important. Larvae hatch in February to early April (Wright and Bailey, 1996; Jensen, 2001). Newly hatched sandeel larvae are found in the vicinity of the sandeel grounds in the ICES 1st Quarter IBTS MIKeyM sampling (see Annex 2 WD 01). From 2016 sampling in January to March will occur annually, covering the whole of the North Sea. Larval distribution in April/May 2012 and 2013, were also mostly found in close proximity to sandeel grounds, which may suggest that larvae were not transported far from their origin in those years. A similar situation was seen during the same period in 2016 although low densities of larvae were also found over much of the Norwegian Trench. However, length stratification of the larval abundance data is needed for a more robust comparison between larval distribution and biophysical model predictions.

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*. (See Annex 2 WD 02) (Figure 1.1.1.3a and b). 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).

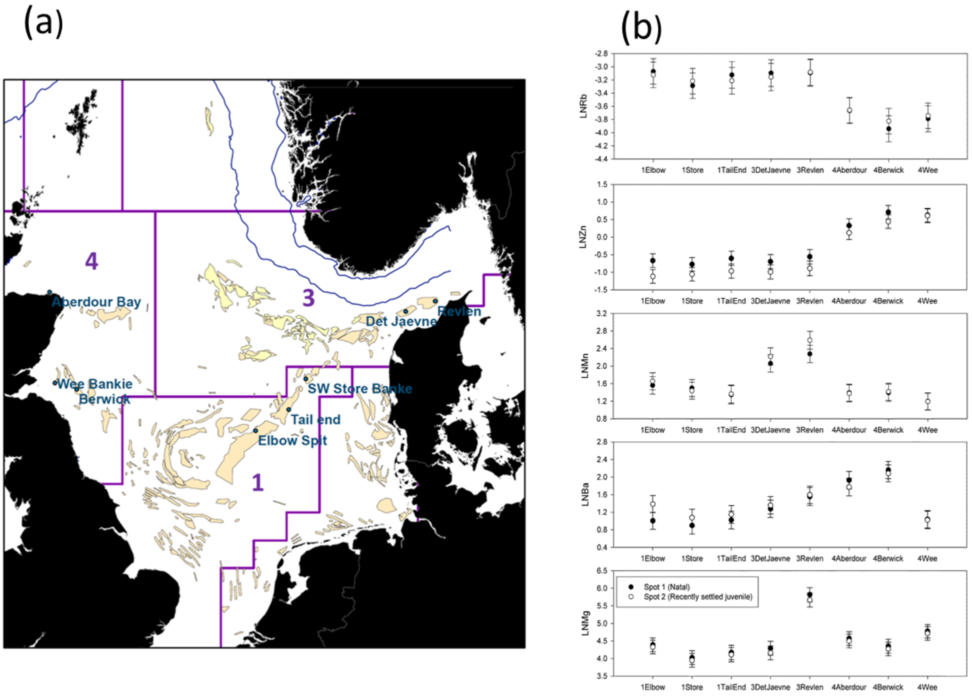

Figure 1.1.1.3 a) Chart showing location of samples in the 8 grounds (named yellow polygons) and 3 sandeel assessment areas (purple lines denote boundaries, ICES 2010) and 1.1.1.3b) fitted mean (± standard error) element ratio for larval (spot 1) and settled juvenile (spot 2) based on a linear mixed model.

1.1.1.1 Agreed sandeel areas for use in the 2017 assessments and advice

The final assessments were conducted on seven agreed sandeel stock areas that differ from those presented in the above discussion. Table 1.1.1.1.1 below details the former and WKSand 2016 agreed sandeel areas, their ICES stock codes and statistical rectangles. Figure 1.1.1.1.1 is a map of the WKSand 2016 agreed sandeel areas, which will be used in the ICES assessments and advice and Figure 1.1.1.1.2 shows a map with all statistical rectangles marked to ease identification.

Table 1.1.1.1.1 At the 2016 ICES benchmark of Sandeel (*Ammodytes* spp.) the stock assessment areas were redefined for Sandeel areas 1, 2, 3, 5 and 7. The 2016 stock codes, full names, and statistical rectangles are given below for Sandeel areas 1-7 (left), and the newly defined areas for 2017 are also provided (right).

Stock code_2016	**Full name_2016**	**ICES Statistical Rectangles 2016**	**Stock code_2017**	**Full name_2017**	**ICES Statistical Rectangles 2017**
san-ns1	Sandeel (*Ammodytes* spp.) in Divisions 4.b and 4.c, SA 1 (Central and South North Sea, Dogger Bank)	31–34 E9–F2; 35 E9–F3; 36 E9–F4; 37 E9–F5; 38–40 F0–F5; 41 F5–F6	san-sa.1r	Sandeel (*Ammodytes* spp.) in divisions 4.b and 4.c, Sandeel Area 1r (central and southern North Sea, Dogger Bank)	31-33 E9-F4; 33 F5; 34-37 E9-F6; 38-40 F0-F5; 41 F4-F5
san-ns2	Sandeel (*Ammodytes* spp.) in Divisions 4.b and 4.c, SA 2 (Central and South North Sea)	31–34 F3–F4; 35 F4–F6; 36 F5–F8; 37–40 F6–F8; 41 F7–F8	san-sa.2r	Sandeel (*Ammodytes* spp.) in divisions 4.b and 4.c and Subdivision 20, Sandeel Area 2r (central and southern North Sea)	35 F7-F8; 36 F7-F9; 37 F7-F8; 38-41 F6-F8; 42 F6-F9; 43 F7-F9; 44 F9-G0; 45 G0-G1; 46 G1
san-ns3	Sandeel (*Ammodytes* spp.) in Divisions 3.a, 4.a and 4.b, SA 3 (Skagerrak and Kattegat, North and Central North Sea)	41 F1–F4; 42–43 F1–F9; 44 F1–G0; 45–46 F1–G1; 47 G0	san-sa.3r	Sandeel (*Ammodytes* spp.) in divisions 4.a and 4.b and Subdivision 20, Sandeel Area 3r (Skagerrak and Kattegat, northern and central North Sea)	41-46 F1-F3; 42-46 F4-F5; 43-46 F6; 44-46 F7-F8; 45-46 F9; 46-48 G0; 47 G1
san-ns4	Sandeel (*Ammodytes* spp.) in Divisions 4.a and 4.b, SA 4 (North and Central North Sea)	38–40 E7–E9; 41–46 E6–F0	san.sa.4	Sandeel (*Ammodytes* spp.) in divisions 4.a and 4.b, Sandeel Area 4 (northern and central North Sea)	38–40 E7–E9; 41–46 E6–F0
san-ns5	Sandeel (*Ammodytes* spp.) in Division 4.a, SA 5 (Northern North Sea, Viking and Bergen Banks)	47–51 E6 + F0–F5; 52 E6–F5	san.sa.5r	Sandeel (*Ammodytes* spp.) in Division 4.a, Sandeel Area 5r (northern North Sea, Viking and Bergen banks)	47-52 F1-F5
san-ns6	Sandeel (*Ammodytes* spp.) in Division 3.a East, SA 6 (Kattegat)	41–43 G0–G3; 44 G1	san.sa.6	Sandeel (*Ammodytes* spp.) in subdivisions 20-22, Sandeel Area 6 (Kattegat)	41–43 G0–G3; 44 G1
san-ns7	Sandeel (*Ammodytes* spp.) in Division 4.a, SA 7 (Northern North Sea, Shetland)	47–51 E7–E9	san.sa.7r	Sandeel (*Ammodytes* spp.) in Division 4.a, Sandeel Area 7r (northern North Sea, Shetland)	47-52 E6-F0

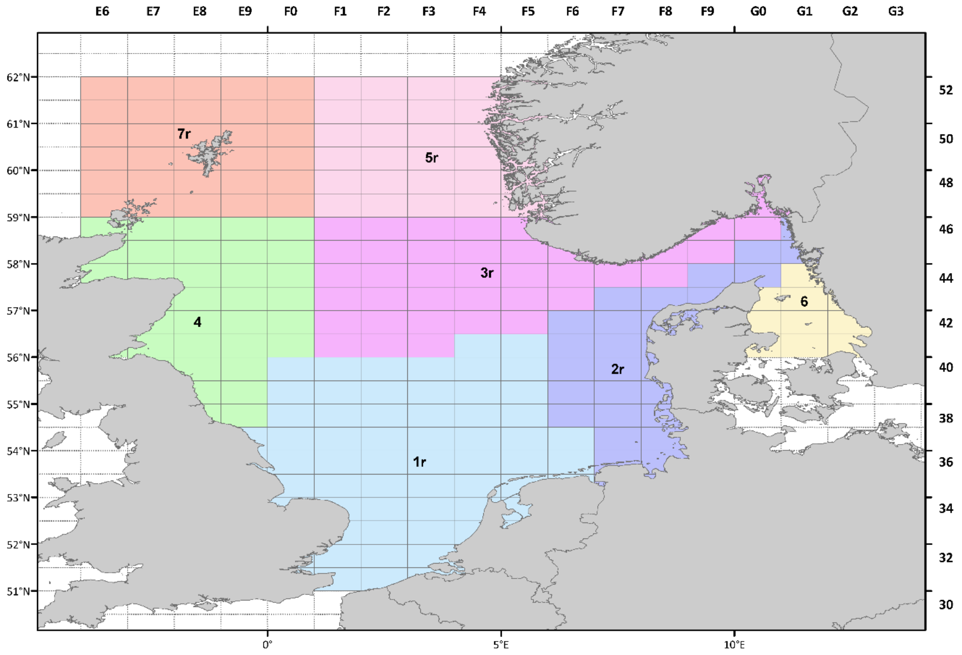

Figure 1.1.1.1.1 Map of ICES Sandeel assessment areas agreed in WKSand 2016 (to be used in ICES advice in 2017).

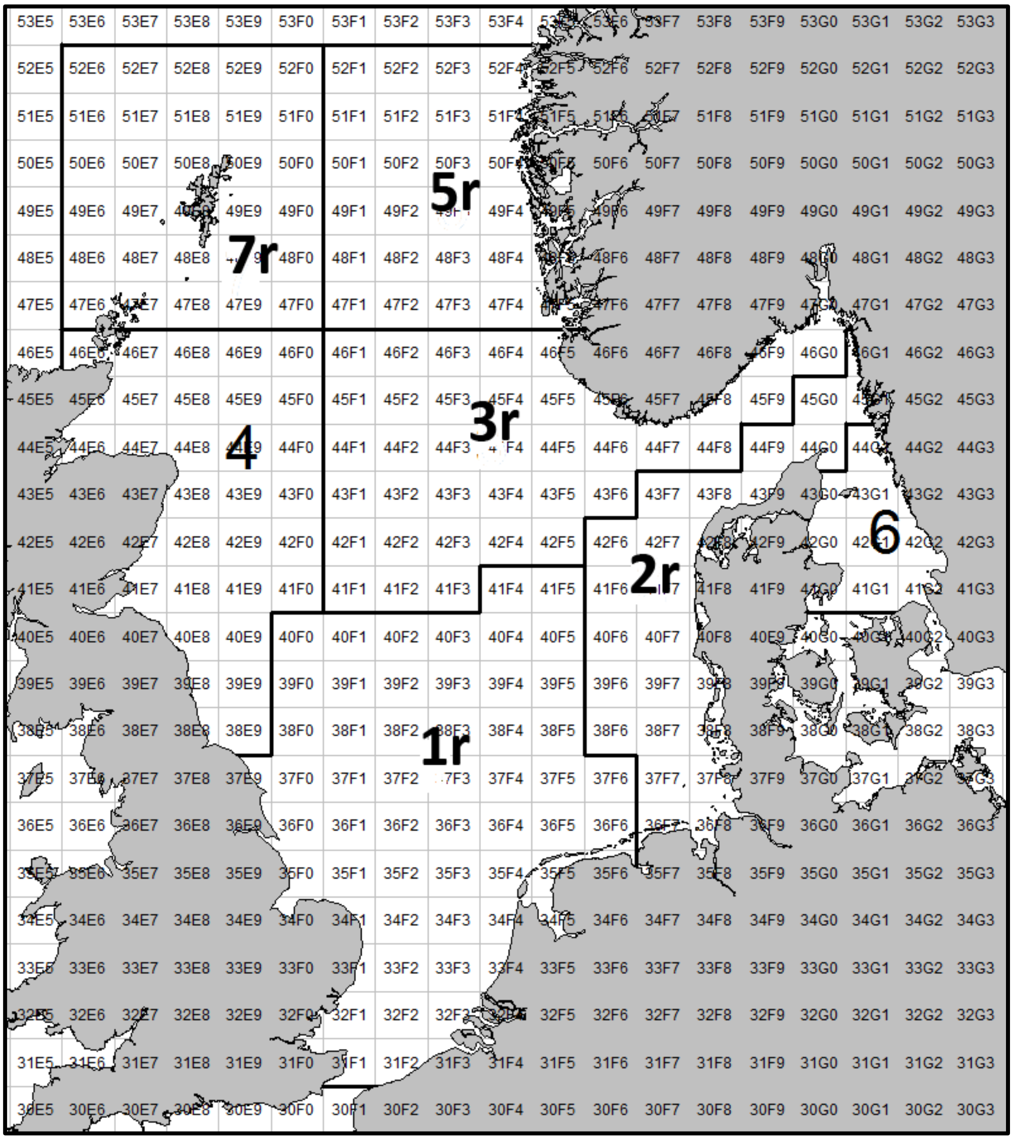

Figure 1.1.1.1.2. Map of ICES Sandeel assessment areas in 2017 as agreed at WKSand 2016 with all statistical rectangles labelled.

1.1.2 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 spatial age-length key modelling approach using continuation ratio logits (Berg and Kristensen, 2012) was applied to dredge survey data to identify areas of similar age and size composition (here referred to as the SWAP-analysis. Only data from areas 1-3 were considered. The SWAP analysis used a back and forth iterative process to find area divisions that resulted in the best continuation ratio logits model based on AIC. The SWAP analysis confirmed that with the exception of a few squares swapped from SA1 to SA3, the WKSAN 2010 area division reflected the best fit to regional differences in length at age. However, the analysis also found that merging SA1 and SA2 provided a similar alternative fit (Figure 1.1.2.1).

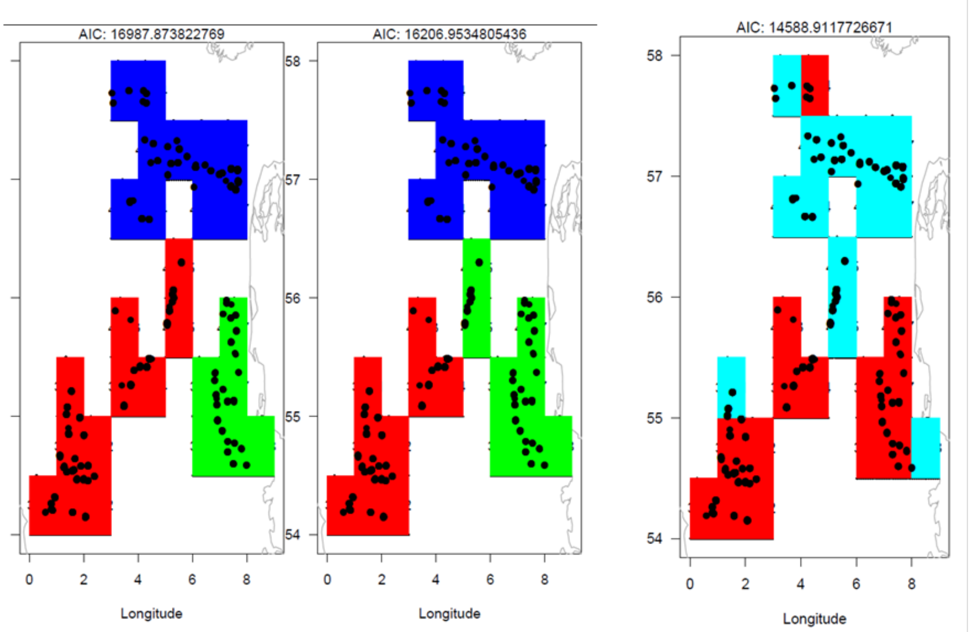

Figure 1.1.2.1 Area divisions proposed by a spatial age-length key modelling (SWAP) approach using continuation ratio logits applied to dredge survey data. The map to the left is the offset (which is the currently applied area division). The program then swaps squares forth and back and iteratively finds the area division that results in the best continuation ratio logits model (using AIC). The map in the center is the best solution given three areas, whereas, the map to the left is the best solution given two areas. Black dots represents dredge survey stations. SA4 survey data were not included.

1.1.3 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 analysis of external consistency between CPUE in different areas is described in Annex 2 WD 03 External consistency between CPUE at age in different areas. For the purposes of this analysis two of the assessment areas were divided in two: SA4 was divided into Turbot bank and the Firth of Forth. Area 3 was divided into the Norwegian EEZ and an EU Zone. A significant correlation between CPUE of age 1 in different areas would indicate common recruitment patterns. If this is the case, the correlation between CPUE of age 2 would indicate whether the total mortality experienced is similar in the different areas. No sandeel assessment area was found to be significantly correlated with the Firth of Forth (SA4). High correlations ($r^2>0.5$) were found between recruitment in the WKSAN 2010 SA1 and 2 and between recruitment in the Norwegian and EU components of SA3. Moderate correlations ($r^2>0.25<0.5$) 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 (see working document for details). 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 Annex 2 WD 03. 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. The proposal to divide SA3 into a Norwegian and EU component appears to be supported by this analysis as differences in recruitment were detected in some years.

1.2 Issue lists

Stock	Sandeel SA1, SA2, SA3, SA4, SA6, SA7			
Stock coordinators	Name: Cecilie Kvamme/Espen Johnsen	Email: cecilie.kvamme@imr.no /espen.johnsen@imr.no		
Stock assessor	Name: Anna Rindorf	Email: ar@aqua.dtu.dk		
Data contact	Name: Lotte Worsøe Clausen	Email: law@aqua.dtu.dk		
Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names
(New) data to be Considered and/or quantified[1]	Additional M - predator relations	Review latest multispecies-key run. Investigate natural mortality estimates from acoustic estimates of cohorts and last key-run in WGSAM	-	-
	Prey relations	Review output from pilot study on copepod species and sandeel abundance	Data from the ongoing GUDP-VIND project and output from the EMFF project on sandeel (Mikael van Deurs project leader)	-
	Ecosystem drivers	Analyse possible shifts in productivity in the North Sea pelagic community and their relation to sandeel abundance	Work undertaken in the Myfish project	-
	Other ecosystem parameters that may need to be explored? Old time-series of larvae abundance (2004-2009) evaluated Catch in numbers and mean	Time series estimated	Larval catch rates available	

Stock	Sandeel SA1, SA2, SA3, SA4, SA6, SA7			
Stock coordinators	Name: Cecilie Kvamme/Espen Johnsen	Email: cecilie.kvamme@imr.no /espen.johnsen@imr.no		
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Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names
	weight at age	Data from all biological samples taken from the fishery by all countries should be made available to the working group. Danish and Norwegian samples are already provided to HAWG.	Data from other countries should be extracted	
	Estimation of last years' catches	Methods to estimate last year's catches evaluated	Catches from all countries by year, square and month	
	Evaluation of mis-reporting of catches	VMS and reported effort and catch by square from all countries	VMS and reported effort and catch by square from all countries	
	Investigation of link between oil-content and the occurrence in the dredge-survey.	*Oil-data from the industry could be useful in terms of a link between oil-content and the occurrence in the dredge-survey.*	*Marine Ingredients and the Norwegian fish oil industry will supply the data.*	*This is a preliminary issue; analyses will have to be done by the industry-stakeholders*
Tuning series	Effort time series validation	Explore different measures of CPUE and estimates of search time.	VMS estimates of effort for recent years from all participating countries and corresponding	

Stock	Sandeel SA1, SA2, SA3, SA4, SA6, SA7			
Stock coordinators	Name: Cecilie Kvamme/Espen Johnsen	Email: cecilie.kvamme@imr.no /espen.johnsen@imr.no		
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Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names
		Explore technical creep in catchability	catches. Logbook records from all participating countries for as far back as possible. Possible issues with confidentiality. Periods of similar gear/fishery defined by industry members. Use of information from other vessels in choosing fishing ground. Data on length of trawl hauls and biological composition of catches	Lead of this task should be the stakeholders given they hold the necessary information
		Evaluate the effect of length of trawling time/trawling timing on the day on catchability at age Evaluate the development in catchability at age and size over a season	Sandeel size and otolith size throughout the fishery season from samples (in house) Acoustic time series CPR series	
	Acoustic survey	Include the acoustic survey	Dredge survey data including old timeseries	

Stock	Sandeel SA1, SA2, SA3, SA4, SA6, SA7			
Stock coordinators	Name: Cecilie Kvamme/Espen Johnsen	Email: cecilie.kvamme@imr.no /espen.johnsen@imr.no		
Stock assessor	Name: Anna Rindorf	Email: ar@aqua.dtu.dk		
Data contact	Name: Lotte Worsøe Clausen	Email: law@aqua.dtu.dk		
Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names
	CPR as a potential index of the recruitment Dredge-index calculation	Include CPR index of recruitment Identify the most appropriate estimate of annual dredge catches		
Discards	Evaluation of the historic extent of discarding/slipping	By-catches of sandeel in other fisheries may have occurred in the past. In the historic time-series the reporting of catches from other fisheries taken during quarter 1 and 4 are subtracted.	A survey of anecdotal knowledge within the fishing community regarding the bycatch, slipping, misreporting. Fishing industry should lead this preparatory work for the DAWK. Further examination of e.g. the number of samples available	Lead of this task should be the stakeholders given they hold the necessary information

Stock	Sandeel SA1, SA2, SA3, SA4, SA6, SA7			
Stock coordinators	Name: Cecilie Kvamme/Espen Johnsen	Email: cecilie.kvamme@imr.no /espen.johnsen@imr.no		
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Data contact	Name: Lotte Worsøe Clausen	Email: law@aqua.dtu.dk		
Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names
Biological Parameters	Species (sandeel) composition of catches in various areas, in particular SA2; Stock structure in terms of the area-division of the North Sea Exchange of fish between fishing grounds Biological parameters back in time (weight at age, etc.)	Fluctuations in the species composition could be an important information (is the management precautionary for all species?). Review of: species composition of sandeel in the NS; stock structure for *Ammodytes marinus*; life-cycle, growth, reproduction by area; larval drift simulations S-R link based on drifting models should be re-evaluated, thus update of these needed. Weight at age may depend on the sample-type Age-reading calibration exercise using 'validated age' based on microstructure analysis.	Data needed on species information from sandeel samples were recorded to estimate proportions of sandeel species in the catches back in time. This information may be available from the age-readings back in time and on-going genetic studies on Danish samples. This task is a review of all possible information on sandeel stock structure. Fishing ground specific data and all available data on stock, larvae and drift Mark-recapture results (GUDP-VIND). IMR will bring an advanced drift model with depth integration Available already in HAWG Enquire WGBIOP to undertake a fast-track exchange on sandeel	Dorte Bekkevold (genetics) Casper Berg (assessment modelling)

Stock	Sandeel SA1, SA2, SA3, SA4, SA6, SA7			
Stock coordinators	Name: Cecilie Kvamme/Espen Johnsen	Email: cecilie.kvamme@imr.no /espen.johnsen@imr.no		
Stock assessor	Name: Anna Rindorf	Email: ar@aqua.dtu.dk		
Data contact	Name: Lotte Worsøe Clausen	Email: law@aqua.dtu.dk		
Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names
Assessment method	Area division of the North Sea should be re-evaluated in the assessment set-up; Alternative stock-assessment models tested Development of the fishery and CPUE (modelled in the stock assessment)	Migration could be taken into account in the assessment model. IMR have experience and data to develop this point. Stock assessment: Evaluate if the certainty in the total biomass available for fishery in the NS is higher than the divided area TACs Quarter-based SAM tested Linked area-separate assessment models could be tested (Valerio) Gear-development, TAC as supplement information for the F-variation model Check signals in the assessment when changing the recruitment indices; Include 0 group catches in the assessment model	IMR model and estimates of migration (IMR/Espen Johnsen) Quarter based SAM (DTU/Mikael) Linked models (SLU/Valerio) Data available already in the working group	Morten Vinther Casper Berg/Anders Nielsen

Stock	Sandeel SA1, SA2, SA3, SA4, SA6, SA7			
Stock coordinators	Name: Cecilie Kvamme/Espen Johnsen	Email: cecilie.kvamme@imr.no /espen.johnsen@imr.no		
Stock assessor	Name: Anna Rindorf	Email: ar@aqua.dtu.dk		
Data contact	Name: Lotte Worsøe Clausen	Email: law@aqua.dtu.dk		
Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names
	Analyses of the recruitment-model and indices Potential effects of an inhomogeneous geographical distribution of recruitment and catchability of sandeel in relation to the fishery SA4: No analytical assessment available	Check for bias related to fishery in relation to the spatial choice of fishing grounds ('Black box') Collate all available data and set-up an analytical assessment for SA4	Data from the Scottish and Danish surveys in the area (monitory surveys, dredge-survey, bird-related surveys)	Casper Berg/Anders Nielsen Peter Wright, Sally Wanless
Biological Reference Points	Ecosystem reference points seen in relation to the existing biological reference points	Analyse if a limit biomass to be available for the ecosystem		Morten Frederiksen, Niels Øien, Sofie Schmout. Norway pout is benchmarked at the same time as the sandeel which

Stock	Sandeel SA1, SA2, SA3, SA4, SA6, SA7			
Stock coordinators	Name: Cecilie Kvamme/Espen Johnsen	Email: cecilie.kvamme@imr.no /espen.johnsen@imr.no		
Stock assessor	Name: Anna Rindorf	Email: ar@aqua.dtu.dk		
Data contact	Name: Lotte Worsøe Clausen	Email: law@aqua.dtu.dk		
Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names
				can facilitate exchange of ecosystem knowledge/expertise.
	Effect of/on copepod biomass	Analyses of copepod biomass data: timeseries for the North Sea	Copepod biomass timeseries for the North Sea	
	Review of the existing biological and management related reference points	Analyses done including the Fcap		
	Economical 'reference points'	Estimation of whether a 'natural cap' for fishing, as in stopping fishing when the bank is not returning an economically sane output, exists.	This should be delivered by the fishery stakeholders	

1.3 Scorecard on data quality

The accuracy (potential bias) of input data for the assessment is evaluated according to the scorecard developed by the Workshop on Methods to Evaluate and Estimate the Accuracy of Fisheries Data used for Assessment (WKACCU, ICES, 2008). The workshop developed a practical framework for detecting potential sources of bias in fisheries data collection programs. A scorecard was applied to indicators of bias for a suite of parameters that are important for stock assessments. The scorecard can be used to evaluate the quality of data sources used for stock assessments, and to reduce bias in future data collections by identifying steps in the data collection process that must be improved.

The scorecard was compiled for all sandeel stocks combined given that the data collection, sample analyses and raising procedures are identical across the stocks. Where there is stock-specific bias it is mentioned in 'Comment'. No major biases have been identified for the sandeel stocks.

WKACCU scorecard	No bias	Potential bias	Confirmed bias	Comment
A. SPECIES IDENTIFICATION				
1. Species subject to confusion and trained staff	1			
2. Species misreporting	1			
3. Taxonomic change	1			
4. Grouping statistics	1			
5. Identification Key	1			
Final indicator				
B. LANDINGS WEIGHT				
Recall of bias indicator on species identification				
1. Missing part	1			
2. Area misreporting	1			Occurred in 2014 and 2015 between SA1 and SA3; corrected in timeseries
3. Quantity misreporting	1			no current misreporting
4. Population of vessels	1			
5. Source of information	1			
6. Conversion factor	1			
7. Percentage of mixed in the landings	1			
8. Damaged fish landed	1			
Final indicator				
C. DISCARDS WEIGHT				
Recall of bias indicator on species identification				
1. Sampling allocation scheme	1			
2. Raising variable	1			
3. Size of the catch effect	1			
4. Damaged fish discarded	1			
5. Non response rate	1			
6. Temporal coverage	1			
7. Spatial coverage	1			
8. High grading	1			
9. Slipping behaviour	1			
10. Management measures leading to discarding behaviour	1			
11. Working conditions	1			
12. Species replacement	1			
Final indicator				
D. EFFORT				
Recall of bias indicator on species				

WKACCU scorecard	No bias	Potential bias	Confirmed bias	Comment
identification				
1. Unit definition		1		SA 3: Potential bias as Norwegian and EU do not estimate effort in the same way
2. Area misreporting	1			
3. Effort misreporting	1			
4. Source of information	1			
Final indicator	0.5			
E. LENGTH STRUCTURE				
Recall of bias indicator on discards/landing weight				
1. Sampling protocol	1			stratified random
2. Temporal coverage	1			
3. Spatial coverage	1			
4. Random sampling of boxes/trips	1			
5. Availability of all the landings/discards	1			
6. Non sampled strata	1			
7. Raising to the trip	1			
8. Change in selectivity	1			
9. Sampled weight	1			
Final indicator				
F. AGE STRUCTURE				
Recall of bias indicator on length structure				
1. Quality insurance protocol	1			
2. Conventional/actual age validity		1		there are possibilities to construct accurate age sets
3. Calibration workshop	1			
4. International exchange	1			
5. International reference set	1			
6. Species/stock reading easiness and trained staff	1			
7. Age reading method	1			
8. Statistical processing	1			
9. Temporal coverage	1			
10. Spatial coverage	1			
11. Plus group	1			
12. Incomplete ALK	1			
Final indicator	0.5			
G. MEAN WEIGHT				
Recall of bias indicator on length/age structure	0.5			
1. Sampling protocol	1			
2. Temporal coverage	1			
3. Spatial coverage	1			
4. Statistical processing	1			
5. Calibration equipment	1			
6. Working conditions	1			
7. Conversion factor	1			
8. Final indicator				
H. SEX RATIO				sex ratio not used
Recall of bias indicator on length/age structure	0.5			
1. Sampling protocol	1			
2. Temporal coverage	1			
3. Spatial coverage	1			
4. Staff trained	1			
5.Size/maturity effect	1			
6. Catchability effect	1			
Final indicator				
I. MATURITY STAGE				
Recall of bias indicator on length/age structure	0.5			
1. Sampling protocol	1			

WKACCU scorecard	No bias	Potential bias	Confirmed bias	Comment
2. Appropriate time period	1			
3. Spatial coverage		1		SA2: not good coverage in this area
4. Staff trained	1			
5. International reference set	1			
6. Size/maturity effect		1		using constant maturity ogives
7. Histological reference	1			
8. Skipped spawning	1			
Final indicator	0.5			
Final indicator				

1.4 Multispecies and mixed fisheries issues

The fishery for sandeel has mostly single-species catches, although some mixed sandeel catches may occur in the more coastal fishery. The by-catch of other fish species are minor (less than 2% on an annual basis of sprat, herring, horse mackerel, haddock and other species), and bycatch of sea mammals and birds is also very low, i.e. undetectable using observer programmes.

1.5 Ecosystem drivers

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 1.5.1). 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).

1.5.1 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 SA1, 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 1.5.1.1a and b; van Deurs *et al.*, Annex 2 WD 04). 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 1.5.1.1a and b), 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 1.5.1.1c), while the effect of *C. finmarchicus* was linear and positive (Figure 1.5.1.1d). 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 1.5.1.1e and f).

Table 1.5.1.1a. The generalized cross validation scores (GCV) and deviance explained (DEV) after fitting the full S-R model to each abiotic covariate separately. The best covariate is highlighted in bold.

Variable	GCV	DEV	
SST_q1		0.571	0.613
SST_q2		0.398	0.733
SST_q3		0.506	0.647
SST_q4		0.628	0.544
SST_ann		0.461	0.689
SBT_mean		0.555	0.624
NAO_win		0.634	0.508
AMO_win		0.459	0.684

Table 1.5.1.1b. 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 r² (%)
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.**

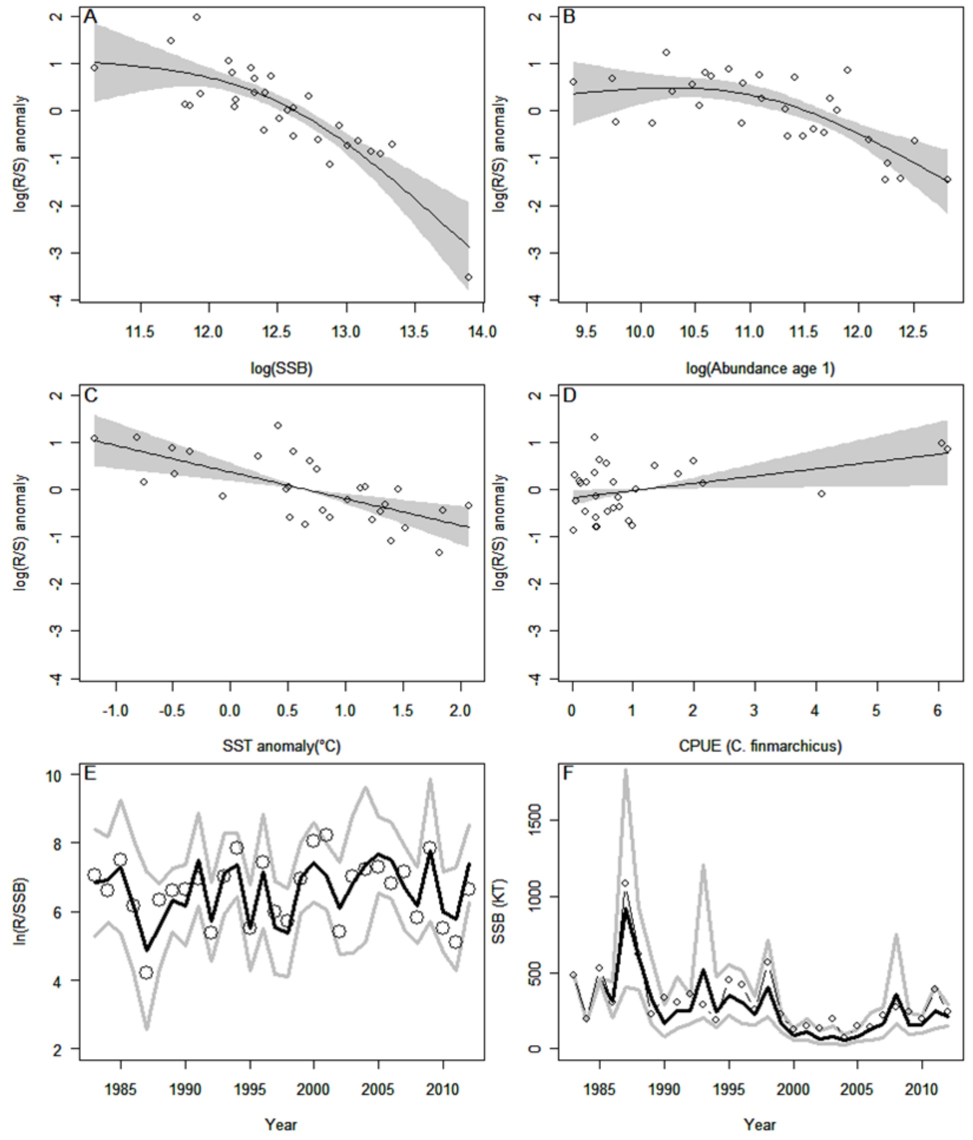


Figure 1.5.1.1 a-f. The effects of final model predictors on sandeel recruitment success with 95% confidence intervals (grey), illustrating non-linear negative relationships with SSB (A) and abundance at age 1 (B), a negative linear relationships with SST (C), as well as positive effects of prey abundance (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.

Thus *C. finmarchicus* appears to be important for the growth and recruitment of sandeel in the central parts of the North Sea. Since this species is strongly affected by the climatic conditions in North Sea, the climate has an indirect effect on the sandeel populations in the North Sea (van Deurs *et al.*, 2009, 2013, 2015).

1.5.2 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 1.5.2.1). 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 1.5.2.1 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%	Breeding success has declined with reduction in sandeel in fulmar diet and breeding numbers have declined considerably in the North Sea, expecially at Shetland. See 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 1.5.2.1).

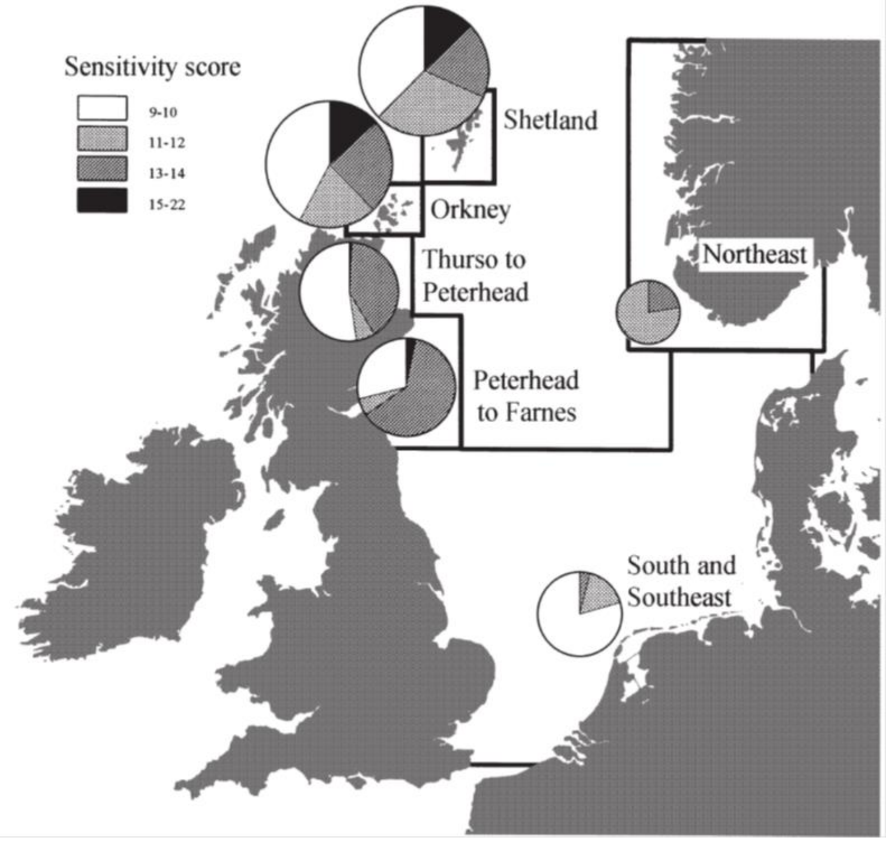
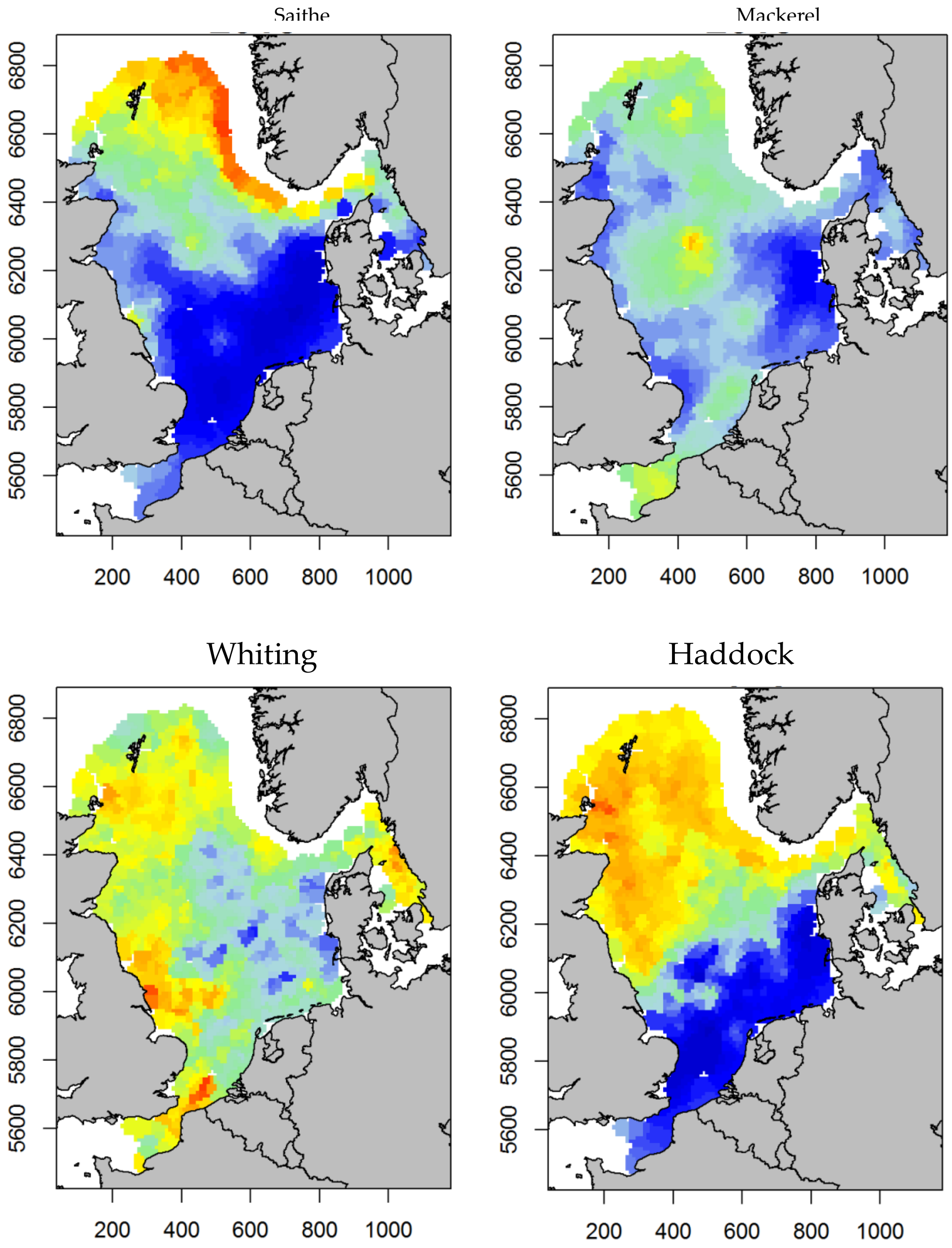


Figure 1.5.2.1. Numbers of pairs of seabirds of high sensitivity to sandeel abundance, breeding in different parts of North Sea. Areas are defined as Shetland, Orkney, Thurso to Peterhead, Peterhead to Farnes (inclusive), southern and southeastern North Sea, and north-eastern North Sea. Size of each circle indicates size of local breeding population of seabirds of high sensitivity score. From Furness and Tasker (2000).

1.5.3 Distribution of sandeel predators

Saithe and haddock tend to have a northerly distribution, whereas Gurnards, whiting and mackerel tend to be more widespread (Figure 1.5.3.1). 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 (Figures 1.5.3.1 and 1.5.3.2). The distribution of cetaceans seems highly variable between years (Figure 1.5.3.3).



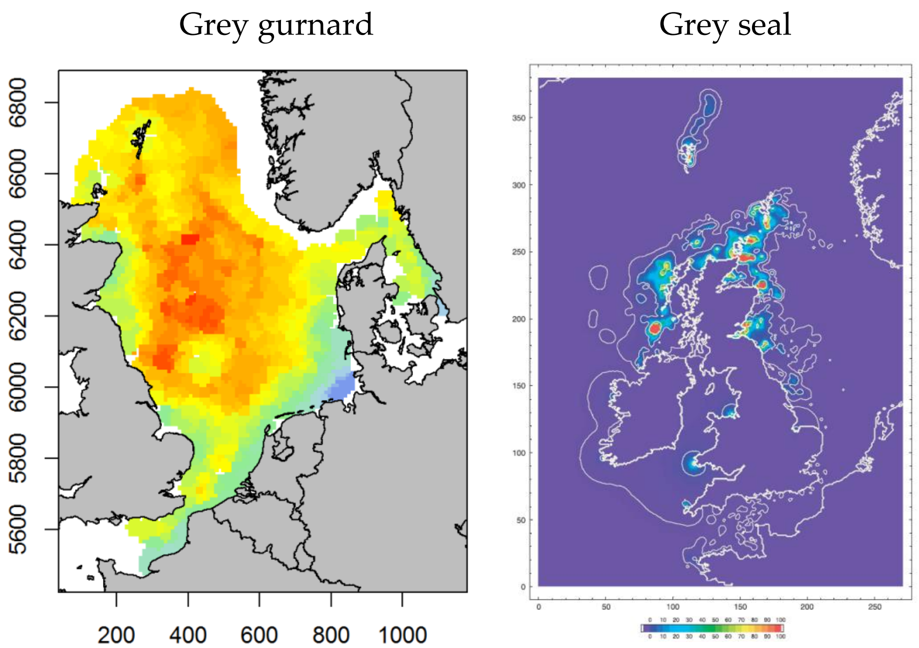
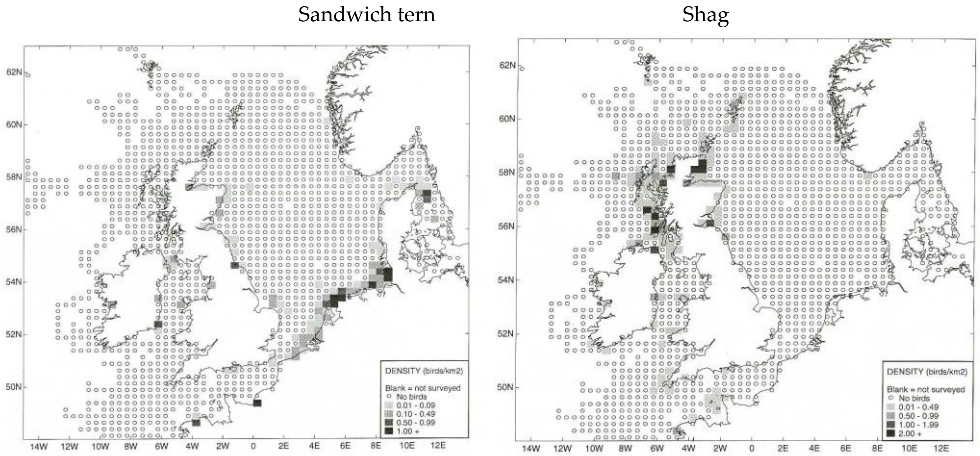
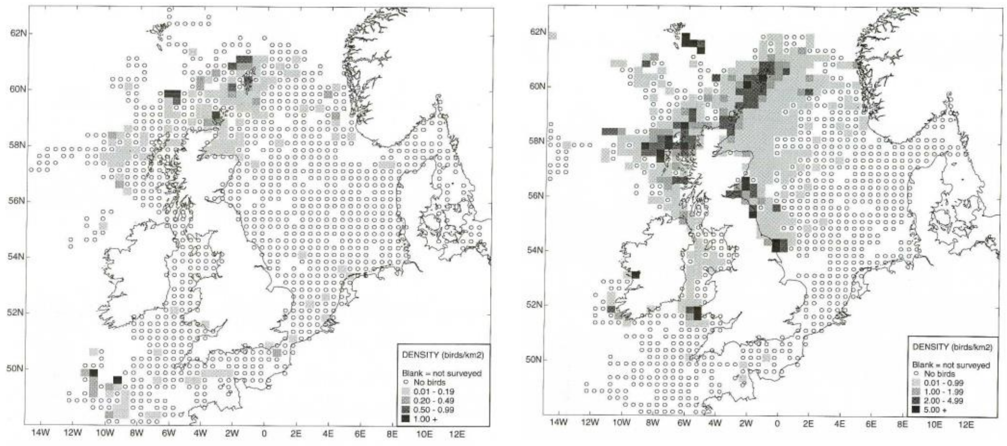


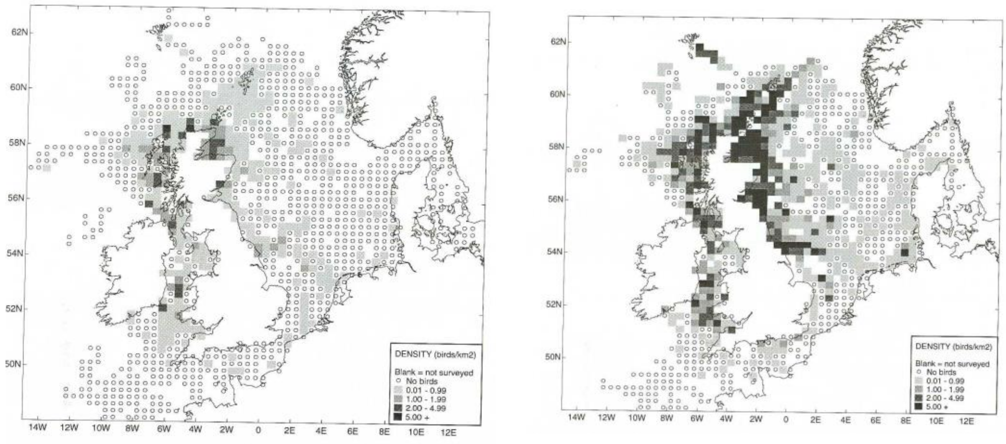
Figure 1.5.3.1. Distribution of saithe, mackerel, whiting, haddock, grey gurnards and grey seals. Fish distributions are 2015 distributions derived from www.FishViz.org. Grey seal distribution is derived from Matthiopoulos *et al.* (2004).



Great Skua Puffin



Guillemot Razorbill



Kittiwake Gannet

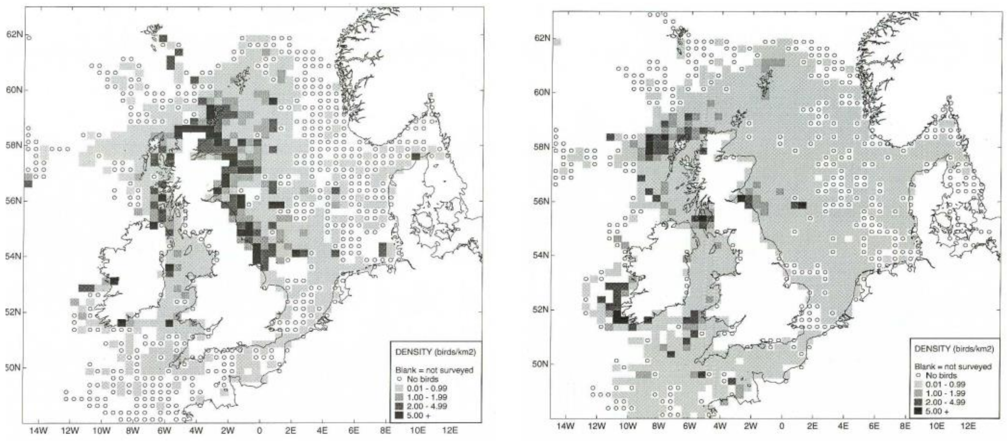


Figure 1.5.3.2. Distribution of North Sea seabirds with a high proportion of sandeel in the diet according to Engelhard *et al.* (2014). From Stone *et al.* 1994. Periods used: Sandwich tern (May/August), Shag (May/August), Great Skua (April/June), Puffin (June/July), Guillemot (May/June), Razorbill (April/June), Kittiwake (June/July), Gannet (May/August).

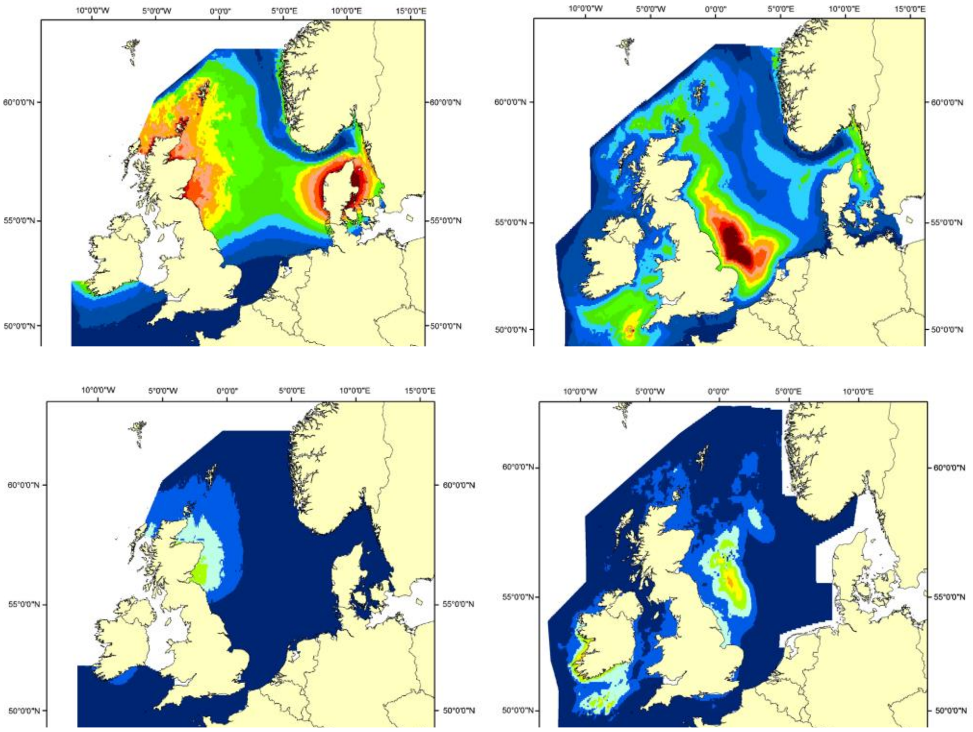


Figure 1.5.3.3. Distribution of harbour porpoise (top) and minke whales (bottom) based on SCANS surveys in 1994 (left) and 2005 (right). From Hammond *et al.* (2013).

1.5.4 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 1.5.4.1). 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).

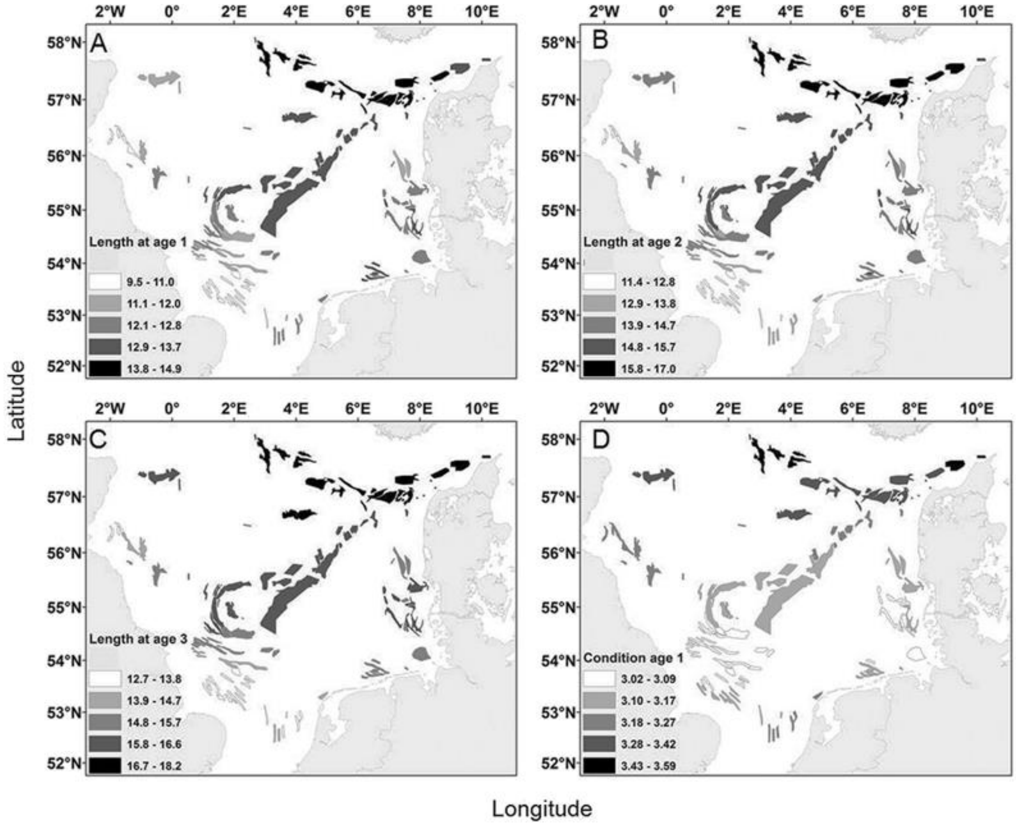


Figure 1.5.4.1. Maps of predicted length at each ground in week 21 at ages 1 (A), 2 (B) and 3 (C) and predicted condition at age 1 in week 21 (D). Shading indicates mean length and condition, respectively, white indicating the lowest level and black the highest. Minimum length at ages 1, 2 and 3: 7.0, 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).

1.5.5 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 1.5.5.1) nor the distribution of fisheries catches 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 1.5.5.1).

Figure 1.5.5.1. 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. Cliff-nesting seabirds, and seabirds requiring predator-free islands on which to breed, tend to be most numerous in the northwest North Sea where suitable nesting habitat is abundant. Nevertheless, the largest colony of kittiwakes in Europe, the seabird considered most vulnerable to effects of low abundance of sandeel, is situated on the east coast of England and is designated a Special Protection Area for breeding kittiwakes (Flamborough and Filey Coast SPA).

This colony is immediately adjacent to the Dogger Bank, the main area fished for sandeel, and GPS tracking studies by RSPB (http://www.rspb.org.uk/our-work/conservation/conservation-projects/details.aspx?id=365020) show that breeding birds from this colony will frequently forage over the Dogger Bank. 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. The Dogger Bank also qualifies as a conservation area (SAC under the EU Habitats Directive) for harbour porpoise, as it holds high concentrations of that species in the Dutch, German and UK sectors of the North Sea. The UK sector is currently a pSAC for harbour porpoise. Distributions of harbour porpoises in UK waters have changed over decades. Whereas their numbers were once high in Shetland, after the sandeel stock at Shetland collapsed in the 1980s, harbour porpoises left Shetland waters and the distribution moved southwards with the highest concentration now found on the Dogger Bank, the area where sandeel abundance has tended to remain relatively high compared to areas in the northern North Sea. The Dogger Bank is also protected under EU law as an SAC for the habitat and community of marine organisms associated with the habitat, and is designated an SCI (Site of Community Importance).Grey seal overlap with the fishery is concentrated off the Scottish east coast.

1.5.6 North East UK Closure

Due to their importance in North Sea food webs, ICES has advised that management should ensure that sandeel abundance be maintained high enough to provide food for a variety of predator species. During the early 1990s a sandeel fishery developed in Area 4, off the Firth of Forth. The landings from this fishery peaked at over 100 000t in 1993 and then subsequently fell. The Firth of Forth area is important for breeding seabirds and the removal of such large quantities of sandeels within their foraging range soon became a matter of concern. In 1999, the U.K called for a moratorium on sandeel fishing adjacent to seabird colonies along the U.K. coast and in response the EU requested advice from ICES. An ICES Study Group, was convened in 1999 in response to this request with two terms of reference (ICES 1999):

a) assess whether removal of sandeel by fisheries has a measurable effect on sandeel predators such as seabirds, marine mammals, and other fish species.

b) assess whether establishment of closed areas and seasons for sandeel fisheries could ameliorate any effects. Identify possible seasons/areas as specifically as possible.

This study group noted that there was suggestion of a negative effect of the Firth of Forth fishery on the local sandeel abundance in 1993 which coincided with a particularly low breeding success of seabirds, especially kittiwakes. The study group concluded that there were two reasons for continued concern about this area that provided the basis for a precautionary closure:

1. sandeels supported a number of potentially sensitive seabird colonies (Lloyd *et al*., 1991).
2. work on population structure indicated that sandeels in this region are reproductively isolated from the main fished aggregations in the North Sea (Wright *et al*. 1998).

The ICES study group noted that, as sandeel assessments are only conducted for the North Sea, there was no reliable information on the state of the sandeel aggregations near the Firth of Forth, which forms part of area division 4 (see Figure 1.5.6.1). Given available information the study group proposed that kittiwake breeding success was the best practical indicator of sandeel availability at least to seabirds and threshold levels of the breeding success of this species should be used to guide futures decisions on re-opening. After ICES Advisory committees and STECF acceptance of the study group's advice, the EU advised that the fishery should be closed whilst maintaining a commercial monitoring. However, the EU did not accept the use of kittiwake breeding success as a harvest control threshold. A 3-year closure, from 2000 to 2002, was decided and the Commission was requested to produce annual reports to the Council on the effects of the restrictions in the sandeel fishery in the Firth of Forth area. On the basis of the second of these reports (Wright *et al.*, 2001) and uncertainty over the impact of the closure the commission proposed a further 3 year extension of the closure. The wording of the Act is stated in article 29a of: "Council Regulation (EC) no 850/98 of 30 March 1998 for the conservation of fishery resources through technical measures for the protection of juveniles of marine organisms". A further scientific review of the closure was made by STECF in 2007, together with other EU fishery closures. That group proposed that it would be prudent to wait for enhanced recruitment and productivity in the area before any re-opening is considered.

Evaluating changes in sandeel abundance in the region has been difficult due to the lack of a single reliable sampling method for assessing sandeel abundance. Nevertheless, the various research (acoustic, trawl and dredge) and commercial abundance indices suggested an initial increase in sandeel abundance during the period of the closure (Greenstreet *et al.*, 2006). This increase began with a relatively large recruitment in the first year of the closure, which would not have been related to any recovery in the spawning stock. Dredge surveys in 1999 and 2000 indicated a detectable decrease on total mortality on 1+ sandeels following the closure. A further indication that sandeel abundance increased in the region came from the observation that in 2003, when landings in the North Sea as whole had severely declined, 39 060 tonnes were taken in the ICES rectangle adjacent to the closed area near Marr and Berwick banks and 63 731 tonnes over the whole of the open part of Area 4.

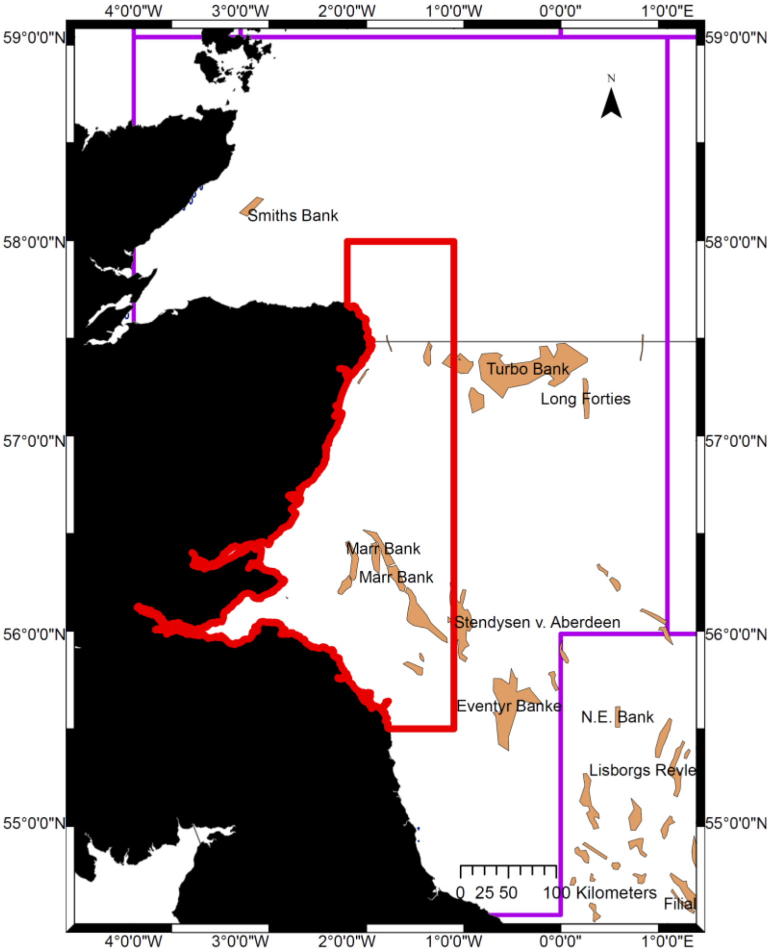


Figure 1.5.6.1. Chart showing the North east closed area (red polygon) within SA4 (purple polygon).

Kittiwake breeding success has tended to be higher since the fishery closure than in the preceding 5 years. However, poor breeding success in 2004 seen along the whole of the east U.K. coast appears partly related to environmental factors affecting the incoming year-class of sandeels. Evidence from studies published since the ICES (1999) study group suggest that the breeding success of this species is not a reliable indicator of sandeel availability to some other coastal seabirds. For example, a downward trend in guillemot breeding success throughout the 1990s has not been reversed by fishery closure (but that species feeds extensively on sprats as well as sandeels in this area). However, kittiwake breeding success appeared to have benefitted from the reduction in mortality on age 1+ sandeels (Daunt *et al*., 2009). After a series of very poor breeding seasons for seabirds since 2004 on the Isle of May, Firth of Forth, the 2009 season was the most successful in recent years, matching evidence of increased sandeel abundance from the dredge survey. Of six seabird species studied intensively, European shag had its highest productivity on record with only razorbill having productivity below average. All other species studied had their most productive season for at least four years. Sandeels remained the main food of young Atlantic puffins, razorbills and kittiwakes. Comparatively few 1+ group sandeels were present in food samples during the chick-rearing period in 2009, however 0-group appeared in large numbers and were substantially longer than in recent years, again matching dredge results. Kittiwakes had a good season with productivity (0.70

chicks per incubated nest) the highest since 2005 and well above the long-term average. The proportion of sandeel in kittiwake diet (89% by biomass) in 2009 was the highest since 2005.

The concern over a possible local impact of sandeel fishing expressed in 1999 has not fundamentally changed. On re-opening, the sandeel aggregations in the Northeast closure could be subject to significant depletion unless there were revised management controls. As originally agreed by the Commission, STECF would have to convene an international meeting of scientists to come up with a consensus on criteria for re-opening. These criteria would not only have to take into account the spawning stock but also the needs of sandeel dependent predators which led to the closure.

1.5.7 The Norwegian spatial management of sandeel in the North Sea

The landings on several of historical important sandeel fishing grounds in NEEZ showed a dramatic decline from the late 1990's, and where commercial depleted for many years. Details about the stock development can be found in ICES (2010), but with the aim of rebuilding the commercial depleted areas a spatial management plan was tested in 2010 and fully implemented in 2011. In 2014, the plan was slightly changed, but the principles of the management plan are very similar.

Management plan and advice process

- The areas with known sandeel fishing grounds are divided into 5 areas (Figure 1.5.7.1) based on the differences in population developments, differences in recruitment and size at age.
- An area is closed for fishery unless the abundance of sandeel is relatively high in the area (biomass estimated from the acoustic survey). There is no strict definition of "high abundance", but no area has been open with biomass estimate has been less than 20000 tonnes.
- All areas are divided in 2 subareas (area 3 is divided in 3 subareas).
- If an area is open for fishery, one of the subareas is closed to prevent too high effort and a total depletion of sandeel in an area
- A preliminary advice is available end of January, which describes the preliminary TAC and what sub-areas that should open. This advice is based on stock developments estimated from the acoustic surveys and data from the fishing fleet, and an assumption of very low recruitment.
- An acoustic survey is carried out around 25 April – 15 May, which is used to estimate the abundance of age 1 and older sandeel. The survey results are used to give a final advice. The TAC can be adjusted upwards and new subareas can be open.
- One TAC advice combined is given for all open subareas.
- There is no analytic stock assessment in place, and to calculate the TAC the survey abundance estimates are used as absolute numbers. A natural mortality of 0.6 is used to estimate the survival of individuals age > 1 at the start of next fishing year.
- To prevent fishing of lean individuals the fishing season starts 23 April (in 2015 and 206 the fishery started 15 April)

- To avoid too high percentage of juvenlies (0-age fish) the fishery ends 23 June
- If the number of sandeel < 10 cm comprise of more than 10% in a catch, the fishing ground is closed for seven days to prevent a fishery on 0-age fish. The fishing ground is re-open automatically after one week.

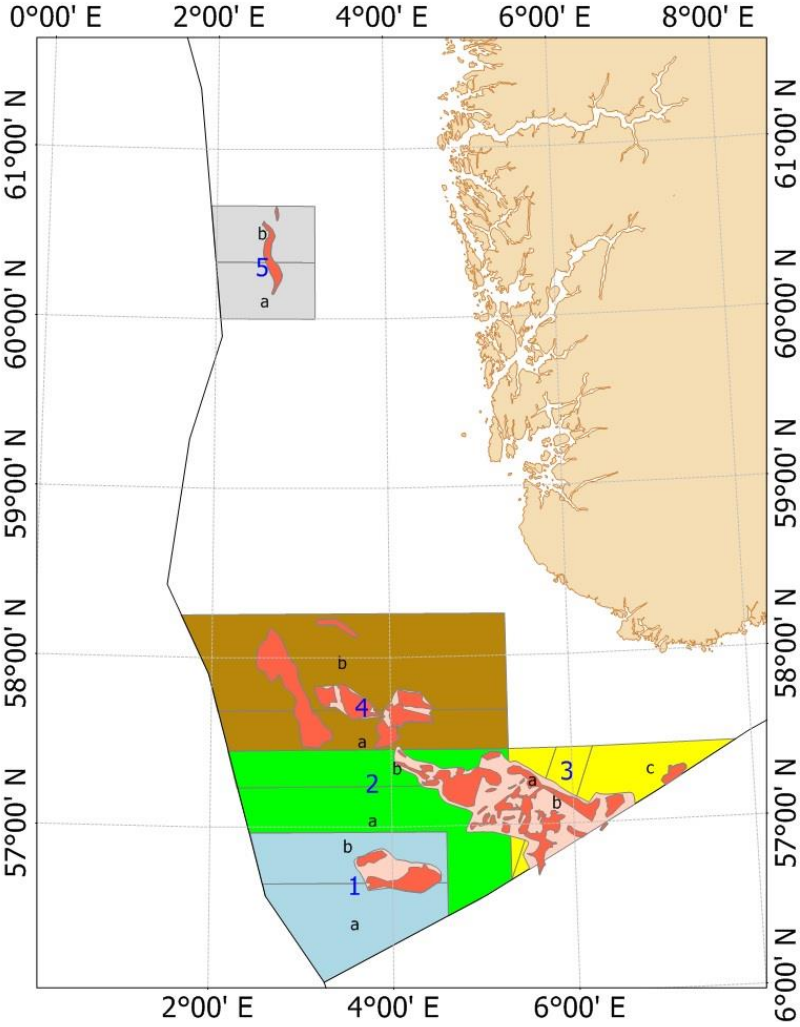


Figure 1.5.7.1. Map of the five Norwegian management areas in the North Sea. Historical important fishing grounds are depicted in red, and areas with suitable sandeel habitat are depicted in pink.

1.6 Catch – quality, misreporting, discards

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 2000-2015 is shown in Figure 1.6.1.

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 tonnes. Table 1 show sandeel landings by country for 1955-2015.

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 1.6.2). In 2004 an introduced ITQ led to a concentration of the fishery quotas and bulding 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 1.6.3). 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.

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 1150t.

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.

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). 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. SA2, SA3, and SA4 were taken through the same process to identify the best sets of breakpoints, resulting in the following sets of break points between period clusters: SA2: 1989, 1999, 2005, 2010; SA3: 1986, 1999; SA4: none. The SESAM model, which was run exploratively 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.

Figure 1.6.1 Reported commercial catches from 2000 to 2015.

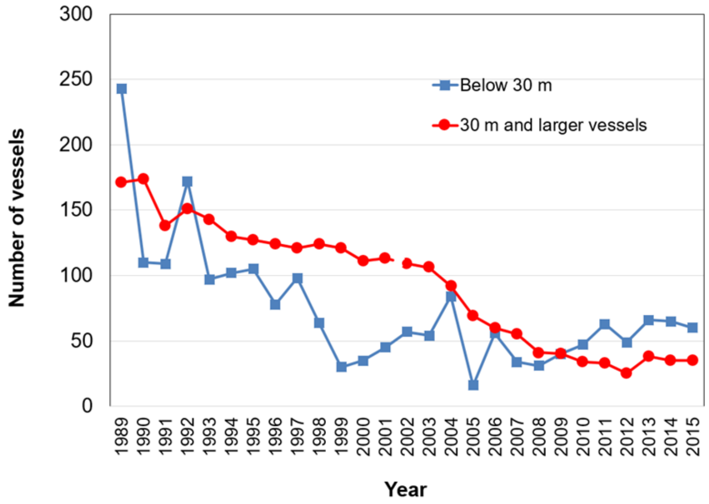


Figure 1.6.2. Number of Danish vessels landing sandeel 1989-2015. (Data: Danish Agrifish Agency 2016).

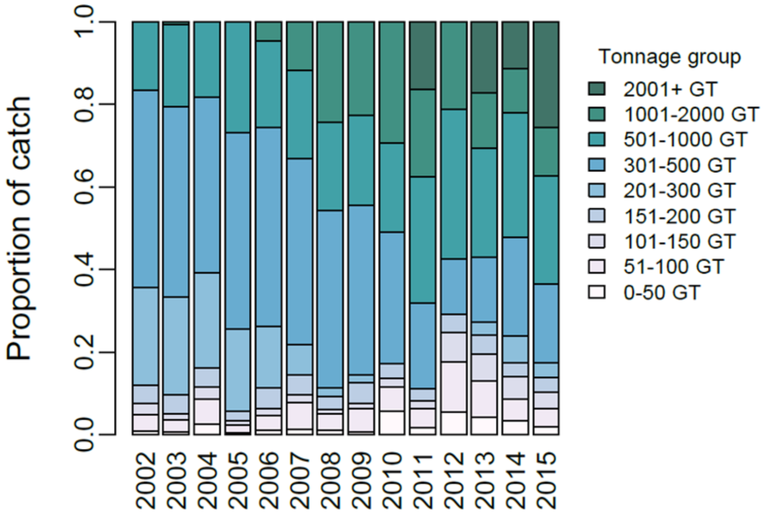


Figure 1.6.3. Bar plot of proportional catch by tonnage group in each year (Ohlberger and Hilborn, 2016).

Table 1.6.1. Sandeel. Catches ('000 t), 1955–2015. (Data provided by ICES Working Group Members).

Year	Denmark	Germany	Faroes	Ireland	Netherlands	Norway	Sweden	UK	Lithuania	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

Year	Denmark	Germany	Faroes	Ireland	Nether-lands	Norway	Sweden	UK	Lithu-ania	Total
1998	628.2	-	11	-	+	343.3	8.6	23.8	-	1014.8
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

1.7 Surveys

1.7.1 Dredge surveys

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 ith haul:

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

Where SP_ID is a categorical variable for assessment area. SubArea is a categorical variable for sub area (see Figure 1.7.1.1). 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.

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

[2] 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.

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

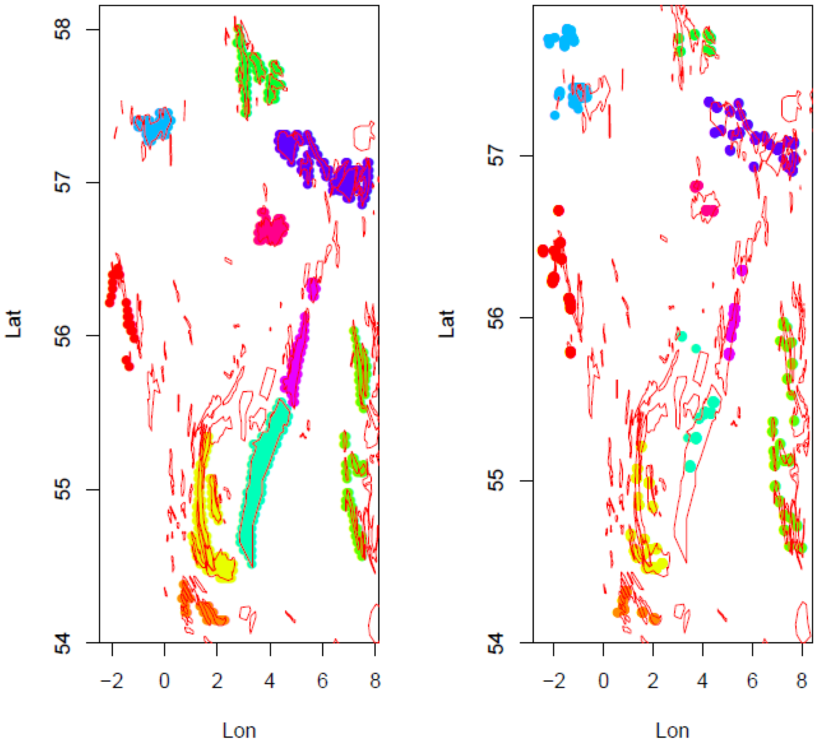


Figure 1.7.1.1: Right: Survey index grid. Each colored dot represents a virtual haul, colors represents sub areas where abundance is assumed constant for a given year. Left: Actual haul positions colored by sub area. Red polygons are sandeel banks. Hauls outside the polygons are assigned a sub area based on the nearest neighbor.

1.7.2 Acoustic survey

The Norwegian acoustic survey

Survey design and survey effort

The acoustic survey is carried out in the peak feeding season (about 25 April – 15 May) during daytime (between sunrise and sunset) when the sandeel form schools to feed on zooplankton. The geographical distribution of sandeel areas is reflected by the historical fishing effort (Figure 1.7.2.1), and the survey area cover all the known fishing ground for 11 geographical strata (Figure 1.7.2.2). To fit the strata to the ICES sandeel assessment areas (SA) 10 strata are assigned to ICES SA3, and one stratum is assigned to SA5 (Table 1.7.2.1).

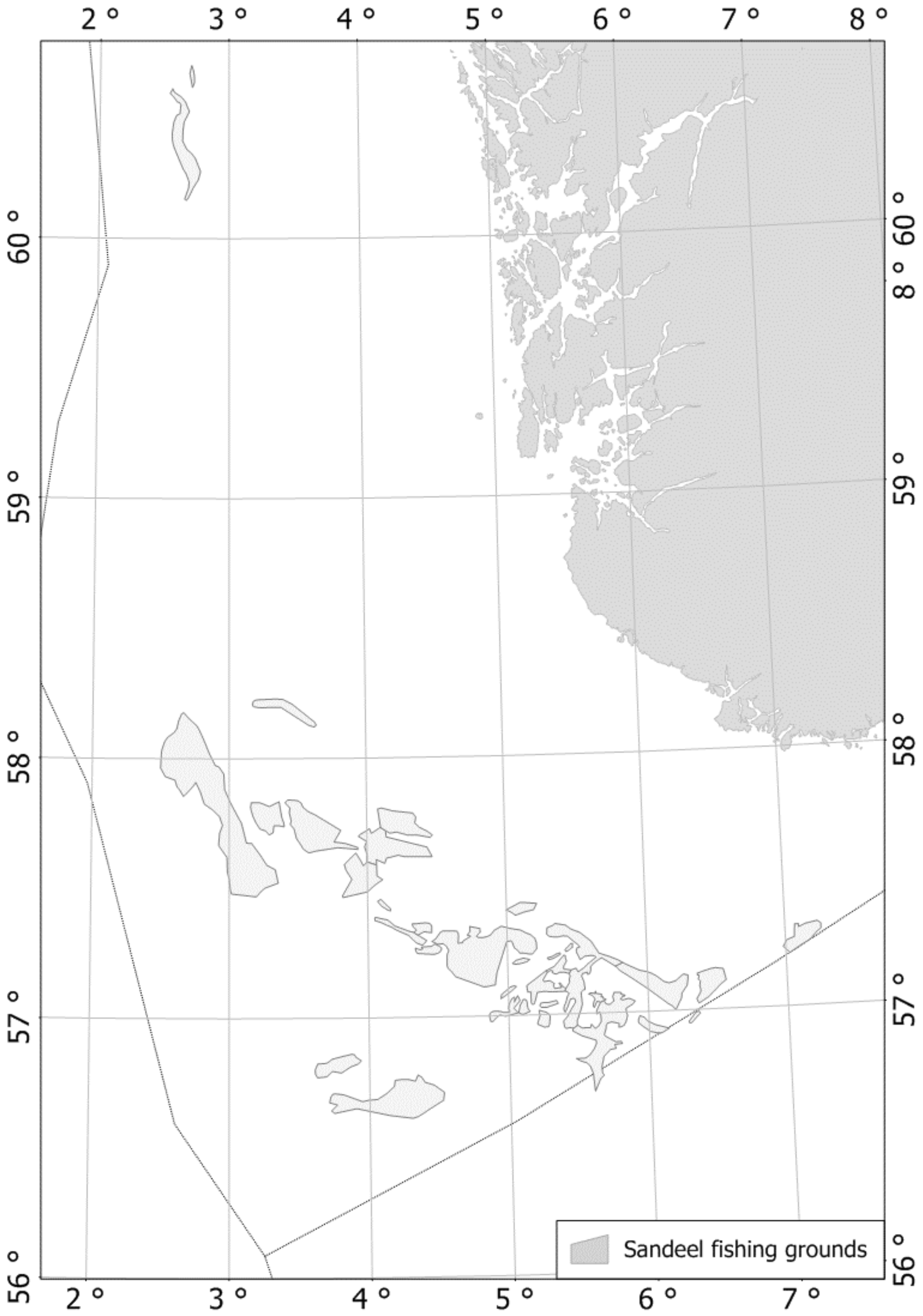


Figure 1.7.2.1. Map of sandeel fishing grounds in the Norwegian EEZ.

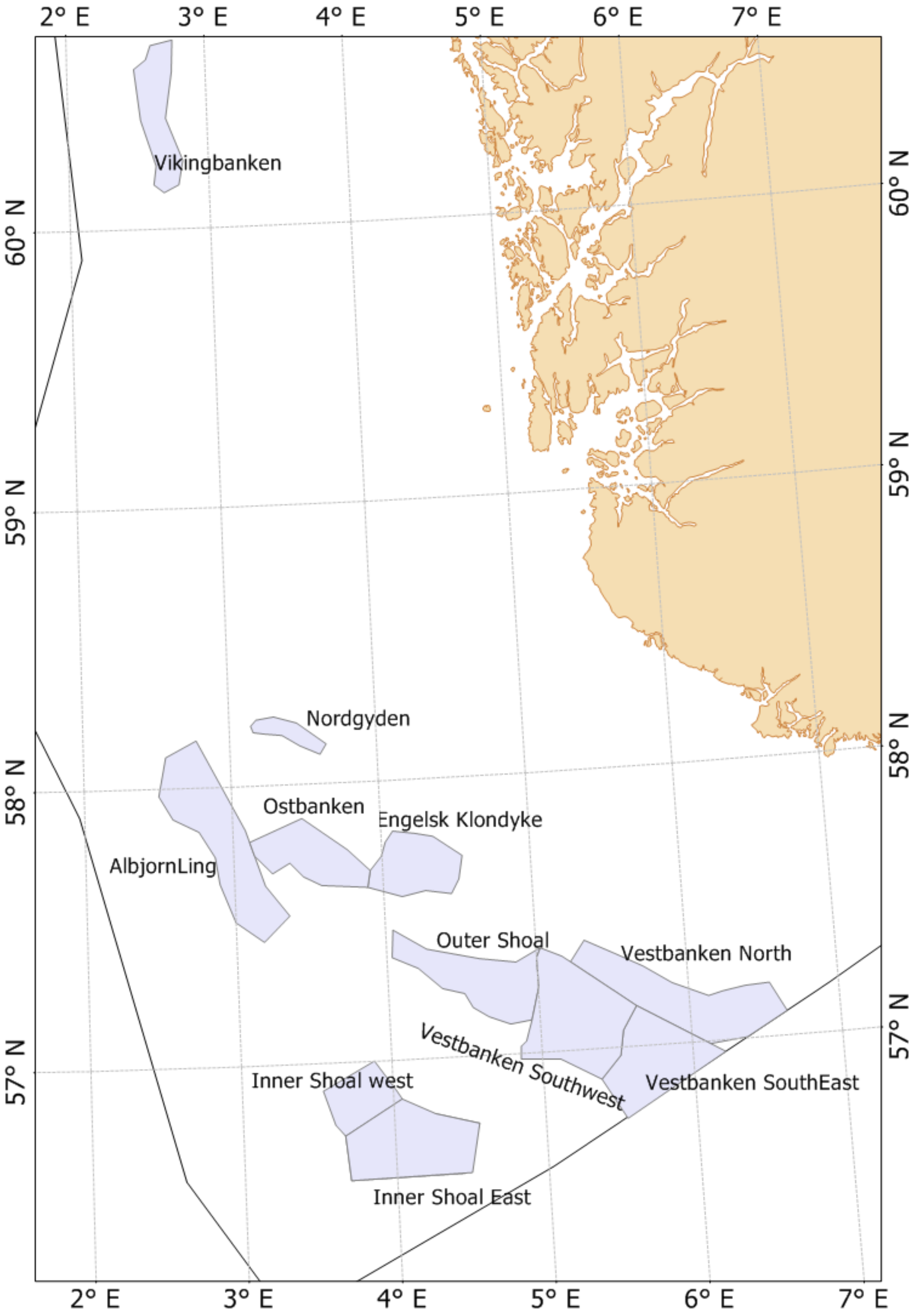


Figure 1.7.2.2. Map of the acoustic survey strata.

Table 1.7.2.1 Overview of strata and the assignment of strata to sandeel stock assessment area

Stratum	ICES SA Area	Survey years
Vikingbanken	5	2009-2016
Vestbanken SouthWest	3	2009-2016
Vestbanken SouthEast	3	2009-2016
Vestbanken North	3	2009-2016
Outer_Shoal	3	2009-2016
Ostbanken	3	2009-2016
Nordgyden*	3	2011-13, 2015-16
Inner Shoal West	3	2009-2016
Inner Shoal East	3	2009-2016
Engelsk Klondyke	3	2009-2016
AlbjornLing	3	2009-2016

***Not included in the total estimate of SA3 as the stratum has not been regularly monitored**

Each stratum (except AlbjornLing, see Figure 1.7.2.2) is small enough to be covered during daylight in one day with a survey coverage = $N/\sqrt{A}$of about 7, where N is the added length of all transects through the square and A is the area of the square which is suggested to give a reasonable high precision (Aglen 1989). Each stratum is covered by standard parallel or zig-zag transects (Figure 1.7.2.2). Zig-zag design is used mainly in elongated strata. For both types of design each transect is defined as a primary sampling unit (PSU) (Jolly and Hampton 2000; Simmonds and MacLennan 2005). Based on abundance of sandeel observed during the first coverage, and thereby the variance, many of the strata are covered twice. The transects of the second coverage are typically in-between the transects of the first coverage (see Figure 1.7.2.2).

Acoustic identification of sandeel

Sandeel form schools when they are out of the sand, and the survey program has developed methods to identify the acoustic backscattering of sandeel based on their acoustic frequency responses (Figure 1.7.2.4) measured at 18, 38, 120, and 200 kHz (see Johnsen *et al.* 2009 for details). Therefore, all surveys have been carried out with research or fishing vessel equipped with retractable keels with scientific SIMRAD EK18, 38, 120 and 200 kHz mounted in accordance with the settings suggested by Korneliussen *et al*. (2008) (Figure 1.7.2.3).

Figure 1.7.2.3. Mounting of EK 18, 38, 70, 120, 200 and 333 kHz echo sounders on the drop keel of RV G.O. Sars.

For many of the surveys, also 70 and 333 kHz echo sounders have been mounted on the drop-keels and used in the surveys. Pulse duration for all frequencies was 1.024

ms and a ping repetition frequency of typically 3-4 Hz was chosen to maximize the number of echoes from small sandeel schools. The acoustic EK60 recordings were interpreted using Large Scale Survey System (LSSS) (Korneliussen *et al*. 2016), where the acoustic backscattering densities of sandeel expressed as nautical area scattering coefficients (NASC, $m^2nmi.^{-2}$) (MacLennan *et al*. 2002) is stored in a database by a horizontal resolution of 0.1 nmi. for all frequencies.

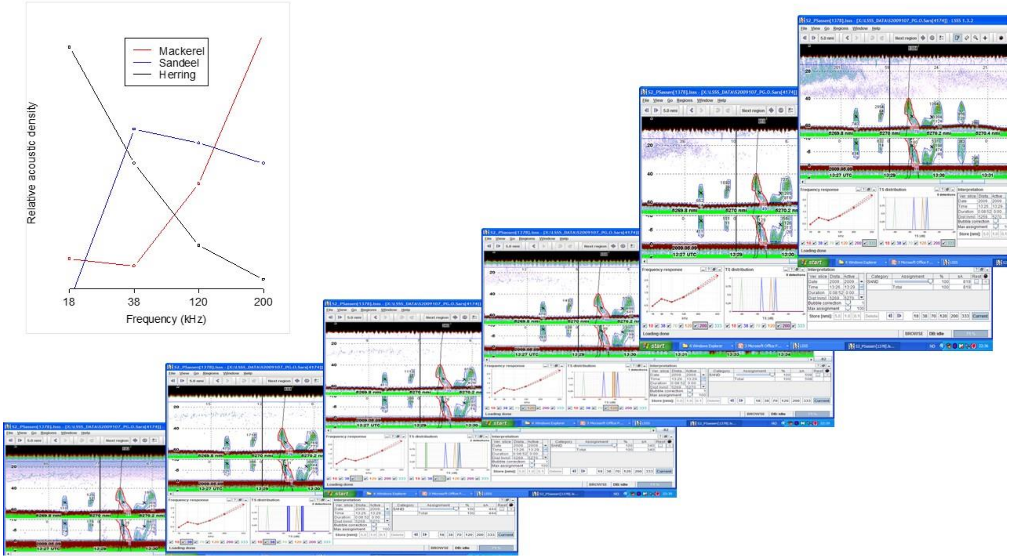


Figure 1.7.2.4. Identification of sandeel schools using different echo sounder frequencies. Difference in acoustic frequency response between mackerel, sandeel, and herring is shown in top left panel.

Biological sampling

At night, the biological sampling is carried out by using dredges and occasionally grabs (Johnsen and Harbitz 2013). Biological sampling at daytime is mainly done by demersal trawling (sometimes pelagic trawling) on observed schools. To explore if sandeel is burrowed in the sand at daytime, dredges are used in the same positions as high catches of sandeel has been taken during the previous night. These dredge samples show that sandeel very seldom occur in the sand during daytime in the survey period. The catch is sorted to species (if the catch is large, only a sub-sample is sorted). For each station, if the catch is large, the lower total length (0.5 cm intervals) and weight is measured for 100 individuals per sandeel species. If the number of individuals is lower, all individuals are measured. Otoliths are taken and stomach fullness observed from the first 25 individuals of the length samples. Aging is carried out during the surveys by experienced age readers.

Converting acoustic backscatter to abundance

The conversion of mean NASC by PSU (transect) (*i*) to abundance by stratum followed a standard procedure where trawl and/or dredge stations were assigned to PSUs. Typically, as the strata are very small all transects within the same stratum had the same biostation assignments. This procedure is now also implemented for many of the acoustic surveys in the North Sea and Norwegian Sea (WGIPS).

The abundance of sandeel by length group (*l*) for each stratum (*k*) was estimated as:

$$\boldsymbol{N_{l,k} = \frac{A_k \sum_{i=1}^{n} L_i \rho_{i,l}}{\sum_{i=1}^{n} L_i}}$$

where *L* is the length of transect *i* and *A* is the area in stratum *k*, and the areal density of fish (n per nmi.^{2}) in length group *l* in transect *i* is:

$$\boldsymbol{\rho_{i,l} = \frac{NASC_{i,l}}{\sigma_l}}$$

and *NASC* of length group *l* is:

$$\boldsymbol{NASC_{i,l} = NASC_i \frac{\sigma_{l,p}}{\sum_l \sigma_{l,p}}}$$

and the backscattering cross-section at length *l* multiplied by the proportion (*p*) of fish of length *l* in the total length distribution is:

$$\boldsymbol{\sigma_{l,p} = \sigma_l p_l}$$

and the acoustic backscattering cross-section (m^2) for a fish of length *l* is:

$$\boldsymbol{\sigma_l = 4\pi 10^{\left(\frac{TS_l}{10}\right)}}$$

and the target strength of a fish with length *l* (cm) is:

$$\boldsymbol{TS_l = m \log_{10}(l) + a}$$

where *m* and *a* are constants in the empirical target strength versus length formula for the species and the given frequency. Different target strengths have been tested (Kubilius & Ona 2012), but the results presented in this WD have used a TS = 20 log L - 93 (Simmonds and MacLennan 2005) for 38 kHz.

To convert abundance by length group to abundance by age, an imputation process is carried out to fill missing age values by random selected aged individuals of the same length group sampled at the same station. If there are no aged individuals for the length group at station level, there is a search for aged individuals in the same stratum; if no individuals are found at stratum level, there is search in all individuals sampled in the survey area. If still no aged individuals are found, the age will stay unknown.

To estimate the mean and variance of the sandeel density (by length) and age we use the methods established by Jolly and Hampton (1990) and implemented in the software StoX (http://www.imr.no/forskning/prosjekter/stox/en). For details regarding the estimation procedure in StoX see : ftp://ftp.imr.no/StoX/Documentation/StoX%20reference%20guide%2020161003.docx

Survey effort and internal consistency

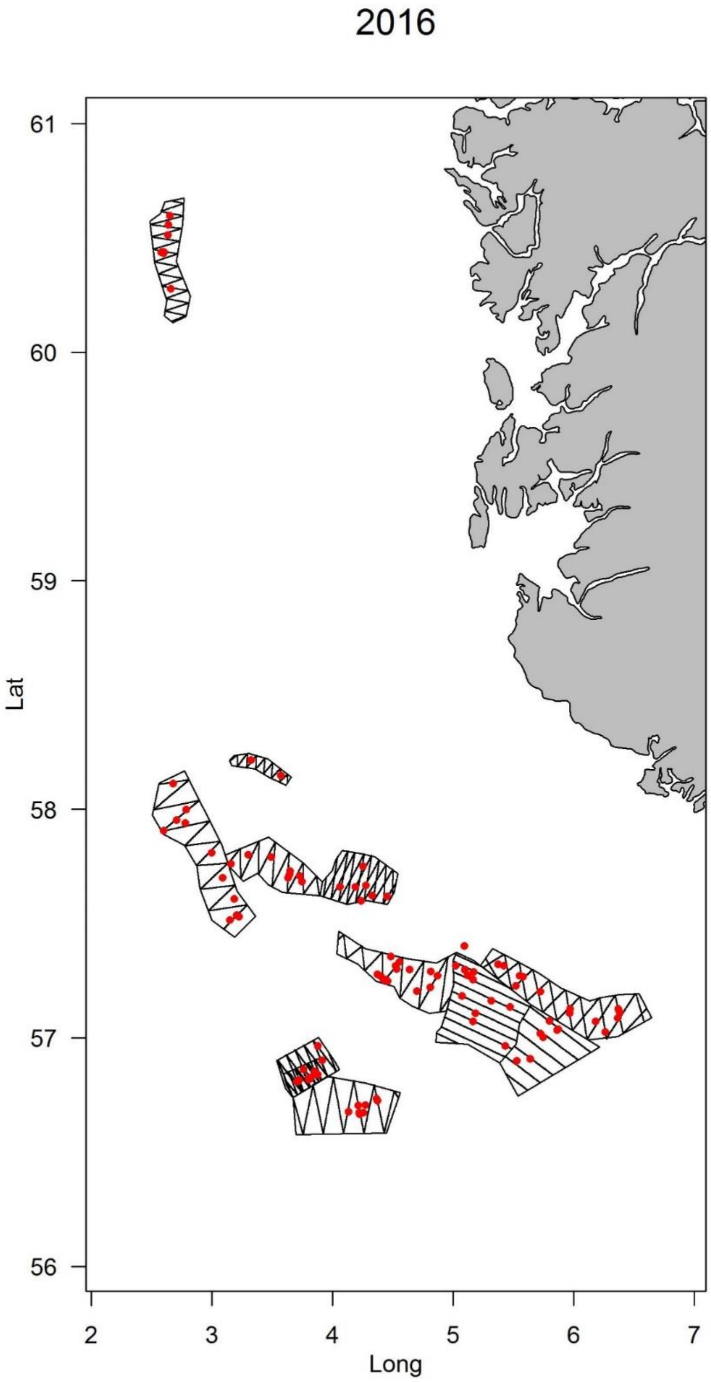
The survey effort is presented in Table 1.7.2.2. The survey effort has been high and relatively constant between years (Figure 1.7.2.5)

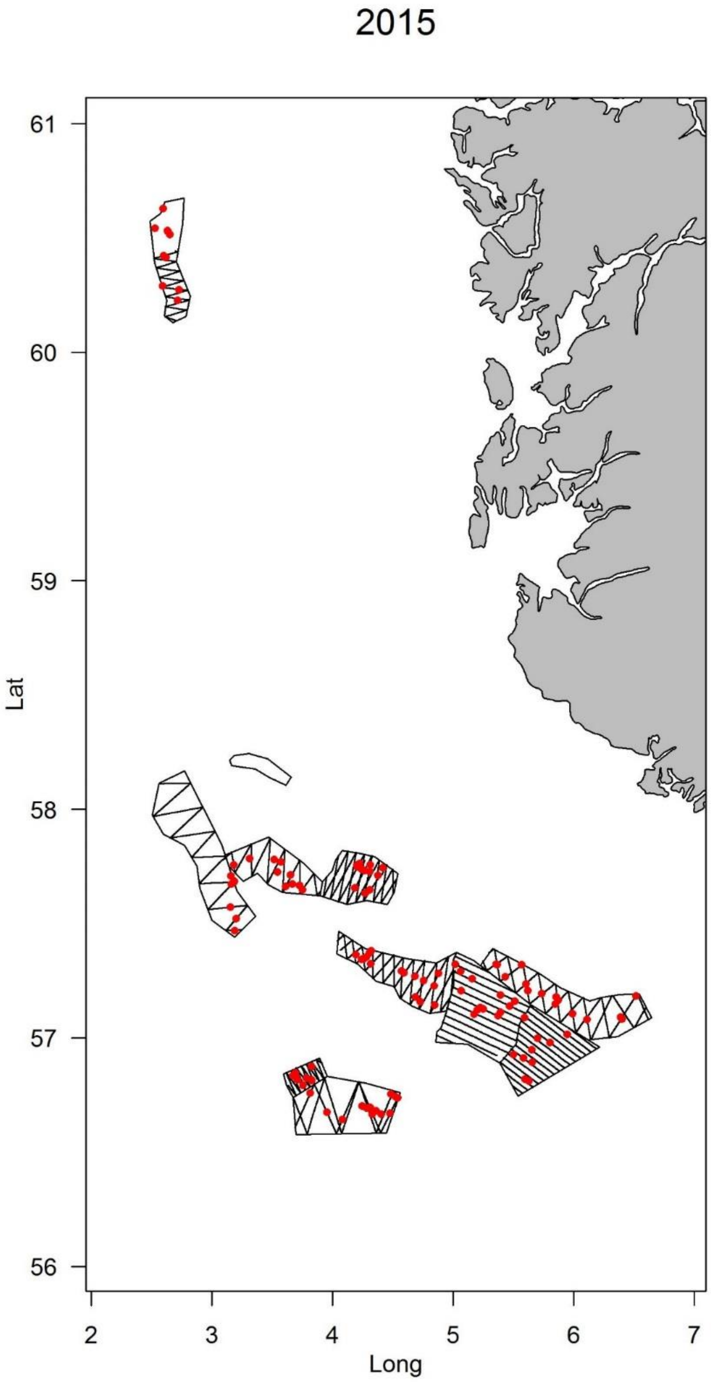
Table 1.7.2.2. Sailing distance (nmi.), number of transects and number of trawl, dredge and grab stations combined.

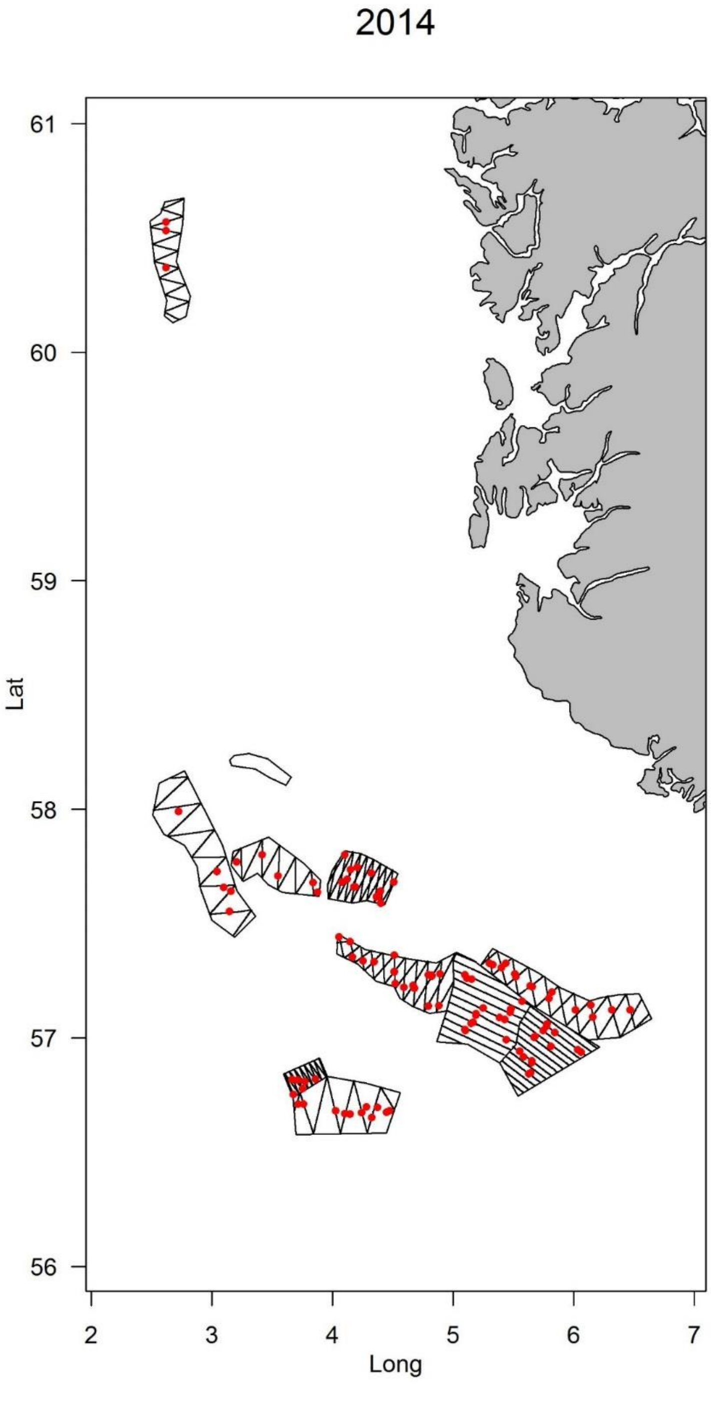
Assessment area	Year	Sailing distance	# transects	# stations
3	2009	824.4	115	122
	2010	967	120	136
	2011	931.1	114	77
	2012	1282.5	148	84
	2013	997.9	116	87
	2014	1216.5	131	111
	2015	1258.2	144	109
	2016	1210.9	139	98
5	2009	66.1	8	6
	2010	36.4	8	3
	2011	64.4	13	2
	2012	73.3	14	3
	2013	130.9	22	16
	2014	79	15	3
	2015	64.1	15	10
	2016	105.1	20	7

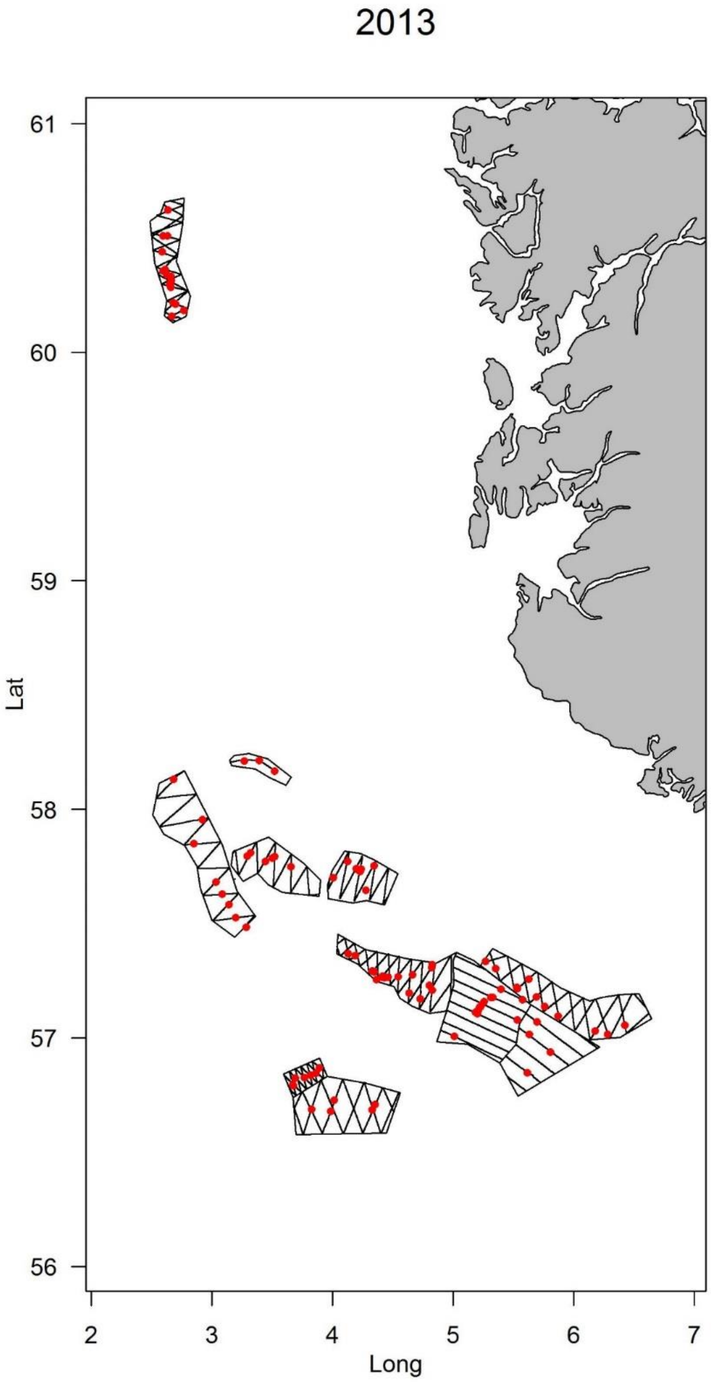
The survey coverage has been good in sandeel assessment area 3 for the period 2009-2016, and the survey abundance index by age and year show that large differences in recruitment of age 1 between years, where the 2009 and 2013 year classes are very strong as age 1 (Annex 2 WD 05).

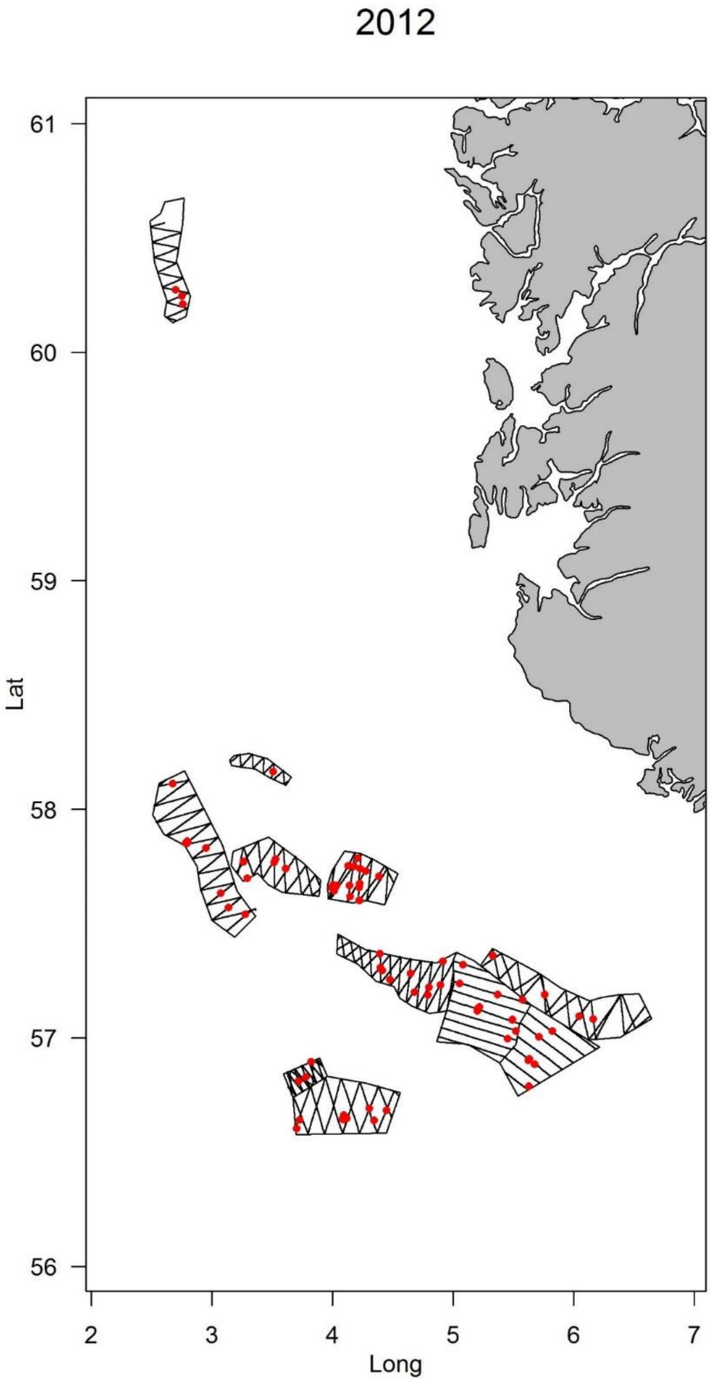
The internal consistency, i.e. the ability of the survey to follow cohorts, was evaluated for the survey in SA3 by plotting the abundance index of an age group in a given year versus the catch rates of the next age group in the following year. The survey abundance indices show high internal consistency, and track the development in cohorts well (Figure 1.7.2.6) (See Annex 2 WD 05).

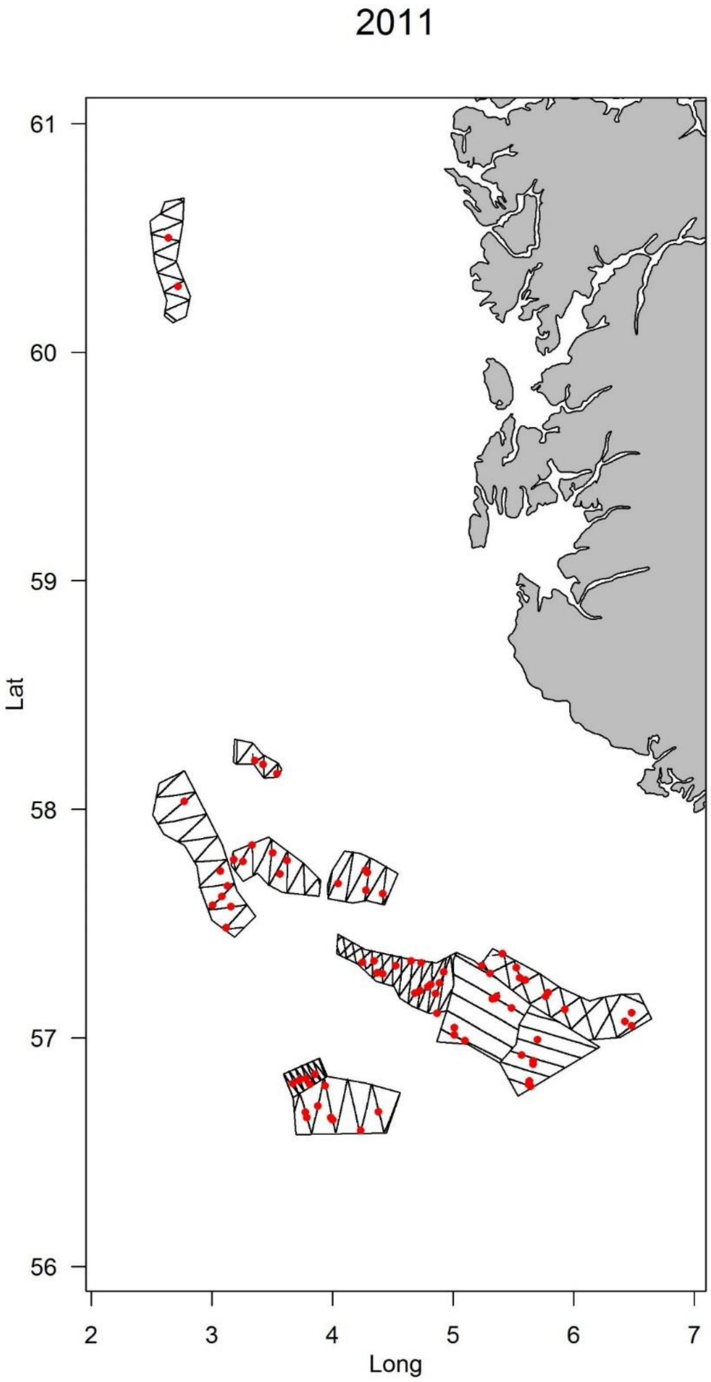

2016
Lat
Long
61
60
59
58
57
56
2
3
4
5
6
7


2015
61
60
59
58
57
56
Lat
2
3
4
5
6
7
Long


2014
61
60
59
58
57
56
Lat
2
3
4
5
6
7
Long


2013
61
60
59
58
57
56
Lat
2
3
4
5
6
7
Long


2012
61
60
59
58
57
56
Lat
2
3
4
5
6
7
Long


2011
Lat
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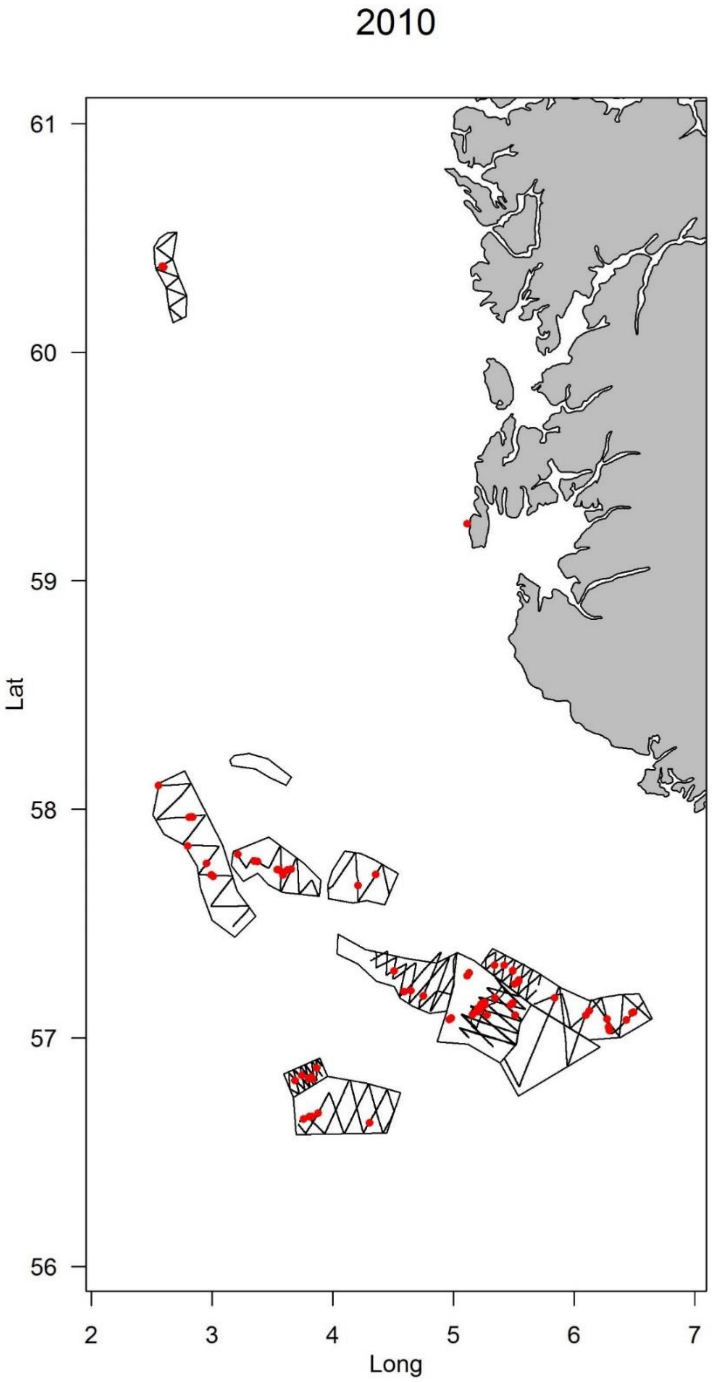
2010
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Long
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2
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6
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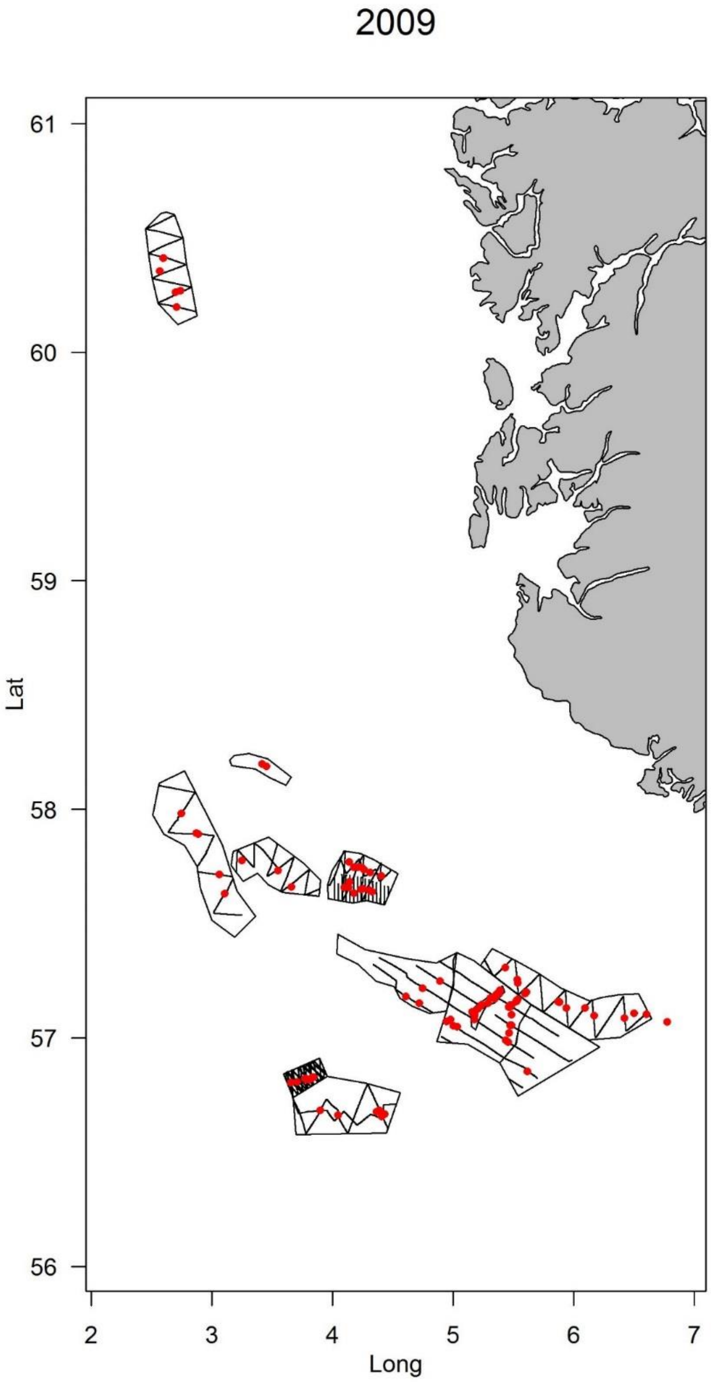

Figure 1.7.2.5. Transects (black lines) and biological stations (red dots) by acoustic survey. The polygons show the strata.

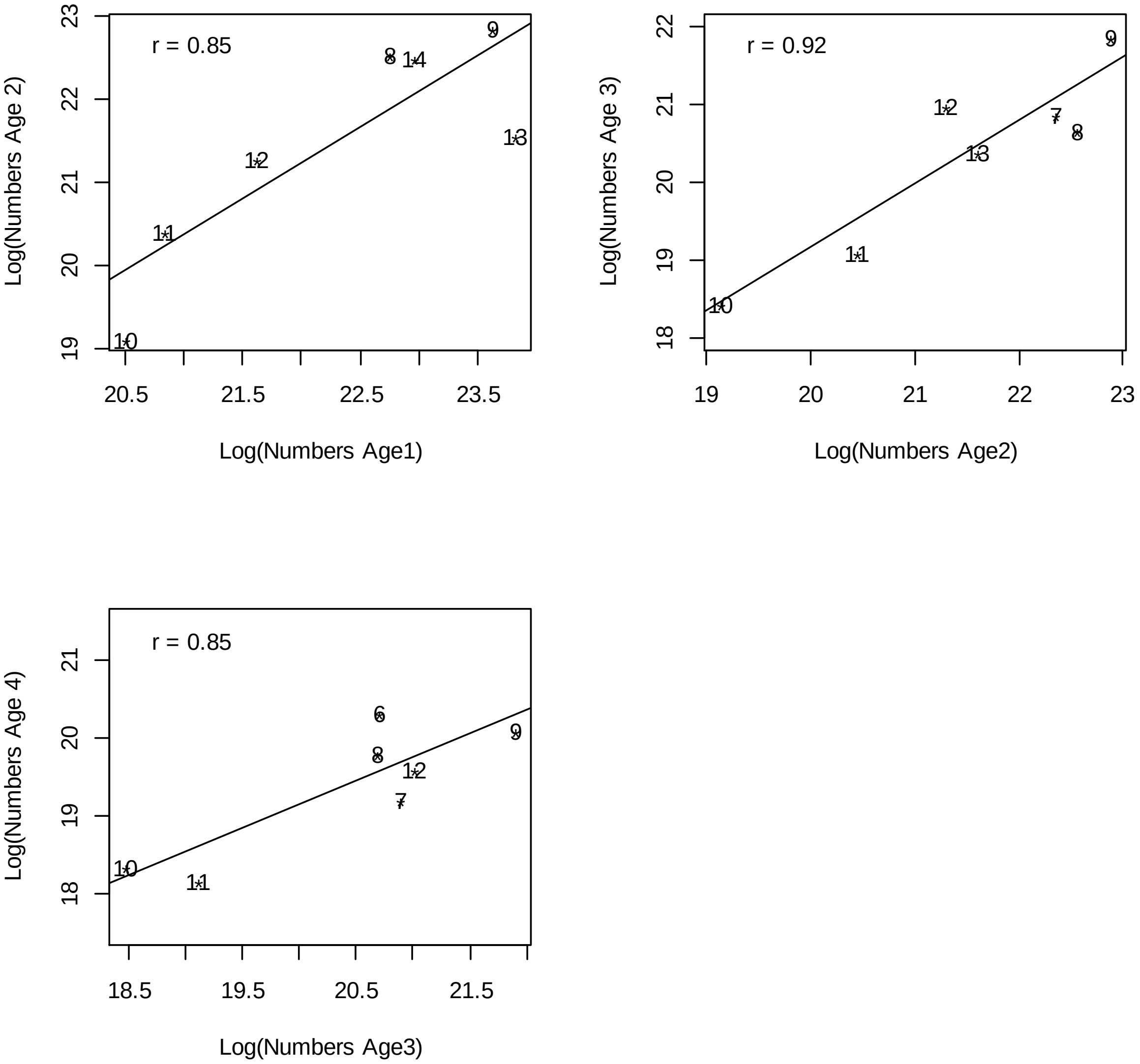

Figure 1.7.2.6. Internal consistency of the acoustic survey abundance indices for SA3.

References

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Johnsen, E., Pedersen, R., Ona, E. 2009 Size-dependent frequency response of sandeel schools. ICES Journal of Marine Science 66:1100-1105.

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Jolly, G. M., & Hampton, I. 1990. A stratified random transect design for acoustic surveys of fish stocks. Canadian Journal of Fisheries and Aquatic Sciences *47*(7):1282-1291.

Korneliussen, R. J., Diner, N., Ona, E., Berger, L., Fernandes, P. G. 2008. Proposals for the collection of multifrequency acoustic data. ICES Journal of Marine Science: Journal du Conseil 65(6):982-994.

Korneliussen, R. J., Heggelund Y., Macaulaya G.J., Patel D, Johnsen E., Eliassen I. K., 2016. Acoustic identification of marine species using a feature library. Methods in Oceanography 17:187–205

Kubilius, R., Ona, E. (2012). Target strength and tilt-angle distribution of the lesser sandeel (Ammodytes marinus). ICES Journal of Marine Science: Journal du Conseil, 69(6), 1099-1107.

MacLennan, D. N., Fernandes, P. G., Dalen, J. 2002. A consistent approach to definitions and symbols in fisheries acoustics. ICES Journal of Marine Science: Journal du Conseil, 59(2):365-369.

1.8 Maturity

At the last benchmark, it was decided to use annually varying maturities. This benchmark, average maturities were used as no trends were observed in maturity in any of the areas and no analyses documented relationships between maturity and stock size or weight at age.

1.8.1 Estimates of main mortality sources and sensitivity of the estimated mortalities to assumptions on overlap with mackerel

The WGSAM implementation of the SMS model (WGSAM 2013) includes sandeel as two stocks, northern sandeel and southern sandeel. This spatial split is similar to the stock definition applied in the single species assessment before 1996 (ICES 1995; 1996). Specific details on the model can be found in WGSAM (2013) and in the SMS method description, Annex 2 WD 06.

The SMS estimate of predation mortality (M2) of both sandeel stocks is high especially for the younger ages. Southern sandeel have historically had lower predation mortalities than the northern stock, though this pattern seems to change and from around 2010 onwards, the mortalities are comparable in the two areas. For the southern stock (Figure 1) mackerel, whiting and seabirds are the main predators, while haddock, saithe, whiting and grey seals are the main predators for the northern stock (Figure).

Mackerel (combined North Sea and Western components) is the major predator on southern sandeel, with rather high partial mortalities in all quarters. Even in quarter 1 and quarter 4 where age 1+ sandeel are in the sediment the majority of the time, M2 from mackerel is high. This may be due to the method SMS uses to estimate M2. For mackerel eating sandeel, the food suitability of sandeel is the product of $\text{vulnerability}_{\text{predator, prey}}$, $\text{sizePreference}_{\text{predator, prey}}$ and $\text{overlap}_{\text{predator, prey, quarter}}$. Due to the limited number of mackerel stomachs the “overlap” is assumed to be the same for all quarters, which leads to a potential biased (too high) M2 for quarter 1 and 4, and a biased (too low) M2 for quarter 2 and 3 where sandeel is available for the pelagic mackerel. The vulnerability and size preference parameters are estimated by the model.

Stomach contents data used by SMS (Figure 1.8.1.2.1) show that sandeel is not observed in the stomachs in quarter 1, but for quarter 4 a small proportion of the diet of both North Sea and Western mackerel consists of southern sandeel.

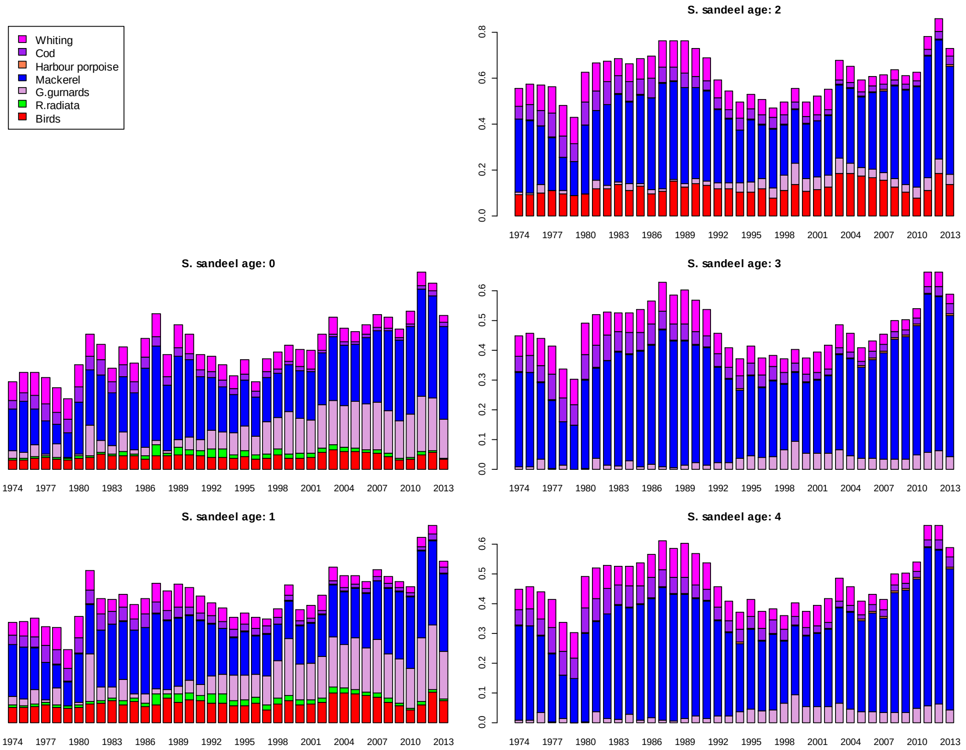


Figure 1.8.1.1 Partial annual predation mortality (M2) of southern sandeel.

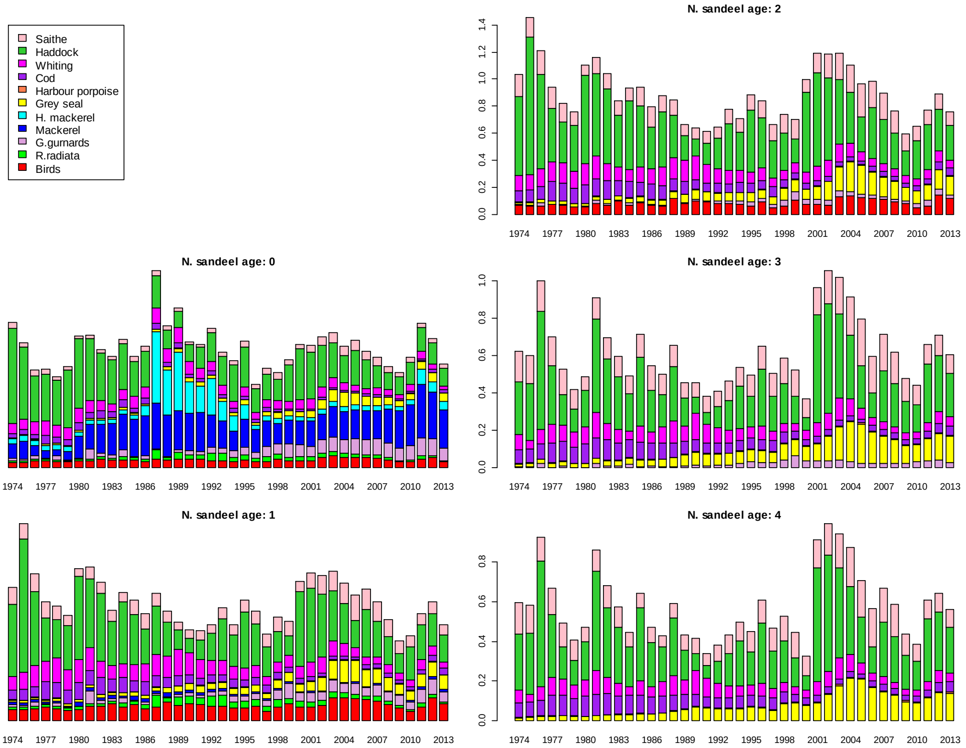


Figure 1.8.1.2. Partial annual predation mortality (M2) of Northern sandeel.

1.8.1.1 Method

The predator prey overlap, as applied in the default SMS configuration uses a fixed spatial overlap as shown below:

North Sea mackerel	Northern Sandeel	Southern Sandeel
Q1	1	1
Q2	1	1
Q3	1	1
Q4	1	1
Western mackerel		
Q1	1	1
Q2	1	1
Q3	1	1
Q4	1	1

Hence, the predator prey overlap is assumed constant across all quarters.

Three different methods were tried to investigate the potential bias in M2 of sandeel introduced if the assumption on overlap is not correct.

Method 1

North Sea mackerel	Northern Sandeel	Southern Sandeel
Q1	1	1
Q2	a	a
Q3	a	a
Q4	1	1
Western mackerel		
Q1	1	1
Q2	a	a
Q3	a	a
Q4	1	1

This option reflects the assumption that sandeel is mainly available to a pelagic predator in the sandeel feeding season (quarter 2 and 3) and that the predator prey "overlap" is independent of mackerel and sandeel stock. The parameter a is estimated within the model resulting in a=1.48, which can be interpreted as the sandeel becomes more available to mackerel (has a higher "overlap") in quarter 2 and 3 compared to the rest of the year.

Method 2

North Sea mackerel	Northern Sandeel	Southern Sandeel
Q1	1	1
Q2	a	b
Q3	a	b

Q4	1	1
Western mackerel		
Q1	1	1
Q2	a	b
Q3	a	b
Q4	1	1

This option assumes a similar temporal shift in "overlap" as method 1, but the overlap is prey species dependent. The parameters a and b are estimated within the model resulting in a=20 and b=1.16. The a parameter is constrained by an upper value (20). For Northern sandeel the "overlap" is thereby 20 times higher in the sandeel feeding period compared to the dormant period. For southern sandeel the "overlap" is similar for all quarters.

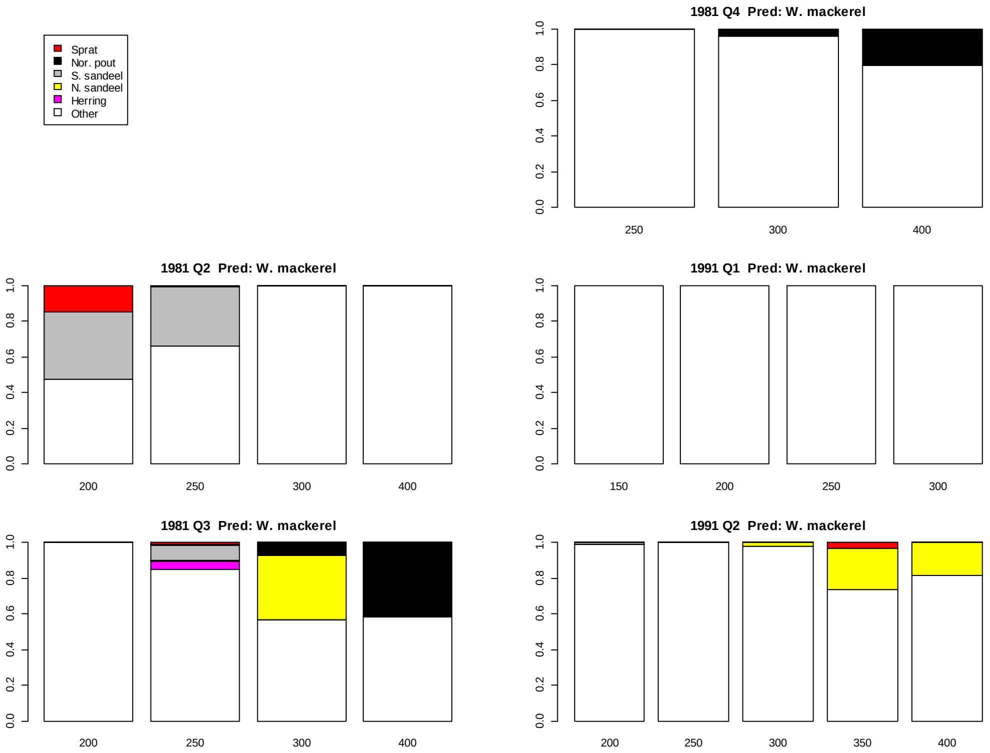
Method 3

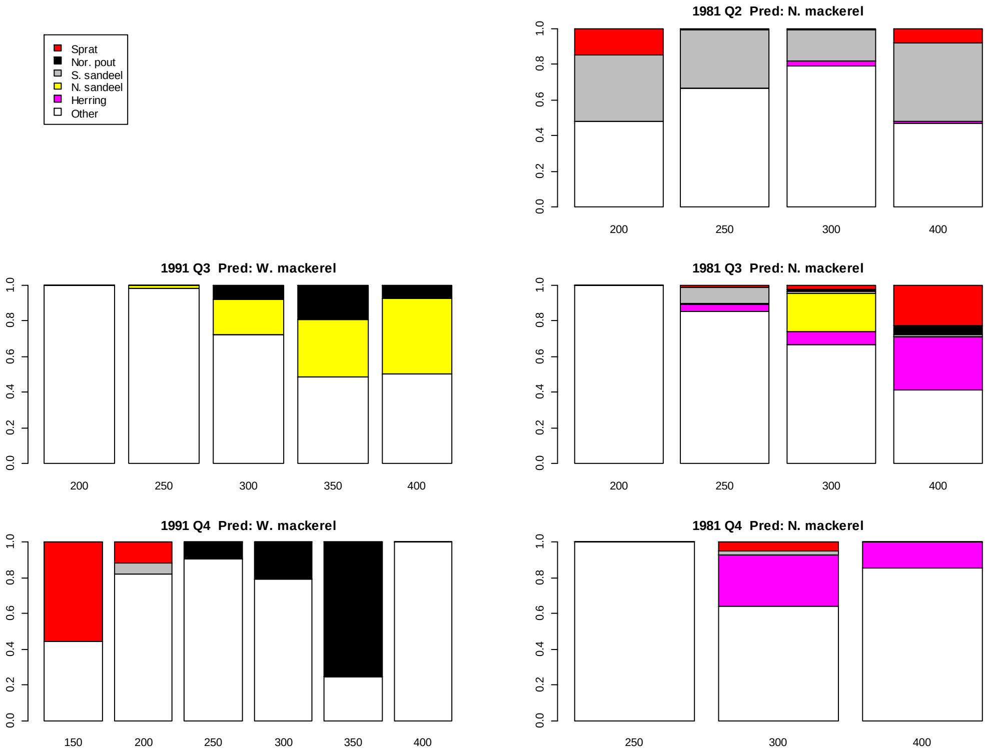
North Sea mackerel	**Northern Sandeel**	**Southern Sandeel**
Q1	0.01	0.01
Q2	10	10
Q3	10	10
Q4	1	1
Western mackerel		
Q1	0.01	0.01
Q2	10	10
Q3	10	10
Q4	1	1

This option assumes a similar temporal shift in "overlap" as method 1, but the "overlap" is assumed known. As no sandeel has been observed in the diet in quarter 1 this "overlap" is set to a very low number (0.01). The option assumes that the "overlap" is ten times higher in the feeding season compared to quarter 4.

1.8.1.2 Results

Estimated M2 for the four methods for predator prey overlap are almost identical (Figure 1.8.1.2.1 and Figure 1.8.1.2.2). Even for method 3 with very low spatial overlap between mackerel and sandeel in quarter 1, the partial predation mortalities are similar to the default method. Such very robust M2 indicates that catch and survey information influence most the overall model fit, while the fit of observations of mackerel eating sandeel hardly changes the estimated predation mortalities.


Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Other
1981 Q4 Pred: W. mackerel
250
300
400
1981 Q2 Pred: W. mackerel
200
250
300
400
1991 Q1 Pred: W. mackerel
150
200
250
300
1981 Q3 Pred: W. mackerel
200
250
300
400
1991 Q2 Pred: W. mackerel
200
250
300
350
400
0.0
0.2
0.4
0.6
0.8
1.0


Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Other
1981 Q2 Pred: N. mackerel
200
250
300
400
1991 Q3 Pred: W. mackerel
200
250
300
350
400
1981 Q3 Pred: N. mackerel
200
250
300
400
1991 Q4 Pred: W. mackerel
150
200
250
300
350
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1981 Q4 Pred: N. mackerel
250
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400
0.0
0.2
0.4
0.6
0.8
1.0

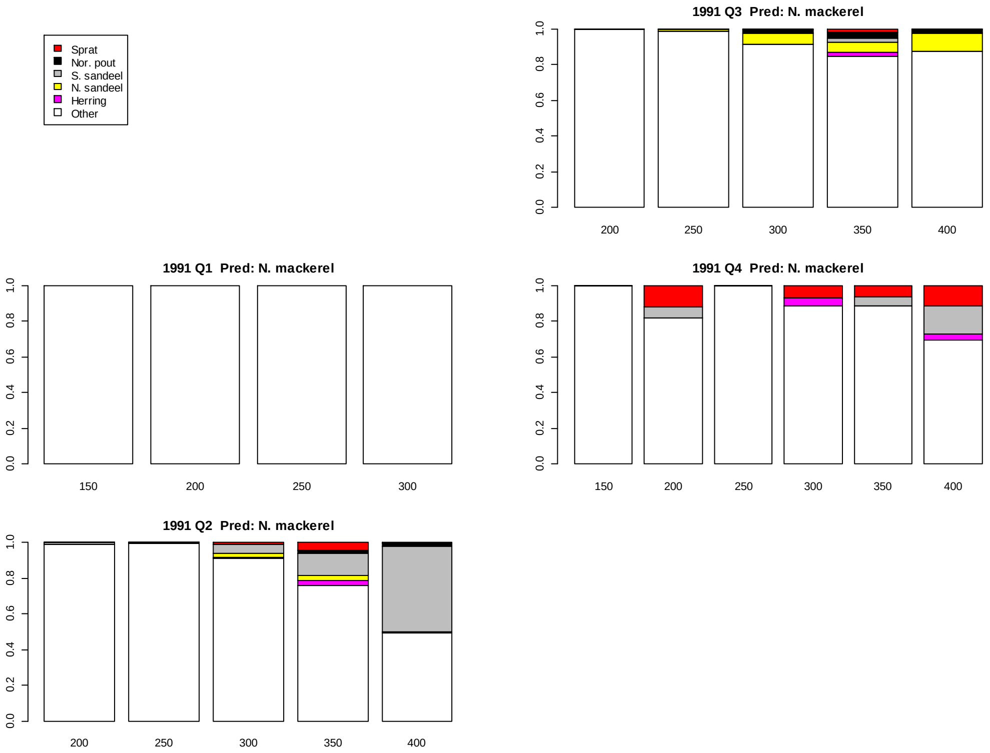

Figure 1.8.1.2.1. Relative observed stomach contents of North Sea, and Western stock mackerel, by year, quarter predator and predator size class

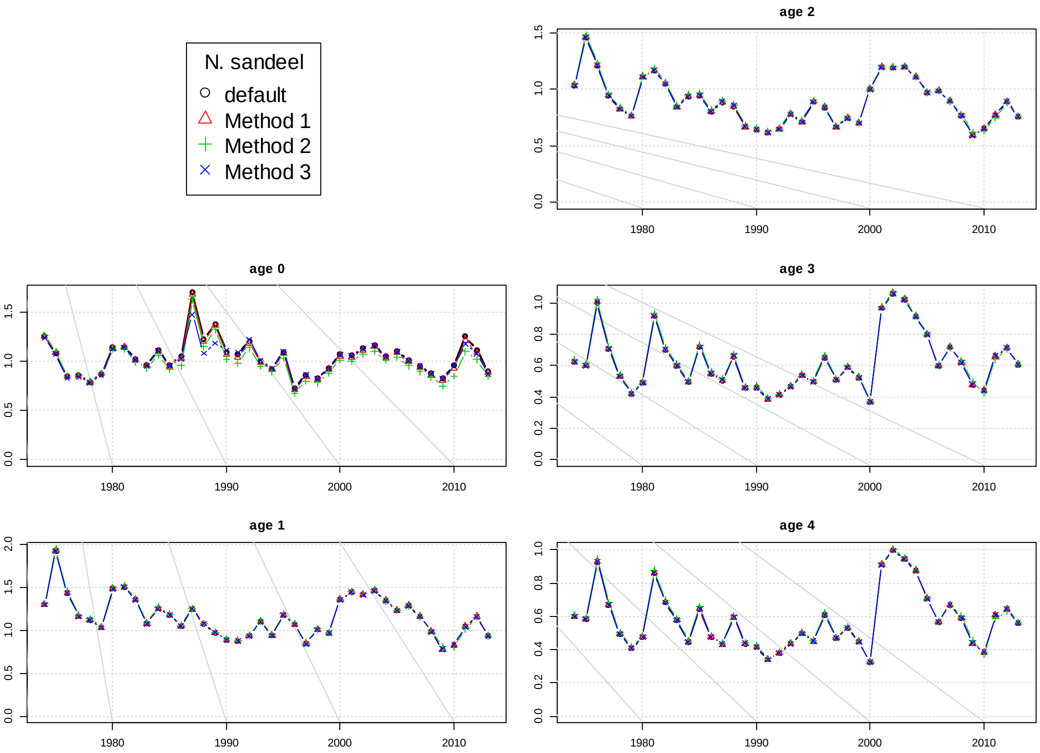

Figure 1.8.1.2.2. Predation mortality by age and year estimated by 4 methods for predator prey overlap.

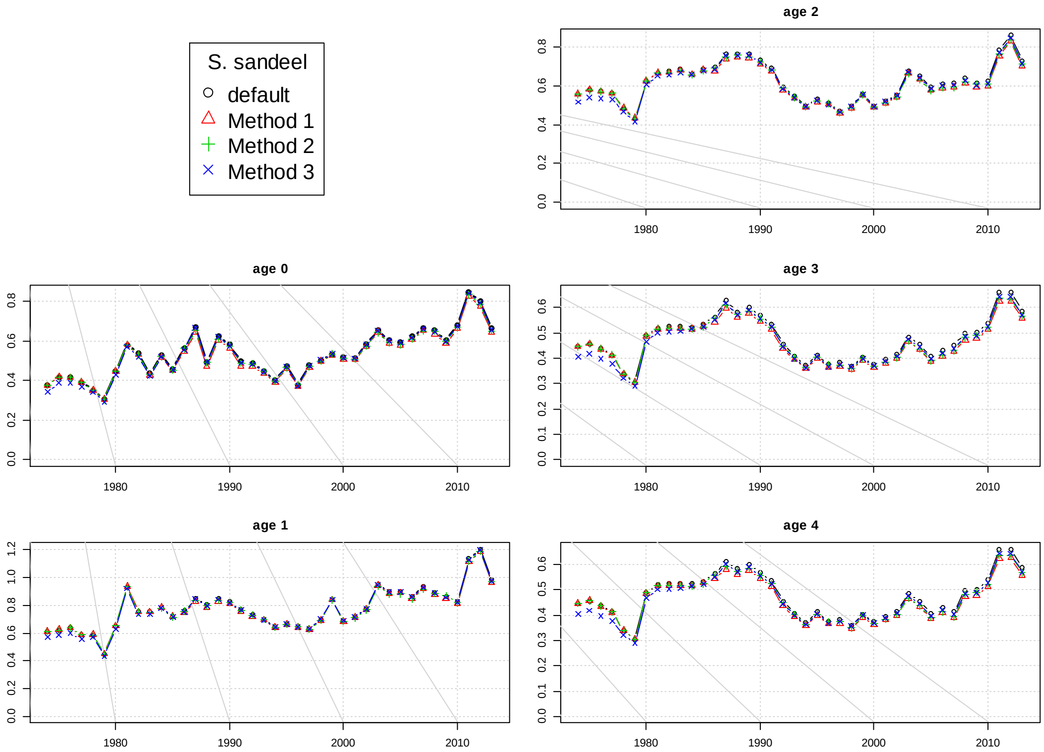

Figure 1.8.1.2.3. Predation mortality by age and year estimated by 4 methods for predator prey overlap.

1.9 Changes in SMS estimates of M in different WGSAM key runs

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 1.9.1 and Table 1.9.1).

Table 1.9.1. 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.

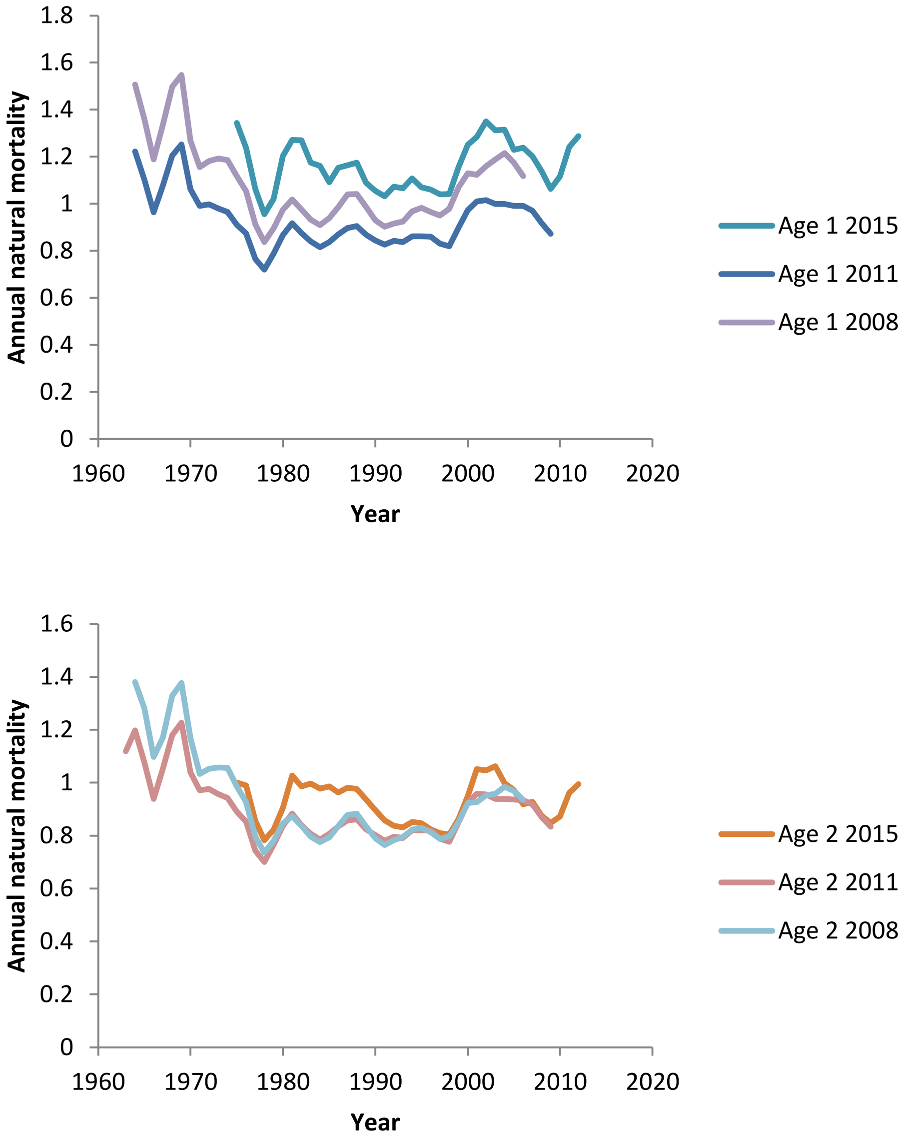

Figure 1.9.1. Estimates of annual natural mortality based on 2008, 2011 and 2015 key runs of the multispecies model SMS (WGSAM 2008, 2011, 2014 and 2015). The values of the 2015 key run are derived as the average of northern and southern areas, weighted by the abundance of the age group in the beginning of the year.

1.10 Natural mortalities modified for inclusion in assessment

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 halfyear. Figure 1.10.1 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 northen 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 1.10.1). 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.

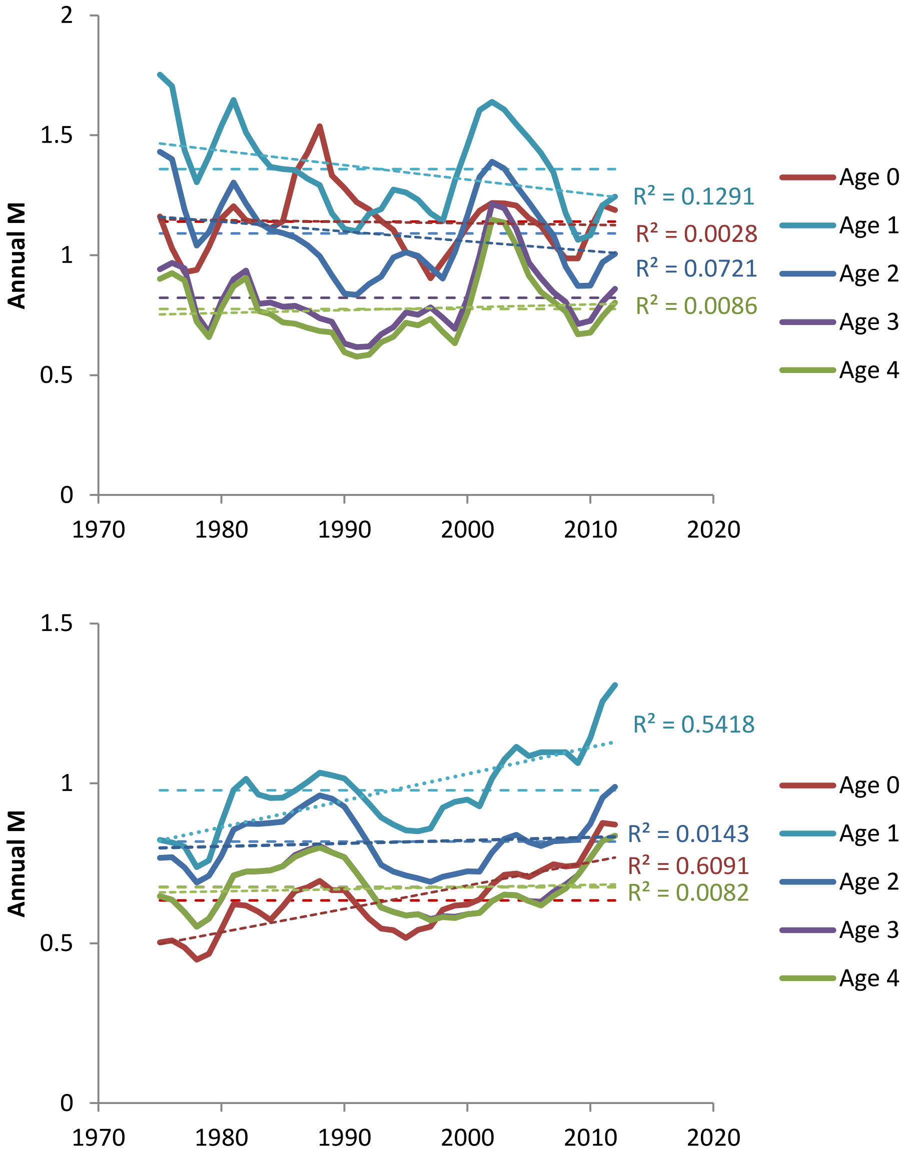

Figure 1.10.1. Estimated annual M in the northern (top) and southern (bottom) sandeel stock. Averages over the entire time period are shown at broken lines, trends as dotted lines.

Table 1.10.1. 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%

Given all this information, it was decided to use 3-year average values of natural mortality at age in the areas 1, 3, 3a and 3b while areas 2 and 4 used long term average M at age for the southern and northern North Sea, respectively and area 2+3b used averages across the time series and North Sea (weighted values by the number of fish at age in each of the northern and southern components).

1.11 References

ICES 1995. Report of the working group on the assessment of Norway pout and Sandeel. ICES C.M.1995/Assess:5

ICES 1996. Report of the working group on the assessment of demersal stocks in the North sea and Skagerrak. ICES CM 1996/Assess:6

ICES 2008. Report of the Working Group on Multispecies Assessment Methods (WGSAM). ICES CM 2008/RMC:06

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ICES 2015. Report of the Working Group on Multispecies Assessment Methods (WGSAM). ICES CM 2015/SSGEPI:20

1.12 Weight at age

Weight at age in the stock is estimated as weight at age in the catch (see under commercial data series).

1.13 Weight at age

Weight at age in the stock is estimated as weight at age in the catch (see under commercial data series).

1.14 Commercial data

1.14.1 Age composition and mean individual weight

1.14.1.1 Data available

Data available 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. 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; see Figure 4.2.1).

$$W = aL^b$$

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 and that no differences in age reading existed.

1.14.1.2 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 4.1.1). 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 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.

1.14.1.3 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 1.14.1.3.1). 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 1.14.1.3.2), 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 1.14.1.3.1. Aggregation levels for age-length keys and length distributions. For sandeel sampling areas see Figure 4.1.2.

Level	Space	Time
1	Square	Jan–Feb, March, April (1–15),April (16–30), May (1–15), May (16–31), June (1–15), Jun (16–30), July, Aug, Sep–Oct, Nov–Dec
2	Sandeel sampling areas within asesment areas(Figure 1)	Jan–Feb, March, April (1–15),April (16–30), May (1–15), May (16–31), June (1–15), Jun (16–30), July, Aug, Sep–Oct, Nov–Dec
3	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), Jun (16–30), July, Aug, Sep–Oct, Nov–Dec
4	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
5	Sandeel assessment areas	Jan–Mar, April–May, June–Aug, Sep–Dec
6	Sandeel assessment areas	Jan–June, July–Dec
7	All areas together	Jan–June, July–Dec
8	All areas together	Jan–Dec

Table 1.14.1.3.2. Aggregation levels for estimating the number of sandeel per age per kg. For sandeel areas, see Figure 4.1.2.

Level	Space	Time
1	Rectangle	Jan–Feb, March, April, May, June, July, Aug, Sep–Oct, No Dec
2	Sandeel sampling areas within asessment areas(Figure 1)	Jan–Feb, March, April, May, June, July, Aug, Sep–Oct, No Dec
3	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, No Dec
4	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
5	Sandeel assessment areas	Jan–Mar, April–May, June–Aug, Sep–Dec
6	Sandeel assessment areas	Jan–June, July–Dec
7	All areas together	Jan–June, July–Dec

1.14.1.4 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 1.14.1.4.1 and Table 1.14.1.4.1. and total effort in figure 1.14.1.4.2 and Table 1.14.1.4.2.

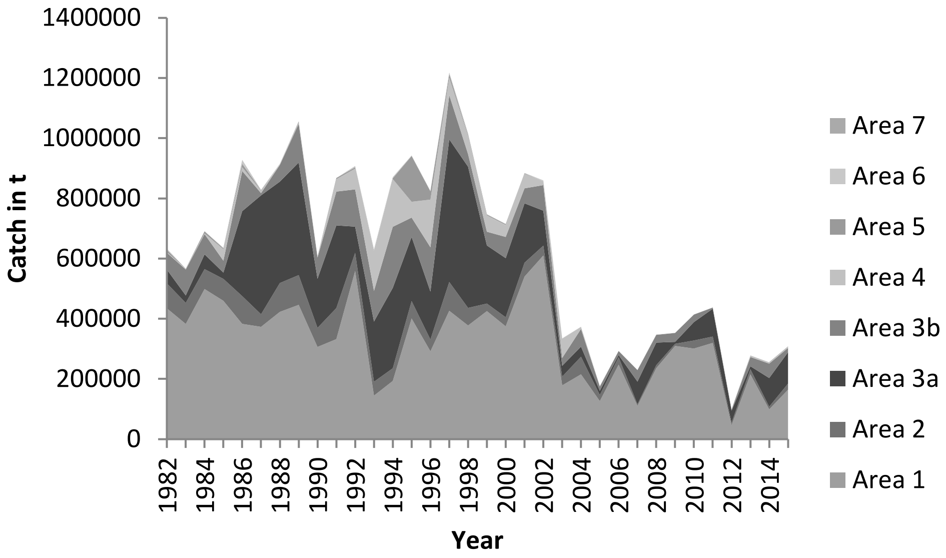


Figure 1.14.1.4.1. Total annual catch in each area.

Table 1.14.1.4.1. Total annual catches by area.

YEAR	AREA 1	AREA 2	AREA 3A	AREA 3B	AREA 4	AREA 5	AREA 6	AREA 7
1982	434401	82940	45648	55959	2406	7393	3698	0
1983	382629	69945	24828	86262	2782	0	364	0
1984	498671	66187	49111	67211	2563	6565	791	0
1985	459489	72900	20859	39557	38122	3004	1927	0
1986	382844	92294	282334	133288	12718	11277	13219	0
1987	373021	41786	395298	7281	8154	1713	1163	0
1988	422805	95893	336919	55650	1338	0	2726	0
1989	446129	98846	374252	128446	4384	3353	909	0
1990	306240	63313	163224	70544	3314	374	499	0
1991	332204	103136	274839	112430	41372	3697	17	0
1992	558602	60532	87022	123709	68905	4554	4277	0
1993	144370	46116	200123	101867	133136	666	4490	0
1994	193241	42099	267281	202844	158690	2762	3748	0
1995	400759	57846	213168	64309	52591	152274	1830	0
1996	291709	39151	159304	147309	158490	27571	1263	0
1997	426414	95700	474093	146980	58446	11689	2372	2143
1998	377473	58558	469183	41867	58746	2952	941	5121
1999	425272	25078	193093	45614	53334	145	132	4415
2000	374692	30093	196572	70456	37792	324	683	4350
2001	540074	46055	197308	49951	47918	1678	306	971
2002	610123	32729	116310	84833	12761	8	2386	453
2003	178412	29122	35965	25967	64048	44	900	187
2004	215188	58459	33658	58543	6882	0	573	0
2005	126190	20384	13994	14256	1557	0	259	0
2006	247510	24773	7094	13179	55	0	161	0

2007	110389	5236	75391	38166	11	4	652	0
2008	235559	10144	74992	25501	1168	0	472	0
2009	309591	7070	6362	29639	0	0	260	0
2010	300893	26754	61243	24886	275	0	132	0
2011	319656	21048	92452	3850	272	0	484	0
2012	46117	8240	40123	2838	2585	0	0	0
2013	214981	17201	9844	30646	5225	0	90	0
2014	98732	8929	95223	47886	4414	0	0	0
2015	164027	20321	104236	14376	4384	0	0	0

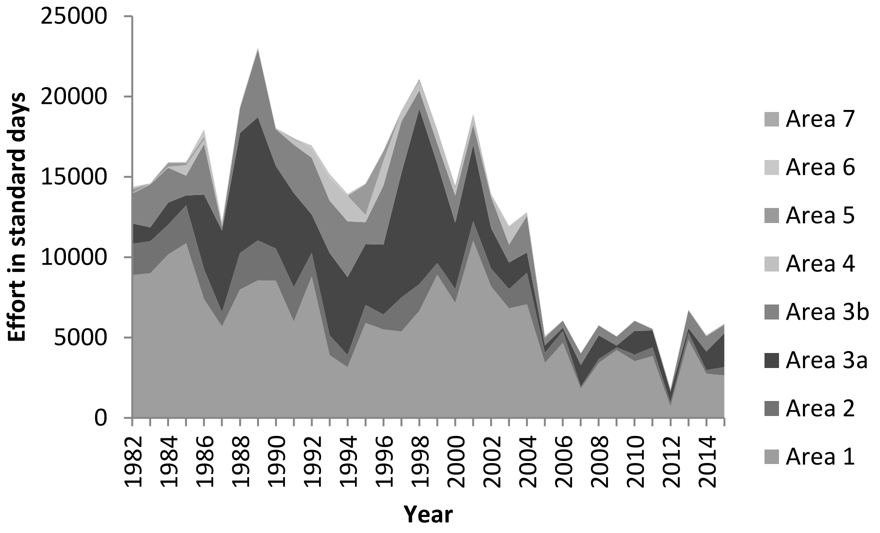


Figure. 1.14.1.4.2. Total effort by area

Table 1.14.1.4.2. Total annual catches by area.

YEAR	AREA 1	AREA 2	AREA 3A	AREA 3B	AREA 4	AREA 5	AREA 6	AREA 7
1982	8880	1951	1267	1857	37	242	142	0
1983	8992	1998	864	2670	64	0	9	0
1984	10166	1855	1378	2169	49	249	50	0
1985	10862	2359	618	1232	655	139	65	0
1986	7373	1878	4642	3146	284	164	468	0
1987	5682	884	5095	252	177	64	45	0
1988	7982	2269	7473	1539	42	0	90	0
1989	8552	2486	7676	4214	55	40	44	0
1990	8526	2006	5142	2285	57	0	24	0
1991	5990	2140	5863	3009	335	62	1	0
1992	8804	1467	2383	3531	570	0	198	0
1993	3892	1241	5123	3255	1387	8	266	0
1994	3148	751	4853	3475	1591	0	114	0
1995	5897	1125	3790	1361	450	1914	50	0
1996	5495	932	4351	3678	1529	604	48	0

1997	5364	2125	7747	3201	630	0	60	4
1998	6660	1660	10920	1132	610	94	26	0
1999	8907	731	6169	1265	856	0	1	0
2000	7148	864	4123	1697	421	5	16	148
2001	11030	1209	4756	1250	669	0	2	0
2002	8172	1119	2516	1934	141	1	65	0
2003	6811	1200	1654	1115	1090	19	47	0
2004	7060	1967	1265	2276	208	0	27	0
2005	3416	626	468	487	88	0	10	0
2006	4670	737	201	441	2	0	4	0
2007	1814	122	1349	721	1	0	14	0
2008	3414	236	1481	614	9	0	12	0
2009	4206	171	119	563	0	0	8	0
2010	3524	408	1479	623	2	0	9	0
2011	3835	541	1057	88	9	0	14	0
2012	708	245	682	93	80	0	0	0
2013	4832	463	289	1106	44	0	8	0
2014	2740	225	1165	944	60	0	0	0
2015	2632	520	2118	522	50	0	0	0

1.14.1.5 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.

1.14.1.6 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 1.14.1.6.1).

Table 1.14.1.6.1. 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

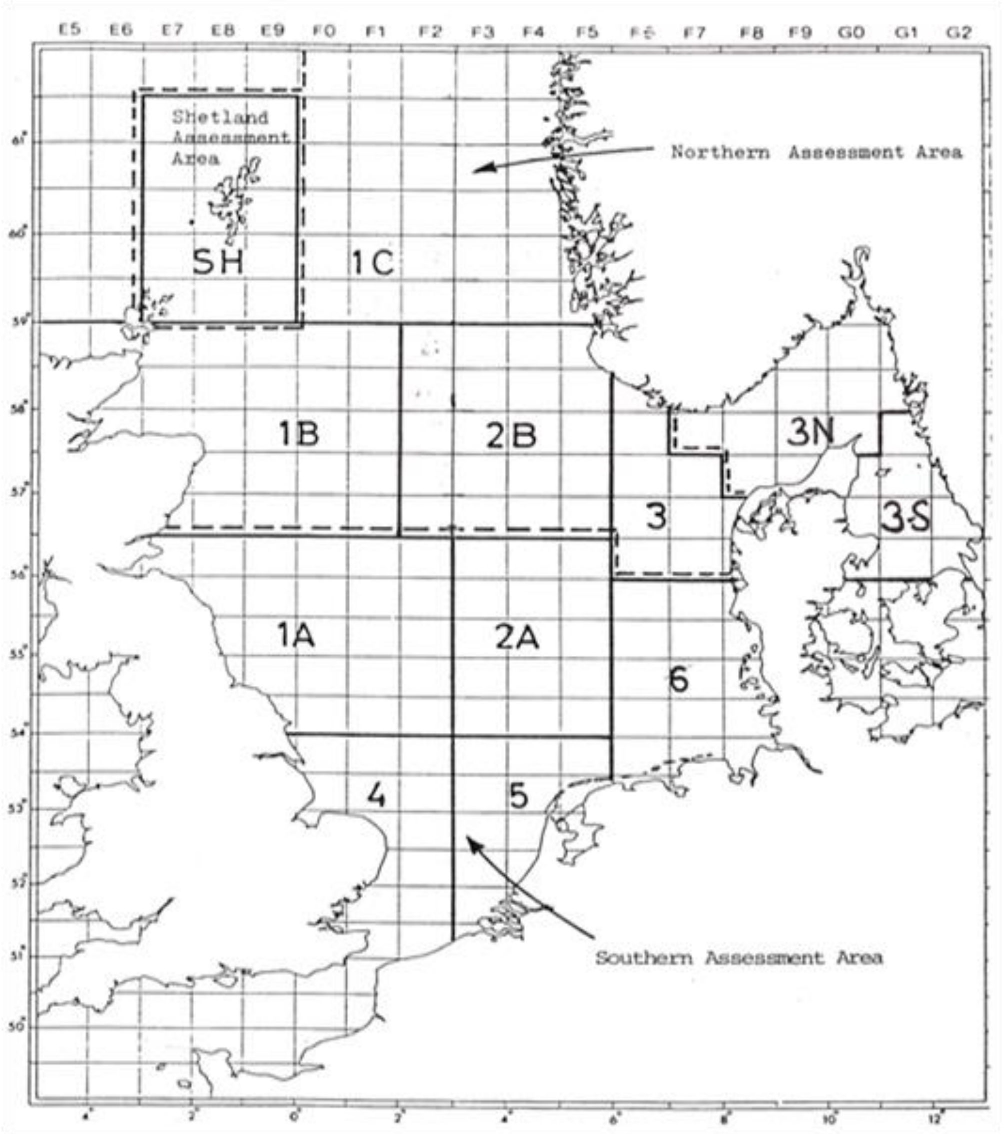


Figure 1.14.1.6.1. Historical Sandeel sampling areas used. The areas are identical to the sampling areas given in the report of the working group on the assessment of Norway pout and sandeel (ICES C.M. 1995/Assess: 5) except that the original areas 1C and 2c are joined to one and the border between area 1B and 2B has been moved 1oW. This border was moved to avoid dividing a fishing ground into two.

1.14.2 Effort time series

Estimates of standardized fishing effort are used as input in North Sea sandeel assessment models where it is assumed that fishing mortality is proportional to effort. More generally, the assumption is that on a given day t, fishing mortality F is

$$F_t = \sum_i q_{t,i} E_{t,i}$$

Where $E_{t,i}$ is effort of vessel i on day t and $q_{t,i}$ is a catchability coefficient. Often, catchability is assumed to be constant over time and vessels. However, in the case of sandeel, we know that catchability varies with vessel size and that the size composition of the fleet has changed over time. In this case, it is preferable to standardise effort to a particular vessel size for which catchability can be assumed constant over time.

1.14.3 Input data

Two sources of data were used, output of the 2016 assessment for Area 1, and individual logbook records from Denmark (1982–2015) and Norway (2011–2015). The Danish data were re-extracted for the benchmark to change the previous praxis of using integer (rounded) fishing days to now using reported fishing days in decimal numbers. Fishing days are indicated in logbooks together with catches in specific statistical squares.

1.14.4 Standardising effort with respect to vessel size

We used the general relationship between vessel size *V* and catchability apparent from logbook data:

$$CPUE_{t,V} = q_0 \left(\frac{V}{V^*} \right)^b B_t$$

where V^* is a standard vessel size. In this case, q_0 denotes the catchability of a standard vessel and is thus independent of changes in size composition in the fleet, B_t is biomass and $CPUE_t$ is catch per unit effort:

$$CPUE_{t,i} = \frac{C_{t,i}}{E_{t,i}} = q_{t,i} B_t$$

Where C_t is total catch on that day.

Rearranging and using $F_t = \frac{C_t}{B_t} = q_t E_t$,

$$F_t = q_0 \sum_i \left(\frac{V}{V^*} \right)^b E_{t,i} \quad (1)$$

To obtain the total standardised effort ($\sum_i \left(\frac{V}{V^*} \right)^b E_{t,i}$) in a given time interval, it is thus necessary to know the size of each vessel, the number of days fished and the value of *b*. Vessel size can be measured in any desirable unit. In the case of sandeel, the units used have traditionally been gross tonnage *GT* or maximum KW of the vessel *KW*. KW was shown in the 2010 benchmark to be poorer related to catch rates than gross tonnage and is hence not examined further here.

1.14.5 Evidence of technical creep

Increasing fisheries efficiency over time (technical creep) means that a fishing day early in the time series is likely to induce a lower fishing mortality than a fishing day late in the time series. To accommodate this, the 2010 benchmark settings use three distinct periods, within each catchability is assumed to be constant: 1983–1988, 1989–1998, 1999 onwards. According to a simple analysis of input effort and output F from the 2016 assessment in Area 1 (Figure 1.14.5.1), a standardised fishing day in each of these three periods induces a fishing mortality of $0.69 \cdot 10^{-4}$, $0.96 \cdot 10^{-4}$ and $1.51 \cdot 10^{-4}$, respectively, corresponding to an increase of 39% and 57%, respectively, between periods. This corresponds to an increase over the full time period of 219% over a period of 34 years, hence an annual increase of 3.4%.

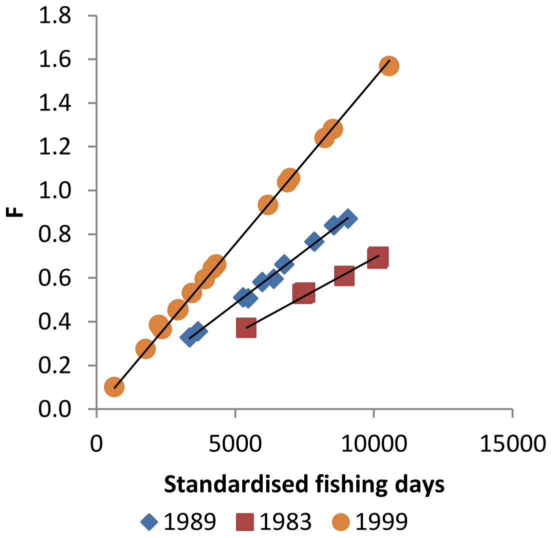


Fig. 1.14.5.1. Fishing mortality as a function of standardised fishing days. Data from Area 1 January 2016 assessment.

A second analysis examined whether there is evidence of abrupt or gradual changes in catchability. The analysis was performed using F estimated from an SMS model without effort divided by effort to derive catchability (Figure 1.14.5..2. Estimating the annual increase from this figure results in an average annual creep of 3.7%, though the development seems to have been more erratic in later years.

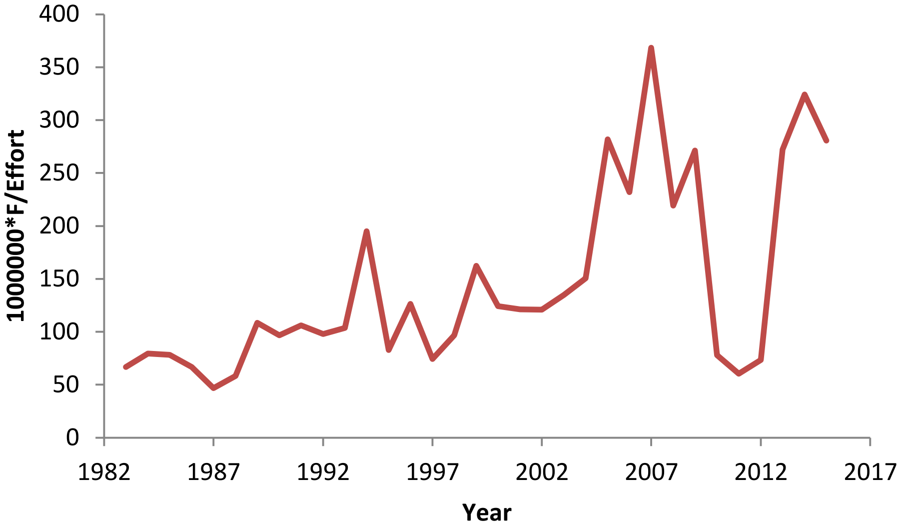


Figure 1.14.5.2. Temporal development in F/effort in area 1.

From both analyses, there seems to have been a substantial increase in catchability over the timer period, with the increase in catchability to the fishery. While they two analyses are not strictly independent, they both indicate an annual increase close to 3%. From the figures, it is not obvious whether this is most appropriately described as a step function or a gradual increase. For comparison, the average technical creep determined by Eigaard *et al.* across a range of fisheries was 3.2% (Eigaard *et al.*, 2014).

Finally, an analysis was performed using F estimated from an SMS model without effort divided by effort to derive catchability and relating this to TSB (Figure 1.14.5.3). This analysis was performed to investigate whether the temporal pattern could be caused by coinciding decreases in total stock biomass and a density dependent catchability to the fishery.

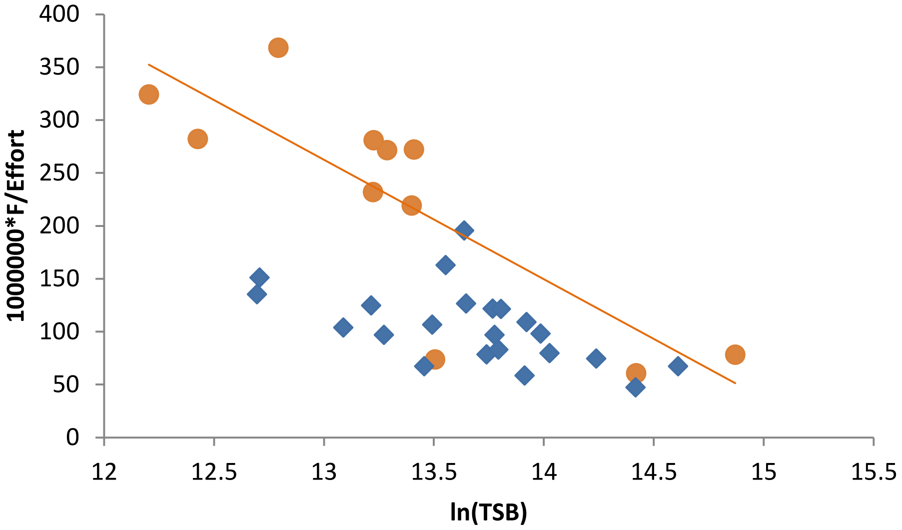


Figure 1.14.5.3. Evidence of density dependent catchability in area 1. Blue dots are years prior to 2005, orange dots are years from 2005 to 2015.

1.14.6 Estimating *b*

In order to estimate the vessel correction factor, several different methods have been suggested. The current method uses catches within the same rectangle, week and year to estimate an annual correction factor. Individual observations of catches by a single vessel are assumed to be similar to those taken by other vessels rather than similar for the specific vessel (no vessel effect). Other methods suggested have included vessel effects and a 'mixed' model to estimate the effect of square. Model improvements, if correct, should act to improve the estimate of the vessel correction factor.

Five effort data sets were produced:

- No standardization (simple sum of effort days per week and year) (summed days)
- Standardization to 200 GT using an annually estimated parameter *b* in a GLM for each year using fixed effects of square and week and ignoring vessel effects (method used since last benchmark)(Fixed 200 GT)
- Standardization to 400 GT using an annually estimated parameter *b* in a GLM for each year using fixed effects of square and week and ignoring vessel effects (Fixed 400 GT)
- Standardization to 200 GT using an annually estimated parameter *b* in a mixed model using mixed effects of square and week and vessel effects (mixed annual weekly)

- Standardization to 200 GT using an annually estimated parameter *b* in a mixed model using mixed effects of square and month and vessel effects (mixed annual monthly)
- Standardization to 200 GT using an common estimated parameter *b* in a mixed model using mixed effects of year, square and week and vessel effects in four separate periods (1982–1988, 1989–1998, 1999–2005, 2006–2016) (mixed periodic)

The standardizations were made using eq. 1 above. The parameter *b* for data set 2 and 3 was estimated using the model

$$\ln(\hat{CPUE}_{w,r,y,V}) = a_{w,r,y} + b_y \ln\left(\frac{V}{V^*}\right)$$

where indices *sq*, *w* and *y* denote square, week (Julian day of midpoint of trip/7) rounded to the nearest integer) and year, respectively, *V* is vessel size, $\hat{CPUE}_{w,r,y,V}$ is median CPUE in the given week, rectangle, and year for a vessel size of *V* and *a* and *b* are estimated using general linear models with normal error distribution. CPUE was estimated as catch per day fished and allocated for each day to the square where the majority of the catch was taken. Trips were allocated to the week where the start of the trip occurred.

For effort series 4, *b* was estimated in a mixed model using mixed effects of square and week and vessel effects but estimating all parameters separately for each year. The model was

$$\ln(\hat{CPUE}_{w,r,y,V}) = \varphi_{w,r,y} + \lambda_{vessel,y} + b_y \ln\left(\frac{V}{V^*}\right)$$

Where $\varphi_{w,r,y}$ and $\lambda_{vessel,y}$ are separate normal distributed parameters, each with a mean of 0.

For effort series 5, *b* was estimated in a mixed model using mixed effects of square and month and vessel effects but estimating all parameters separately for each year. The model was

$$\ln(\hat{CPUE}_{m,r,y,V}) = \varphi_{m,r,y} + \lambda_{vessel,y} + b_y \ln\left(\frac{V}{V^*}\right)$$

Where *m* denotes month, $\varphi_{m,r,y}$ and $\lambda_{vessel,y}$ are separate normal distributed parameters, each with a mean of 0.

For effort series 6, *b* was estimated in a mixed model using mixed effects of year, square and month and vessel effects and estimating all parameters for each of the periods 1982-1988, 1989-1998, 1999-2005 and 2006-2016. The model was

$$\ln(\hat{CPUE}_{m,r,y,V}) = \varphi_{m,r,y} + \lambda_{vessel} + b \ln\left(\frac{V}{V^*}\right)$$

Where $\varphi_{m,r,y}$ and $\lambda_{vessel}$are separate normal distributed parameters, each with a mean of 0.

1.14.7 Results

The parameter estimates of *b* are given in fig. 3. Apart from random variation, there seems to have been a trend in the effect of vessel size, with initially high values followed by low effects of vessel size in the 1990's and increasing effects in later years (fig. 3). The time series of effort are very similar between the different standardisation with the exception of the latest years in area 3 (Figure 1.14.7.1 and Table 1.14.7.1). The difference in these years arise from the fact that the difference in catch rate between Danish and Norwegian vessels is considered a fixed (but very poorly determined) effect in the fixed models but a random effect (and hence not corrected for) in the mixed models. Residuals were examined for signs of non-linearity in the relationship between *CPUE* and *V*, but no such signs were found. There was a tendency for overoccurrence of rather large negative residuals in all periods.

There appears to have been substantial changes in F/effort over the period. As a result, all models were subsequently tested for temporal variation in F/effort and it was decided only to use commercial tuning series such as RTM for a maximum of 10 years. Possibilities to correct for density dependent catchability within the model should be investigated.

Table 1.14.7.1. Correlation between effort time series produced by different models.

Area 1	Summed days	Fixed 200 GT	Fixed 400 GT	Mixed annual
Fixed annual	0.959			
Mixed annual	0.942	0.997	0.989	
Mixed periodic	0.954	0.995	0.994	0.994
Area 3				
Fixed annual	0.938			
Mixed annual	0.962	0.981	0.989	
Mixed periodic	0.970	0.983	0.981	0.999

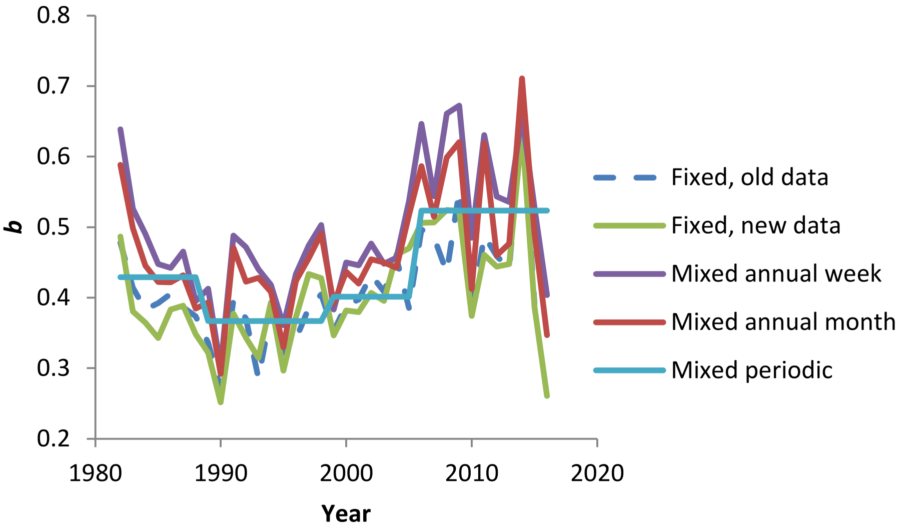
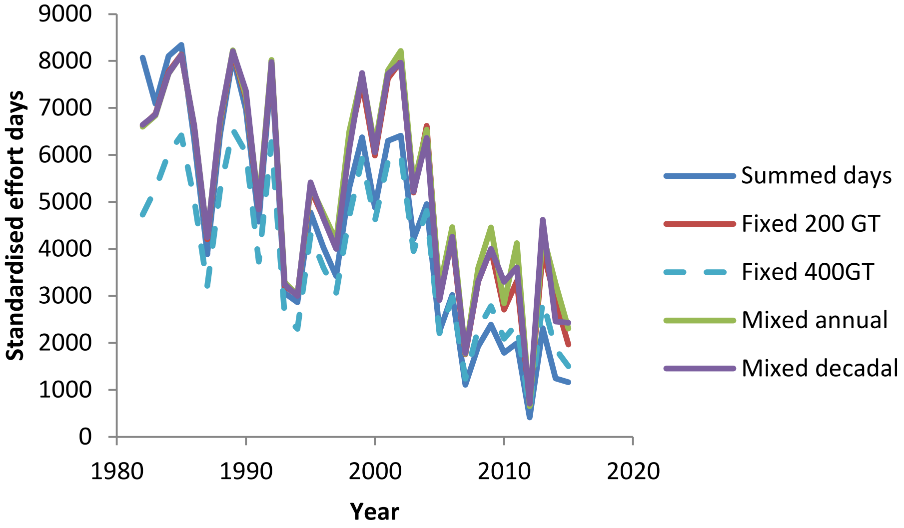


Figure 1.14.7.1. Temporal development in estimated *b* estimating together across all areas using different methods. 2016 includes data only from a very limited fishery.



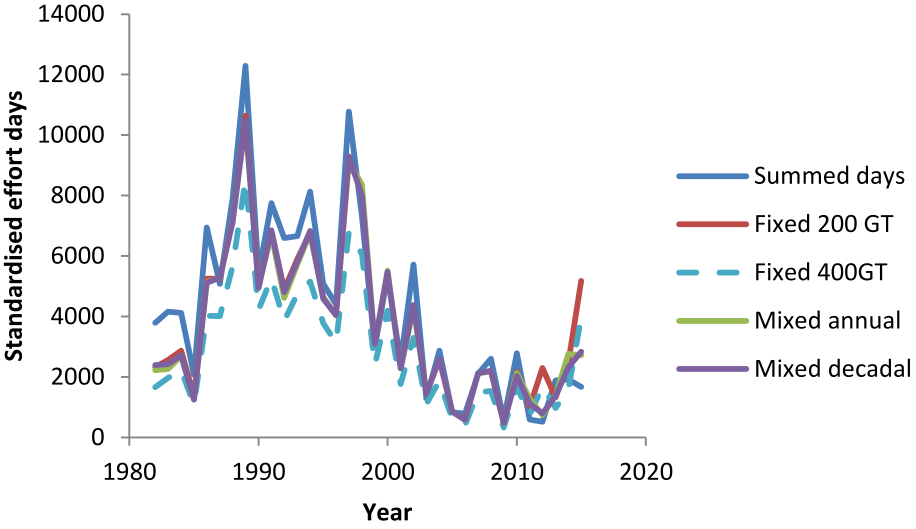


Figure 1.14.7.2. Temporal development in standardised effort using different methods. Area 1 (top) and area 3 (bottom)

1.14.8 References

Eigaard, O. R., Marchal, P., Gislason, H., & Rijnsdorp, A. D. (2014). Technological development and fisheries management. Reviews in Fisheries Science & Aquaculture, 22(2), 156-174

1.14.9 Real time monitoring

In the years from 2004 onwards, the sandeel catch advice was updated within the season based on catch rates in the commercial fishery in April. Originally initiated as a result of the perceived low security of the recruitment forecast, which was by then based on catch rates of 0-group sandeel in the 2nd half of the year, the method was continued even after the introduction of the dredge survey and the resulting much improved estimates of recruitment. 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.' (WKSAN, 2010). 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 aim of the RTM is to estimate stock abundance of sandeel from observations of catch per unit effort (CPUE) from the fishery early in the season (15 April to 6 May). This information is then used as a stock abundance index together with similar information for the period since 1999 as a 'survey' time series in the assessment, forming the basis for an updated TAC estimate after the completion of the RTM period.

This document outlines data and method used for the 2012 and 2016 RTM along with an investigation of the effect of spatial and temporal coverage of the RTM fishery on results.

1.14.9.1 Data and methods

Stock abundance 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:

$$\overline{CPUE} = \frac{1}{N}\frac{\sum_1^N Catch_i}{\sum_1^N Daysabsent_i * \left(\frac{GT_i}{200}\right)^{0.449}}$$

Where N is the number of trips, *Catch* is the catch in tonnes on a given trip, *Daysabsent* 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 Annex 2 WD 07. Effort (days absent), vessel GT and total catch weight of sandeel by trip are obtained from log book data extracted from the Danish AgriFish 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 (Figures 1.14.9.1.1 and 1.14.9.1.2) and shows a reasonable consistency between years (Figure 1.14.9.1.3). There is no trend in the relationship between dredge and RTM recruitment estimates.

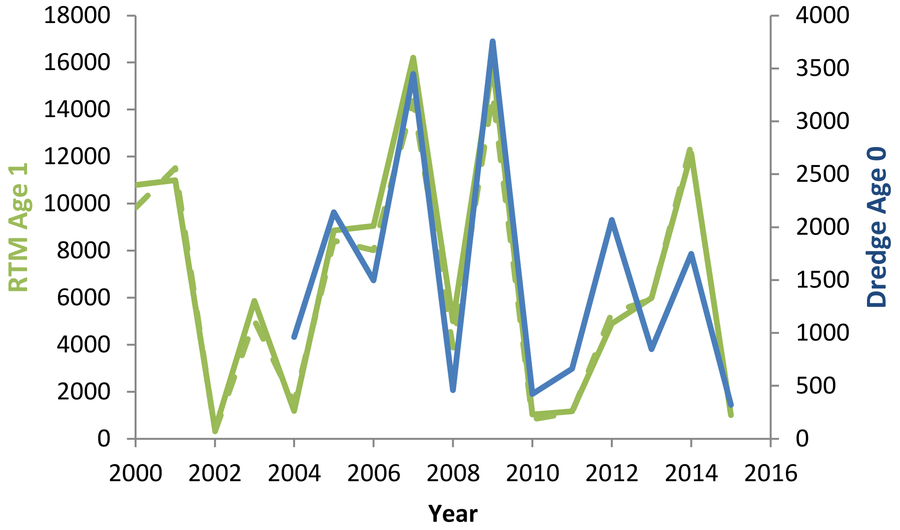


Figure 1.14.9.1.1. Temporal development RTM Age 1 and dredge Age 0 of the 2000 to 2015 cohorts. Solid green line denotes RTM April 15th to May 6th, hatched green line denotes RTM April 1st to May 6th, blue solid line is the dredge index. Years before 2000 had insufficient biological samples to use for the RTM time series.

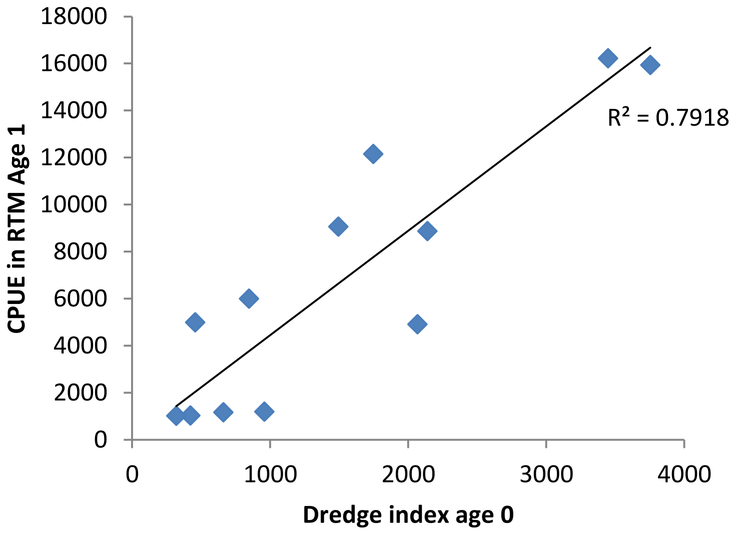


Figure 1.14.9.1.2. CPUE in the 2016 RTM period (15th April to 6th May) of the incoming yearclass (Age 1) as a function of the dredge index at age 0 of the same cohort.

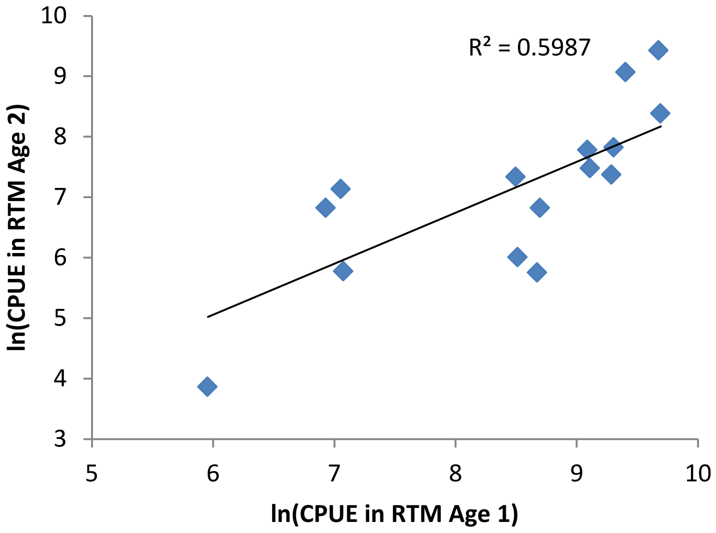


Figure 1.14.9.1.3. Internal consistency of the 2016 RTM series.

In 2012 and 2016, the default ICES assessment did not include the time series of CPUE in April. This lead to some minor differences between the assessment used for advice in the beginning of the year and the assessment used together with the RTM data.

Survey residuals for the Dredge survey in the 2012 RTM assessment showed a very similar picture compared to the default assessment (ICES 2012). The RTM index showed a good correlation between CPUE in April and year class strength. The CV of the catchability of the RTM age 1 index (0.32) was lower than the CV for the 0-group from the dredge survey (0.53).

Survey residuals for the Dredge survey in the 2016 RTM assessment showed a very similar picture compared to the default assessment (ICES 2016). The RTM index showed a good correlation between CPUE in April and year class strength. The CV of the catchability of the RTM age 1 index (0.36) was slightly higher than the CV for the 0-group from the dredge survey (0.30).

1.14.9.2 Effects of changes in spatio-temporal coverage of the fishery in the RTM period

To investigate whether specific demands should be made with respect to the spatial and temporal coverage of an RTM data series, the relation between the residual variation of a model describing CPUE by year, square, week and vessel size was investigated. Neither the residual variation nor the average catch rate was significantly related to the number of days fished in the RTM period (Figure 1.14.9.2.1, correlation 0.01 and 0.23, P=0.9607 and 0.2001). The same was true of the number of statistical rectangles fished in the RTM (Figure 1.14.9.2.2, correlation 0.08 and 0.29, P=0.6621 and 0.1063).

There was a clear tendency for greater variation in catch rates between rectangles in years with lower than average catch rates (Figure 1.14.9.2.3, correlation -.,56, P=0.0010). Three rectangles (39F1, 38F1 and 37F1, all at Dogger) are fished in all years except one (and this year only lacked data for 37F1). Using these rectangles only to estimate catch rates provides an index with a correlation of 0.81 (P<0.0001) with the index based on all rectangles.

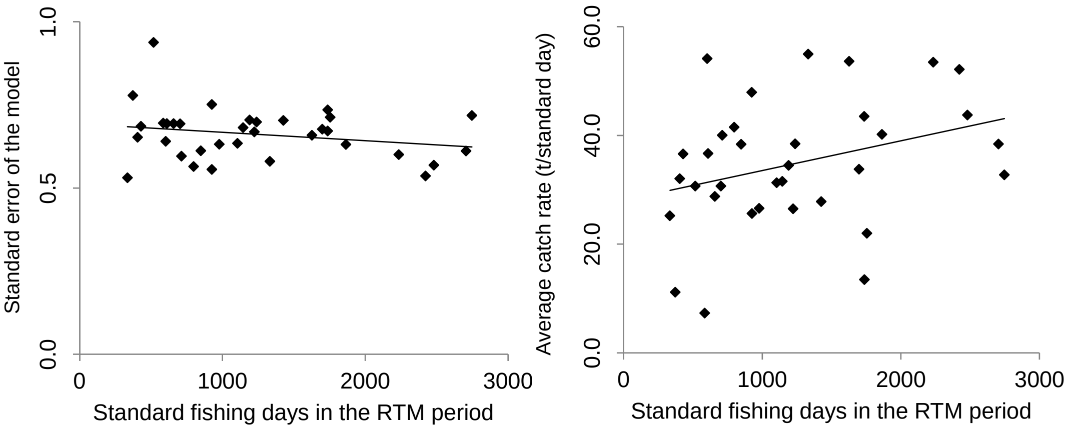


Figure 1.14.9.2.1. Standard error of the model used to estimate average catch and average catch rate as a function of the number of standard fishing days in the period. Note that the time period is longer than the RTM time series used above as the data above are restricted to years with sufficient age samples.

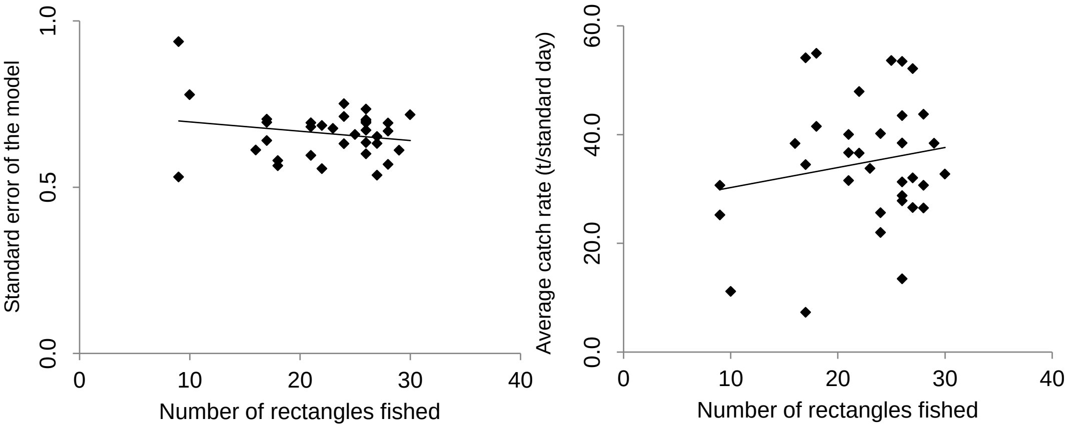


Figure 1.14.9.2.2. Standard error of the model used to estimate average catch and average catch rate as a function of the number of statistical rectangles fished in the RTM period. Note that the time period is longer than the RTM time series used above as the data above are restricted to years with sufficient age samples.

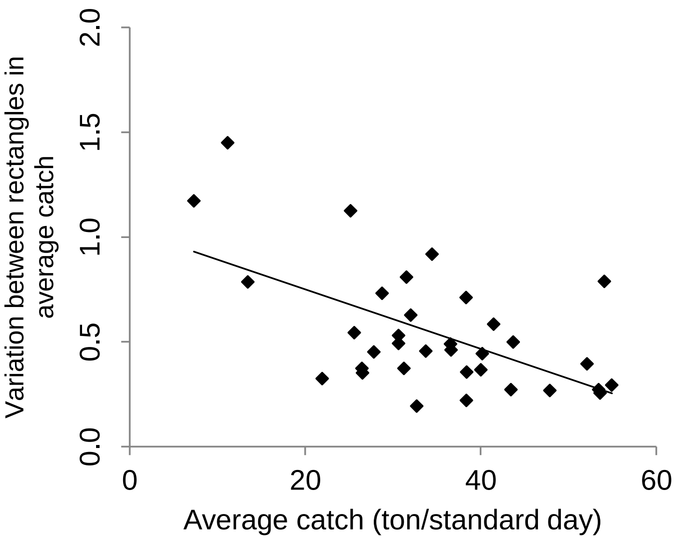


Figure 1.14.9.2.3. Relationship between variation between rectangles in average commercial catch rate and average catch rate.

1.14.9.3 Historical comparisons of original and updated TAC estimates

The current version of RTM has been used on two occasions, in 2012 and 2016. The original advice, the updated advice and the realized catch, all in '000 ton can be seen in the table below.

Year	Original TAC	TAC following RTM	Realised catch
2012	<23	0	46
2016	0, monitoring TAC of 5	0	12

1.14.10 Overview of assessment setting decisions

An overview on the decisions made on input data and assessment settings in the different areas can be seen in Table 1.14.10.1.

Table 1.14.10.1. Overview on the decisions made on input data and assessment settings in the different areas.

	AREA 1	AREA 2	AREA 3A	AREA 3B	AREA 2+3B	AREA 4
Natural mortality	Variable, southern	Constant southern	Variable northern	Variable northern	Constant North Sea	Constant northern
Maturity	Constant area 1	Constant area 2	Constant area 3	Constant area 3	Constant area 3	Constant area 4
Tech development	1989, 1999, 2005, 2010	1989, 1999, 2005, 2010	1989, 1999	1989, 1999, 2005, 2010	1989, 1999, 2005, 2010	none
Surveys	Dredge	Dredge	Dredge and acoustic	Dredge	Dredge	Dredge
In year update?	RTM possible	Not possible	Acoustic, RTM possible	RTM possible	No?	Not possible
Start year	1983	1992	1986	1983	1983	1993

1.15 Proposed assessment models

1.15.1 SMS-Effort

As effort has been shown to be a reasonable proxy for F the SMS model was modified to model fishing mortality as a function of total commercial fishing effort. The new model has options to estimate rates for technical creeping and thereby take into account that the efficiency has increased in the sandeel fishing fleet. The results show that the new model fits to data in a reasonable way, and give results without retrospective bias. Model results show a significant increase in fleet efficiency and a change in exploitation pattern, with more effort directed to the fishing banks with the highest abundance of the one-group sandeel. The model can be applied for assessment with just catch and effort, and for assessment where additional fisheries independent data are available.

Methodology

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.

$$F_{y,q,a} = \text{SesonEffect}(Y,A1) * \text{AgeEffect}(Y,A2,q) * \text{YearEffect}_y \quad \text{(1, original version)}$$
$$F_{y,q,a} = \text{SesonEffect}(Y,A1) * \text{AgeEffect}(Y,A2,q) * \text{Effort}_{y,q} \quad \text{(2, new version)}$$

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.

An example of parameterization with maximum annual effort at 1.0 is shown below. (Unique parameters in bold).

	SEASON EFFECT A1=AGE 0 AND AGE 1-4										
	First half year						Second half year				
YY	Age 0	Age 1	Age 2	Age 3	Age 4		Age 0	Age 1	Age 2	Age 3	Age 4
1983-1998	0.00*	0.426	0.426	0.426	0.426		1.0*	0.5*	0.5*	0.5*	0.5*
1999-2009	0.00*	0.337	0.337	0.337	0.337		1.0*	0.5*	0.5*	0.5*	0.5*

*** kept constant**

	AGE EFFECT A2=AGE 0, AGE 1, AGE2 AND AGE 3-4										
	First half year						Second half year				
YY	Age 0	Age 1	Age 2	Age 3	Age 4		Age 0	Age 1	Age 2	Age 3	Age 4
1983-1998	0.00*	0.488	1.024	1.248	1.248		0.014	0.772	0.847	0.585	0.585
1999-2009	0.00*	0.772	0.857	0.585	0.585		0.010	0.176	0.195	0.133	0.133

"Catchability"-at-age, or more correctly the relation between effort and F by age group, is included in the AgeEffect parameter.

There are two additional options for the SMS-effort version, where technical creeping is taken into account.

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

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

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 indicate 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, *Lc*, 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:

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

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–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.

1.15.2 SESAM

The seasonal state-space assessment model (SESAM) is a newly developed extension to the SAM model and has previously been used for assessment of Norway pout. The model was further extended to be able use effort data and deal with possible technological creep in those data. The model provided similar estimates of the stock status over time compared to the SMS model when applied to the same data both in relative and absolute terms in most cases. However, for some configurations the model had difficulties in consistently estimating temporal development in the efficiency of the commercial fleet (i.e. effort catchability or technological creep), which was revealed by problematic patterns in the retrospective analysis. While this problem could be mitigated by specifying the survival process error outside the model rather than estimating it, the overall impression was that the SMS model was more stable, given that there is sufficient data in the latest SMS period cluster (4–5 years). Nevertheless, the SESAM model's ability to estimate gradual temporal changes in selectivity and effort catchability has some merit over the blocking approach (period clusters) used in the SMS model, since the latter may introduce sudden jumps in the perceived stock status, when new blocks are introduced. Also, the SESAM model incorporates process error unlike the SMS model, which should provide more realistic uncertainty estimates. A more detailed description of the model is provided in the working documents (see annexes), as well as the results of applying it to data from SA1 (old area definition).

2 Stock (SA1r)

Sandeel (*Ammodytes* spp.) in divisions 4.b and 4.c, Sandeel Area 1r (central and southern North Sea, Dogger Bank); ICES Statistical Rectangles 31-33 E9-F4; 33 F5; 34-37 E9-F6; 38-40 F0-F5; 41 F4-F5.

2.1 Ecosystem drivers

There is strong evidence that sandeel stocks are affected by bottom-up processes involving climate and changing plankton stocks. Sandeel are high quality food for many predatory fish, seabirds and marine mammals. Given the semi-sedentary behaviour of sandeel after settling, local depletion of sandeel aggregations at a distance less than 100 km from seabird colonies may affect some species of birds, especially black-legged kittiwake and sandwich tern, whereas the more mobile marine mammals and fish are likely to be less vulnerable to local sandeel depletion.

Section 1.5 contains a comprehensive description of ecosystem aspects.

2.2 Stock Assessment

2.2.1 Catch – quality, misreporting, discards

General information about the sandeel fishery can be found in Section 1.6

The size distribution of the Danish fleet has changed through time, with a clear tendency towards fewer and larger vessels (ICES, 2007). 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.

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.

Catches in SA 1 over time are shown in Table 2.2.1.1 and Figure 2.2.1.1

Table 2.2.1.1 Area-1r Sandeel. Catch at age numbers (millions) by half year

YEAR/AGE	AGE 0, 2ND HALF	AGE 1, 1ST HALF	AGE 1, 2ND HALF	AGE 2, 1ST HALF	AGE 2, 2ND HALF	AGE 3, 1ST HALF	AGE 3, 2ND HALF	AGE 4+, 1ST HALF	AGE 4+, 2ND HALF
1983	10223	1846	264	28971	3085	772	564	320	2
1984	0	47117	9241	1701	90	10002	566	333	43
1985	8524	6217	1354	31364	2305	1987	1595	211	213
1986	87	44940	4163	7553	228	1652	188	31	14
1987	187	4504	1938	23572	4173	1199	123	171	32
1988	0	1997	0	8564	162	15229	1439	2354	47

1989	0	62503	757	6364	77	1346	16	4736	58
1990	522	16846	1257	13917	417	2060	62	622	18
1991	7344	14939	6917	6870	209	983	67	338	0
1992	104	50883	3041	8451	298	845	122	524	26
1993	1624	2181	362	5882	271	1638	156	491	43
1994	0	22172	1533	2669	126	1195	55	882	78
1995	76	36677	3440	6236	940	737	109	289	28
1996	6470	10402	1064	12301	1027	4527	211	860	65
1997	19	38667	8899	2332	177	3522	164	713	56
1998	211	9387	438	28364	1384	2164	136	1505	90
1999	440	44621	2498	5433	205	10158	717	699	149
2000	7887	32625	2760	3355	170	630	84	1076	122
2001	47080	56780	3127	8549	474	1098	49	972	98
2002	16	84878	605	10772	108	1212	15	225	6
2003	2474	3843	386	13302	4390	1117	141	302	31
2004	566	30654	2479	786	110	2364	230	480	47
2005	44	11106	383	4435	211	263	14	435	27
2006	37	33600	800	2590	94	817	43	163	19
2007	0	10581	0	4674	0	315	0	172	0
2008	6	26735	281	4009	75	1205	33	214	6
2009	979	18898	2254	14265	278	1556	12	392	3
2010	10	39951	1184	2130	35	942	16	108	2
2011	5	1894	39	32692	325	1305	14	266	1
2012	0	383	0	419	0	3354	0	129	0
2013	3	18090	598	7916	131	2182	100	4301	49
2014	925	8930	131	3354	98	401	23	360	25
2015	0	25391	0	1922	0	581	0	171	0
arith. mean	2905	24856	1885	9567	657	2405	214	753	42

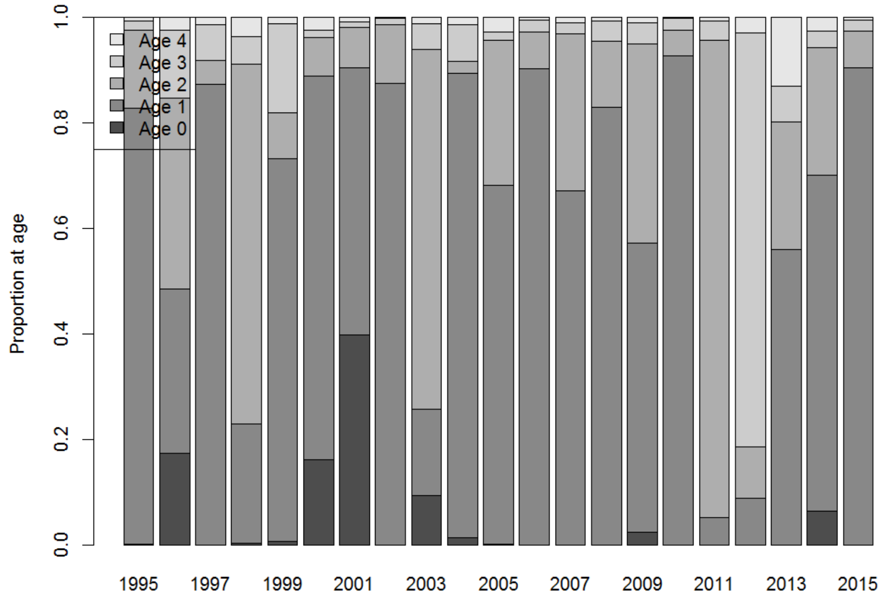


Figure 2.2.1.1. Distribution of catches on ages.

2.2.2 Surveys

Dredge survey catches are given in Table 2.2.2.1 Only ages 0 and 1 are used in assessment.

Table 2.2.2.1 Dredge survey index *10^{-3}.

YEAR	AGE 0	AGE 1	AGE 2+
2004	92.86	3.96	0.04
2005	183.55	2.02	0.25
2006	74.48	7.37	0.01
2007	258.12	3.39	0.53
2008	22.24	8.68	0.27
2009	304.03	5.49	1.48
2010	29.43	78.17	2.37
2011	42.41	16.02	9.47
2012	78.40	2.47	3.67
2013	45.83	7.63	0.49
2014	143.71	2.10	0.42
2015	13.59	7.59	0.41

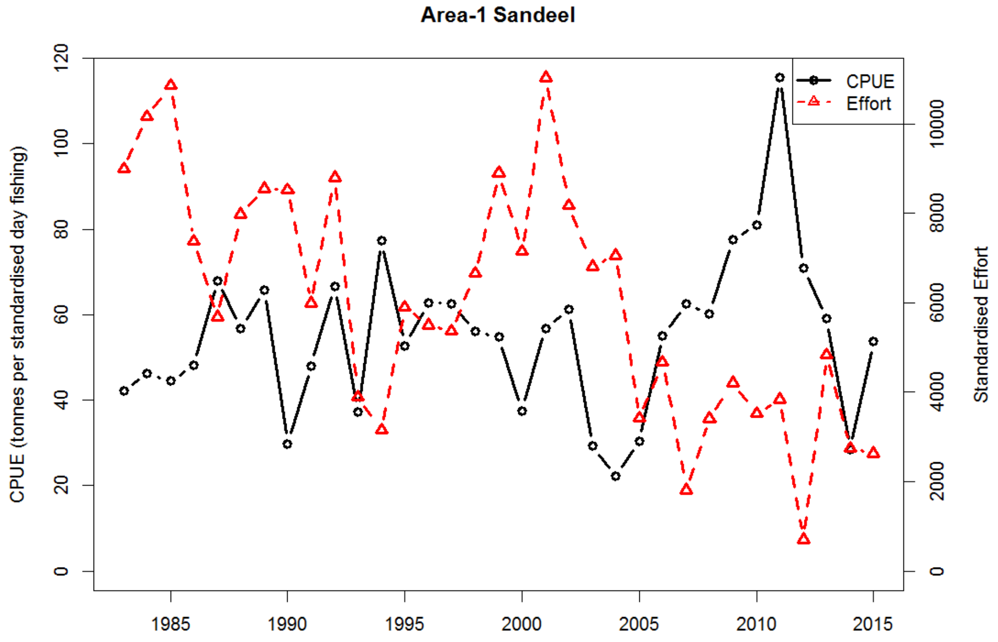


Figure 2.2.1.1. CPUE and effort series.

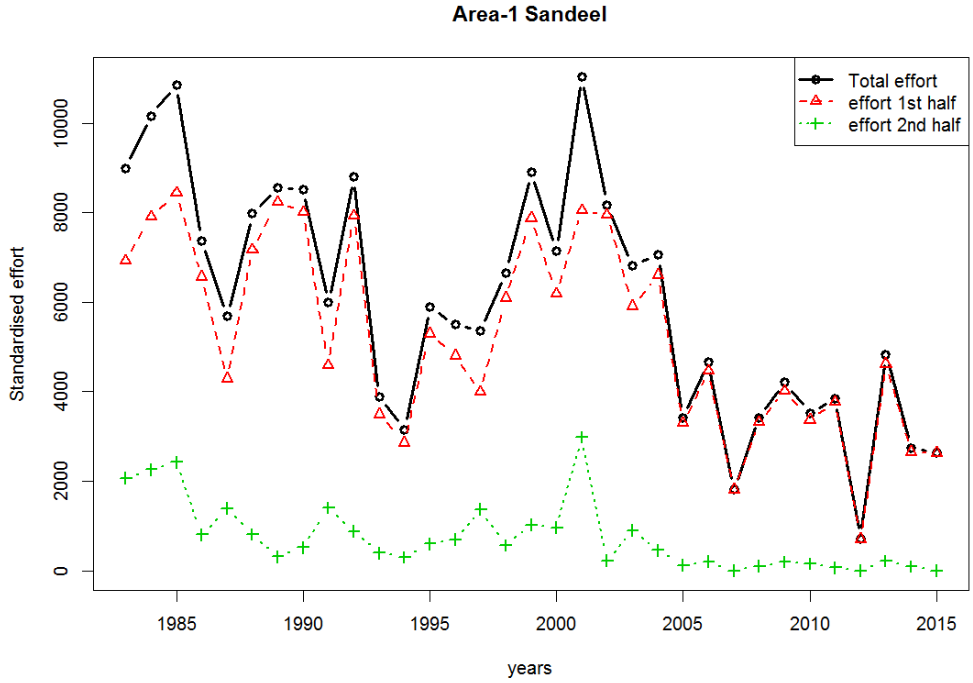


Figure 2.2.1.2. Effort in the first and second half year.

2.2.3 Maturity

Constant average maturity at age from dredge survey catches were used.

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

2.2.4 Natural mortality

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 2.2.4.1a and 2.2.4.1b show natural mortality pr. Year age for Season 1 (a) and 2 (b).

Table 2.2.4.1a; Natural mortality in SA1r 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 2.2.4.1b; Natural mortality in SA1r 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

2.2.5 Weight at age

Weight at age in the stock and catch was estimated from catch samples. Table 2.2.5.1 show the individual mean weight in catch and stock by year, age and season.

Table 2.2.5.1 Area-1r Sandeel. Individual mean weight(g) at age in the catch and in the stock

YEAR/AGE	AGE 0, 2ND HALF	AGE 1, 1ST HALF	AGE 1, 2ND HALF	AGE 2, 1ST HALF	AGE 2, 2ND HALF	AGE 3, 1ST HALF	AGE 3, 2ND HALF	AGE 4+, 1ST HALF	AGE 4+, 2ND HALF
1983	4.7	5.8	5.4	9.3	9.7	11.4	11.4	13.8	14.4
1984	3.3	4.9	4.0	9.7	8.3	17.2	13.2	20.5	11.6
1985	3.7	5.5	7.3	10.1	12.8	14.1	16.8	13.4	15.8
1986	3.0	5.1	5.8	9.2	10.7	16.4	12.9	17.9	16.6
1987	3.0	5.3	7.5	11.7	12.7	11.7	12.8	13.6	14.7
1988	4.0	7.2	7.8	10.6	11.2	18.5	20.2	14.7	16.1
1989	3.9	6.1	6.8	10.4	12.0	16.0	17.0	17.8	24.4
1990	6.2	5.0	9.6	8.6	15.5	9.1	17.2	12.0	28.3
1991	5.0	6.6	9.0	9.6	13.1	14.2	19.3	17.0	23.1
1992	3.8	7.8	6.1	14.2	11.8	37.8	32.0	19.6	17.2
1993	4.9	7.8	9.5	11.9	15.3	17.7	19.7	19.0	21.2
1994	4.0	7.3	7.5	11.5	10.5	14.4	13.6	20.2	18.2
1995	4.4	5.5	7.6	8.7	12.3	12.7	16.3	19.8	18.8
1996	3.8	7.6	6.8	11.3	9.9	14.1	14.1	19.0	19.0
1997	2.9	5.6	4.6	8.4	7.6	12.2	9.5	17.7	14.2
1998	3.7	7.3	8.5	8.3	14.2	9.9	15.5	14.4	16.1
1999	3.2	6.3	6.7	8.9	10.0	11.5	11.9	13.5	14.5
2000	3.4	5.3	5.9	7.5	9.6	10.3	12.8	13.1	14.7
2001	3.1	6.3	4.8	8.7	7.9	11.9	10.6	14.5	12.2
2002	3.1	4.5	5.0	8.7	12.1	11.5	16.5	16.6	23.6
2003	3.8	6.0	6.7	7.4	10.8	9.8	14.4	13.8	16.5
2004	2.2	3.6	2.7	7.2	3.6	9.5	8.4	12.8	9.1
2005	3.5	5.1	4.5	8.3	6.6	9.0	6.7	10.4	8.8
2006	3.0	6.5	5.3	8.7	8.5	10.3	11.3	12.1	13.0
2007	3.2	5.9	5.5	9.7	8.9	11.6	11.9	13.0	13.7
2008	0.0	5.6	0.0	9.4	0.0	13.5	0.0	14.7	0.0
2009	4.5	6.3	7.8	10.9	12.6	13.3	16.8	15.8	19.3
2010	2.8	6.2	4.9	9.4	7.9	12.1	10.5	13.2	12.1
2011	3.4	6.3	5.9	12.4	9.5	13.9	12.6	17.2	14.5
2012	2.8	5.3	4.9	8.7	7.8	12.7	10.4	14.8	12.0
2013	3.8	6.4	6.6	9.5	10.6	11.3	14.1	14.5	16.2
2014	3.8	4.7	6.5	6.5	10.5	10.1	14.0	11.3	16.1
2015	3.0	4.7	5.2	7.1	8.5	9.5	11.3	11.7	13.0
arith. mean	3.5	5.9	6.2	9.5	10.1	13.3	13.8	15.3	15.7

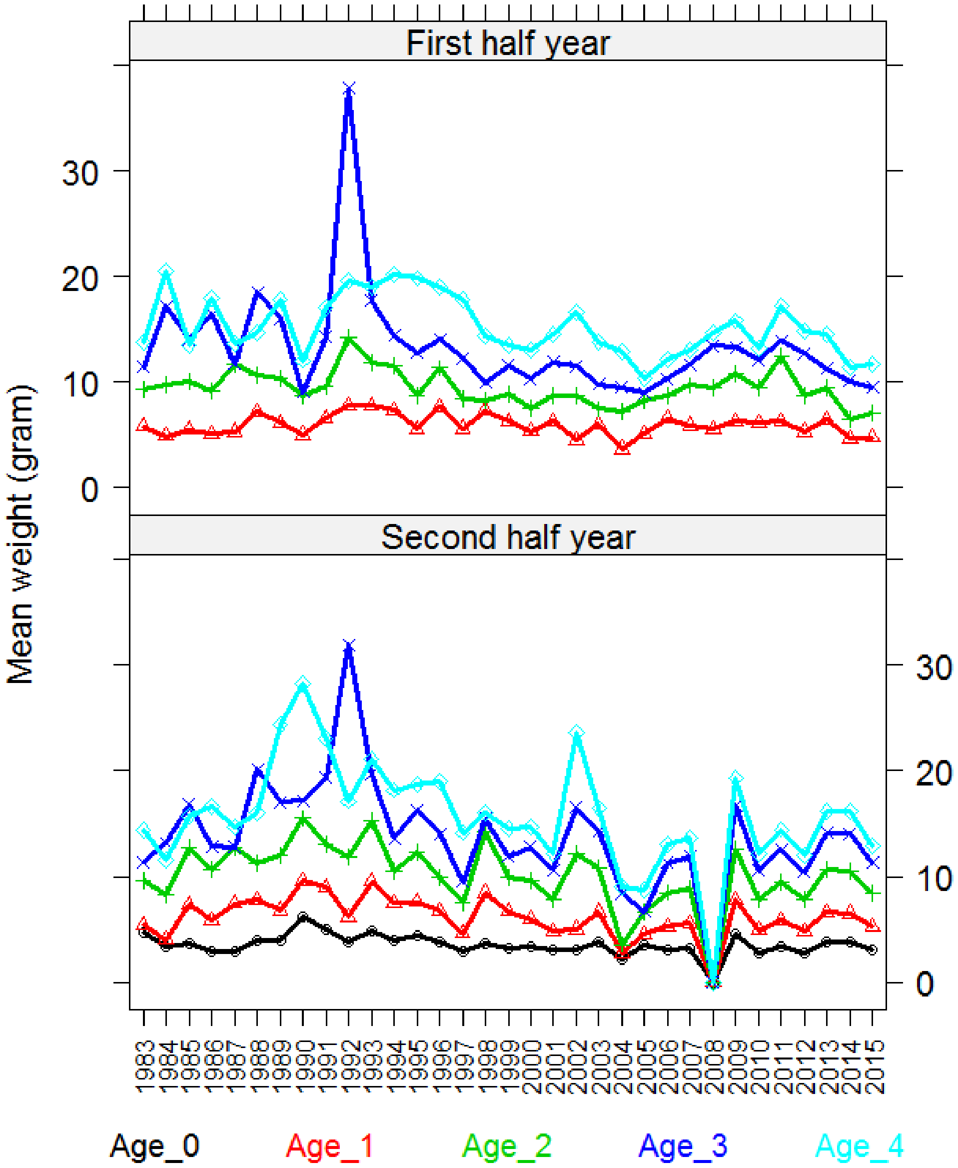


Figure 2.2.5.1 Weight at age in the catch and in the stock.

2.2.6 Commercial data

An RTM series of catch at age in the commercial fishery in April (April 15th to May 6th) is available and given in Table 2.2.6.1. Catch at age is given in Table 2.2.6.2 and input effort is given in Table 2.2.6.3. As model fits suggested a significant temporal trend in catchability and selection pattern in the commercial fishery, it was decided only to use the latest 10 years of data at any point (moving window of 10 years). Age 4+ is not used in the assessment and the final assessment includes data only from the latest 10 years.

Table 2.2.6.1. RTM data series. Catch per day in numbers at age in the period 15th of April to 6th of May.

YEAR	AGE 1	AGE 2	AGE 3	AGE 4+
2001	9825	698	81	22
2002	11515	1663	158	14
2003	304	1951	99	13
2004	5038	41	106	10
2005	1511	400	16	18
2006	8421	305	79	7
2007	8014	2112	111	35
2008	14365	1565	299	34
2009	3873	3380	438	123
2010	14665	372	350	61
2011	829	10008	460	108
2012	1114	880	6563	204
2013	5353	1362	492	1274
2014	5932	1516	88	56
2015	12536	942	280	68

Table 2.2.6.2. Area-1r Sandeel. Catch at age numbers (millions) by half year

Year/Age	Age 0, 2nd half	Age 1, 1st half	Age 1, 2nd half	Age 2, 1st half	Age 2, 2nd half	Age 3, 1st half	Age 3, 2nd half	Age 4+, 1st half	Age 4+, 2nd half
1983	10223	1846	264	28971	3085	772	564	320	2
1984	0	47117	9241	1701	90	10002	566	333	43
1985	8524	6217	1354	31364	2305	1987	1595	211	213
1986	87	44940	4163	7553	228	1652	188	31	14
1987	187	4504	1938	23572	4173	1199	123	171	32
1988	0	1997	0	8564	162	15229	1439	2354	47
1989	0	62503	757	6364	77	1346	16	4736	58
1990	522	16846	1257	13917	417	2060	62	622	18
1991	7344	14939	6917	6870	209	983	67	338	0
1992	104	50883	3041	8451	298	845	122	524	26
1993	1624	2181	362	5882	271	1638	156	491	43
1994	0	22172	1533	2669	126	1195	55	882	78
1995	76	36677	3440	6236	940	737	109	289	28
1996	6470	10402	1064	12301	1027	4527	211	860	65
1997	19	38667	8899	2332	177	3522	164	713	56
1998	211	9387	438	28364	1384	2164	136	1505	90
1999	440	44621	2498	5433	205	10158	717	699	149
2000	7887	32625	2760	3355	170	630	84	1076	122
2001	47080	56780	3127	8549	474	1098	49	972	98
2002	16	84878	605	10772	108	1212	15	225	6

2003	2474	3843	386	13302	4390	1117	141	302	31
2004	566	30654	2479	786	110	2364	230	480	47
2005	44	11106	383	4435	211	263	14	435	27
2006	37	33600	800	2590	94	817	43	163	19
2007	0	10581	0	4674	0	315	0	172	0
2008	6	26735	281	4009	75	1205	33	214	6
2009	979	18898	2254	14265	278	1556	12	392	3
2010	10	39951	1184	2130	35	942	16	108	2
2011	5	1894	39	32692	325	1305	14	266	1
2012	0	383	0	419	0	3354	0	129	0
2013	3	18090	598	7916	131	2182	100	4301	49
2014	925	8930	131	3354	98	401	23	360	25
2015	0	25391	0	1922	0	581	0	171	0
arith. mean	2905	24856	1885	9567	657	2405	214	753	42

Table 2.3.6.3. Area-1r Sandeel. Standardised effort (fishing days for a 200 GT vessels)

Year/Age	1st half year	2nd half year	Sum
1983	6926	2066	8992
1984	7910	2256	10166
1985	8441	2421	10862
1986	6569	805	7373
1987	4288	1394	5682
1988	7173	809	7982
1989	8240	313	8552
1990	8006	520	8526
1991	4587	1403	5990
1992	7925	879	8804
1993	3494	398	3892
1994	2851	297	3148
1995	5296	601	5897
1996	4804	691	5495
1997	3995	1369	5364
1998	6092	567	6660
1999	7881	1026	8907
2000	6188	961	7148
2001	8047	2983	11030
2002	7952	220	8172

2003	5912	899	6811
2004	6603	457	7060
2005	3292	124	3416
2006	4468	202	4670
2007	1814	0	1814
2008	3313	101	3414
2009	4009	197	4206
2010	3368	156	3524
2011	3770	66	3835
2012	708	0	708
2013	4617	215	4832
2014	2647	93	2740
2015	2632	0	2632
arith. mean	5267	742	6009

2.2.7 Assessment model (primary and exploratory)

2.2.7.1 SMS (primary)

The diagnostics output from SMS are shown in Table 2.2.7.1.1 The seasonal effect on the relation between effort and F (“F, Season effect” in the table) is rather constant over the five year ranges used. The “age selection” (“F, age effect” in the table) shows a change in the fishery pattern where the fishery was mainly targeting the age 2+ sandeel in the beginning of the assessment period, to a fishery targeting age 1+ in a similar way.

The CV of the dredge survey (“sqrt (Survey variance) ~CV” in the table) is moderate (0.46) for age 0 and high (0.72) for age 1 and the CV of the RTM series is moderate for all ages (0.51 for age 1 and 0.44 for age 2). The dredge survey residual plot (Figure 2.2.7.1.1) shows clusters of residuals. However, it is not possible to determine if the clusters are due to a systematic bias or systemic noise.

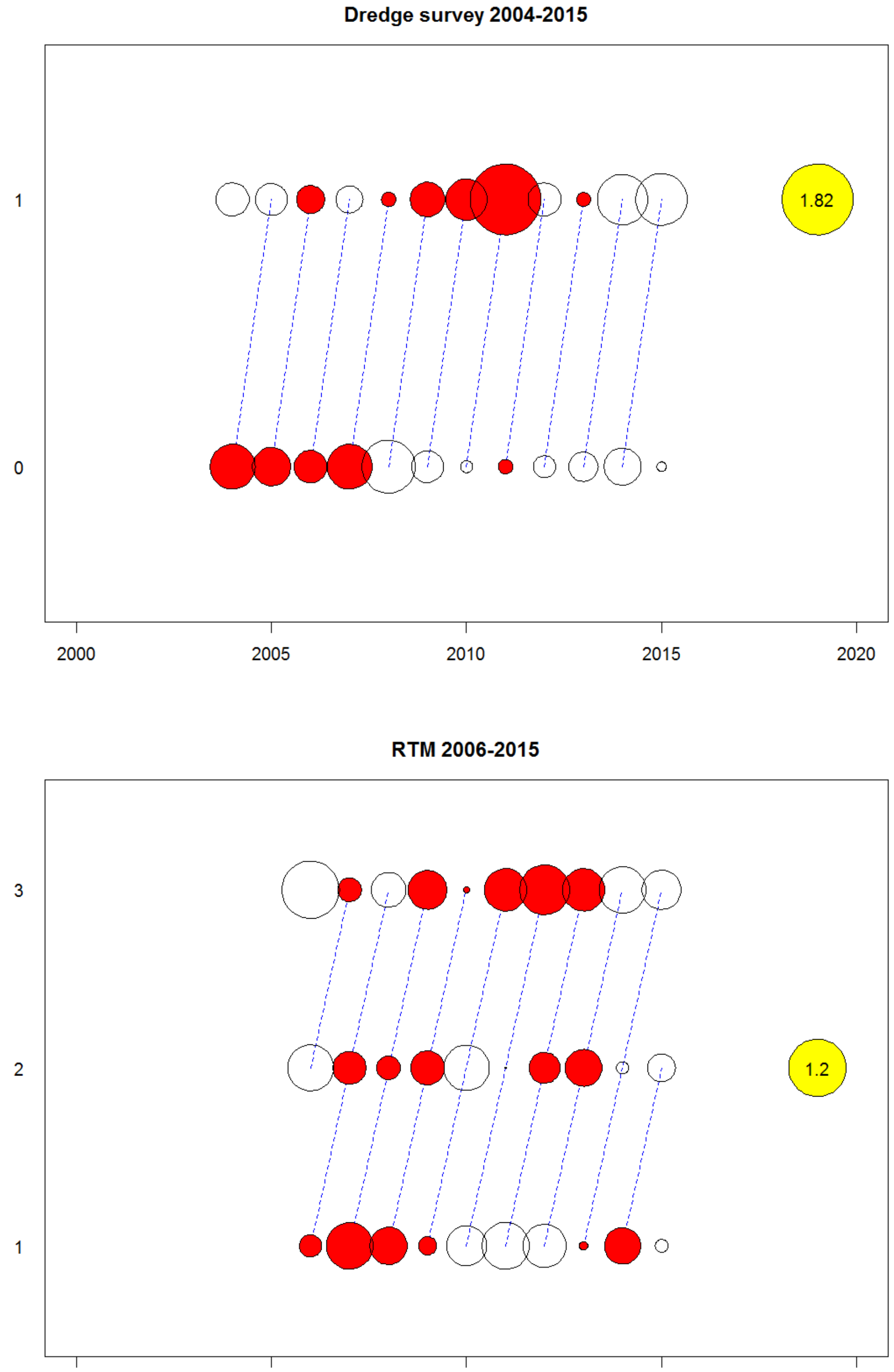


Figure. 2.2.7.1.1 Survey residuals in the SMS model (dredge survey and RTM time series). Red defines negative residuals.

The model CV of catch at age ("sqrt(catch variance) ~CV", in Table 2.2.7.1.1 is low (0.336) for age 1 and age 2 in the first half of the year and high (> 0.59) for the remaining ages and season combinations. The catch at age residuals (Figure 2.2.7.1.2) show no alarming patterns.

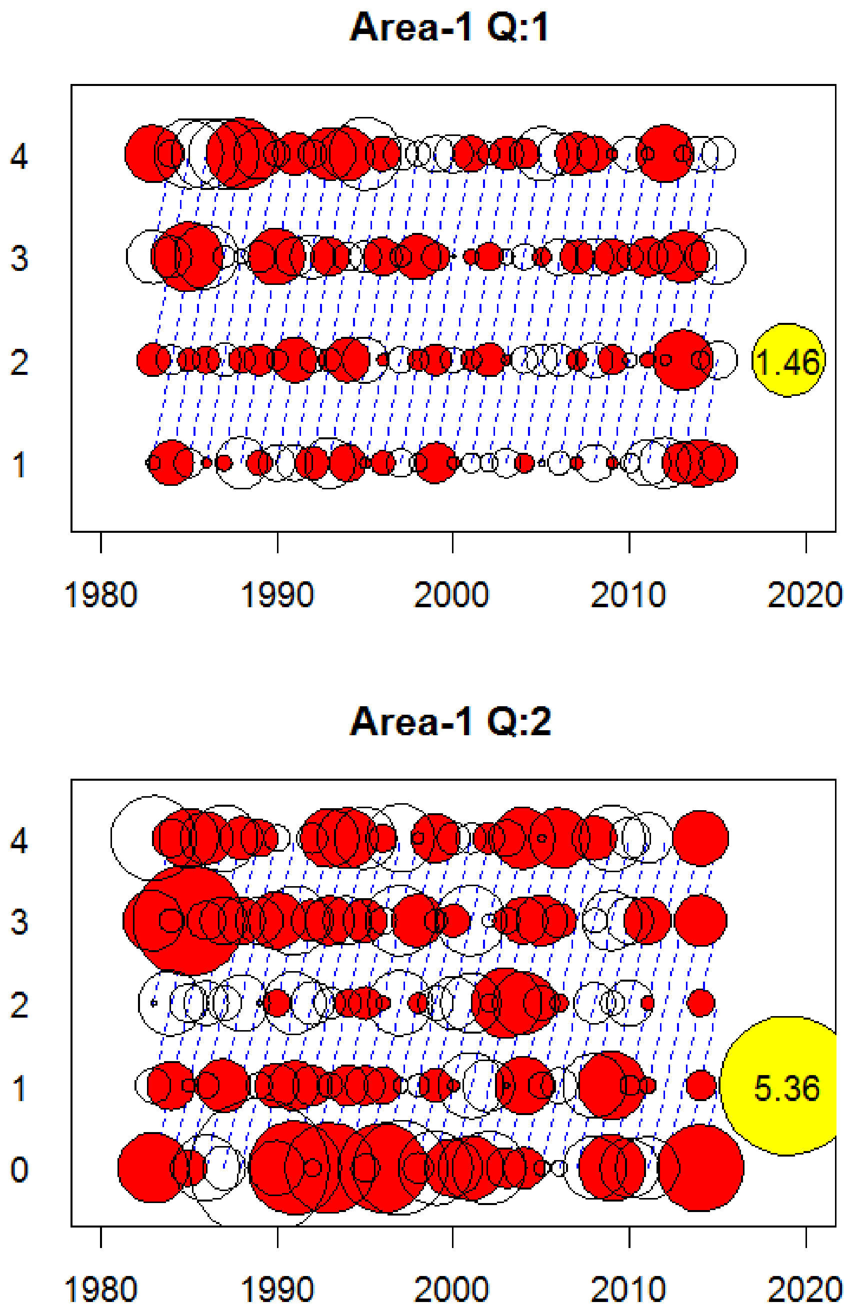


Figure 2.2.7.1.2 Catch residuals.

The CV of the fitted Stock recruitment relationship (Table 2.2.7.1.1) is high (0.834), which is also indicated by the stock recruitment plot (Figure 2.2.7.1.3). The high CV of recruitment is probably due to biological characteristic of the stock and not the quality of the assessment. The *a priori* weight on likelihood contributions from SSR-R observations is therefore set low (0.05 in "objective function weight" in Table 2.2.7.1.1) such that SSB-R estimates do not contribute much to the overall likelihood and model fit.

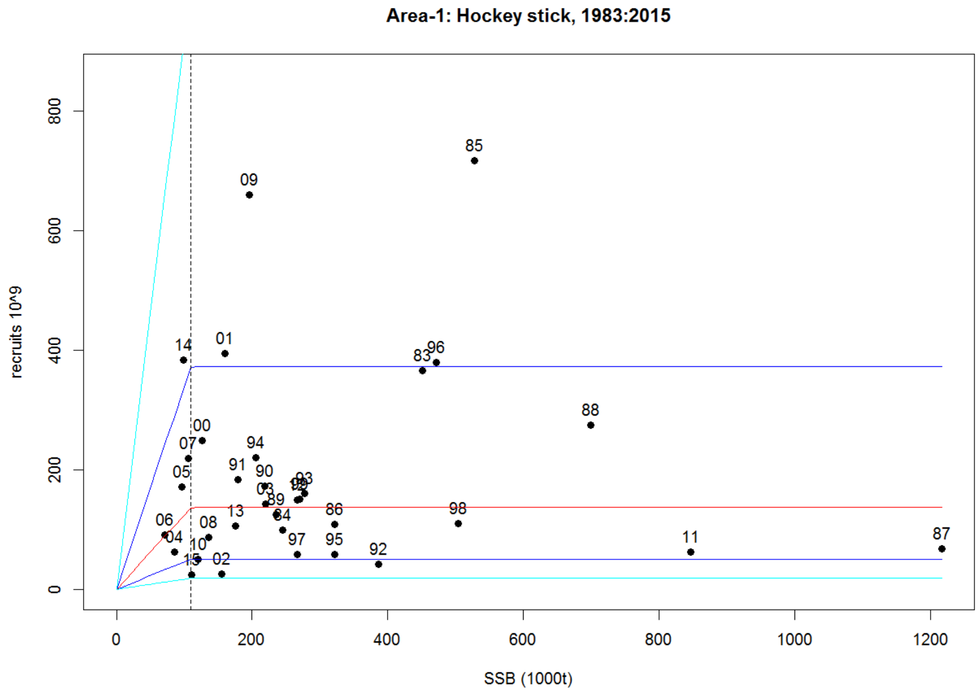


Fig. 2.2.7.1.3. Stock-recruitment relationship.

The retrospective analysis (Figure 2.2.7.1.4) shows very consistent assessment results from one year to the next. This is partly due to the assumed robust relationship between effort and F, which is rather insensitive to removal of a few years.

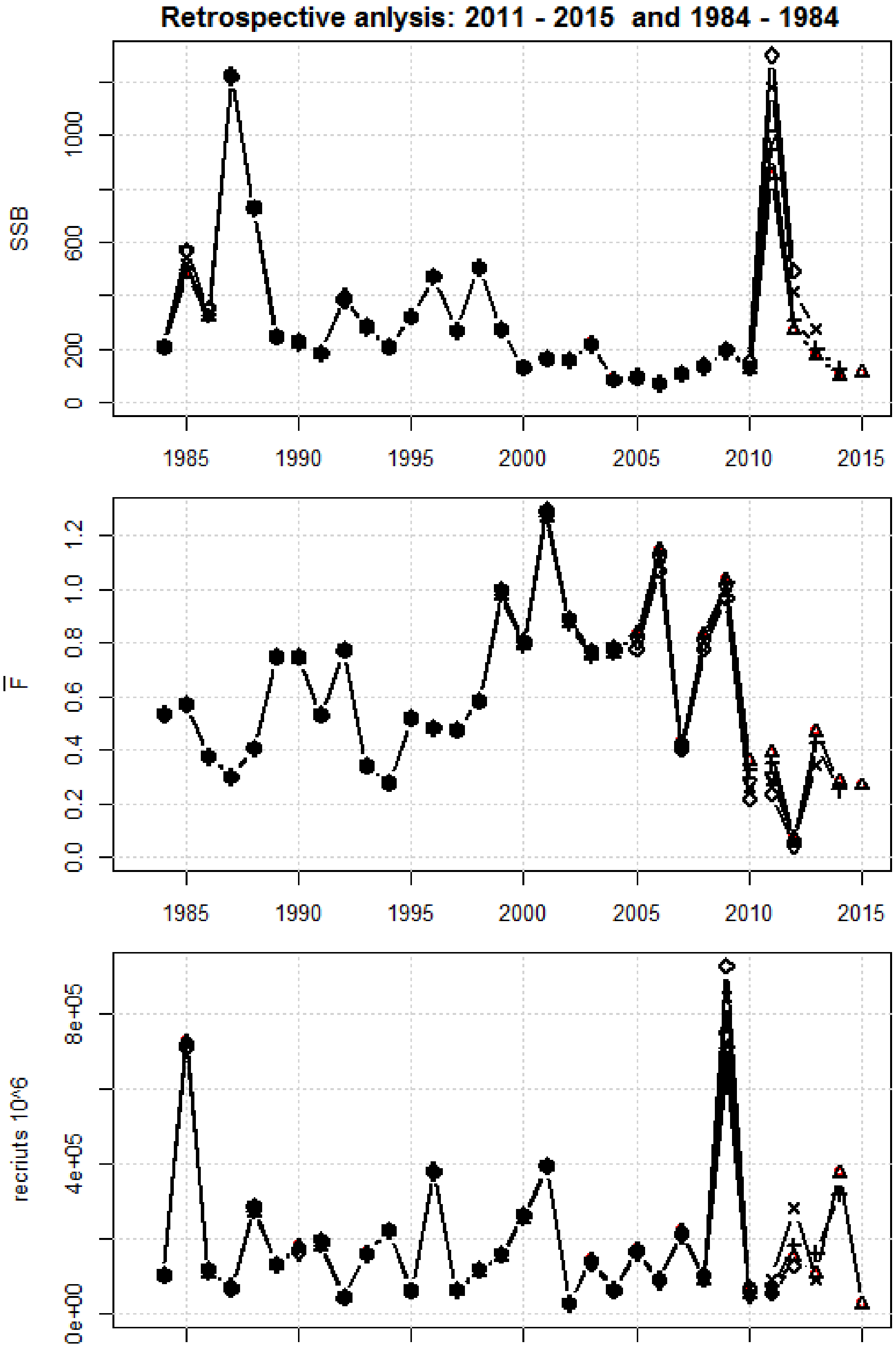


Figure 2.2.7.1.4. Retrospective analysis.

Uncertainties of the estimated SSB, F and recruitment (Figure 2.2.7.1.4) are in general small. For F, uncertainties are lowest for the most recent years, which are not normally seen. This is due to the model fit where the most recent effort values estimate F with a small error (Figure 2.2.7.1.5), while older observations have a larger difference between effort and F (Figure 2.2.7.1.6).

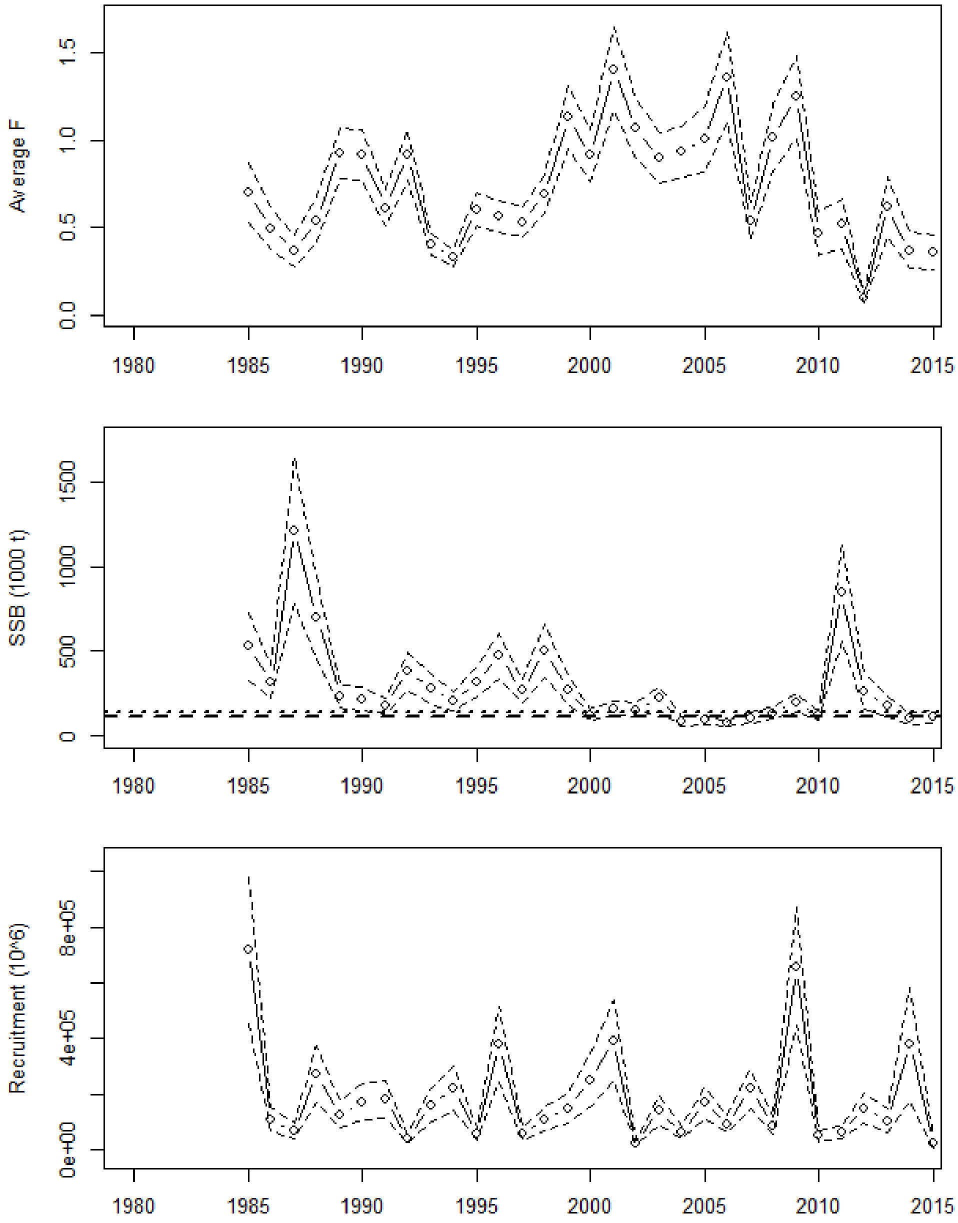


Figure. 2.2.7.1.3. Predicted stock size, F and recruitment and associated uncertainties.

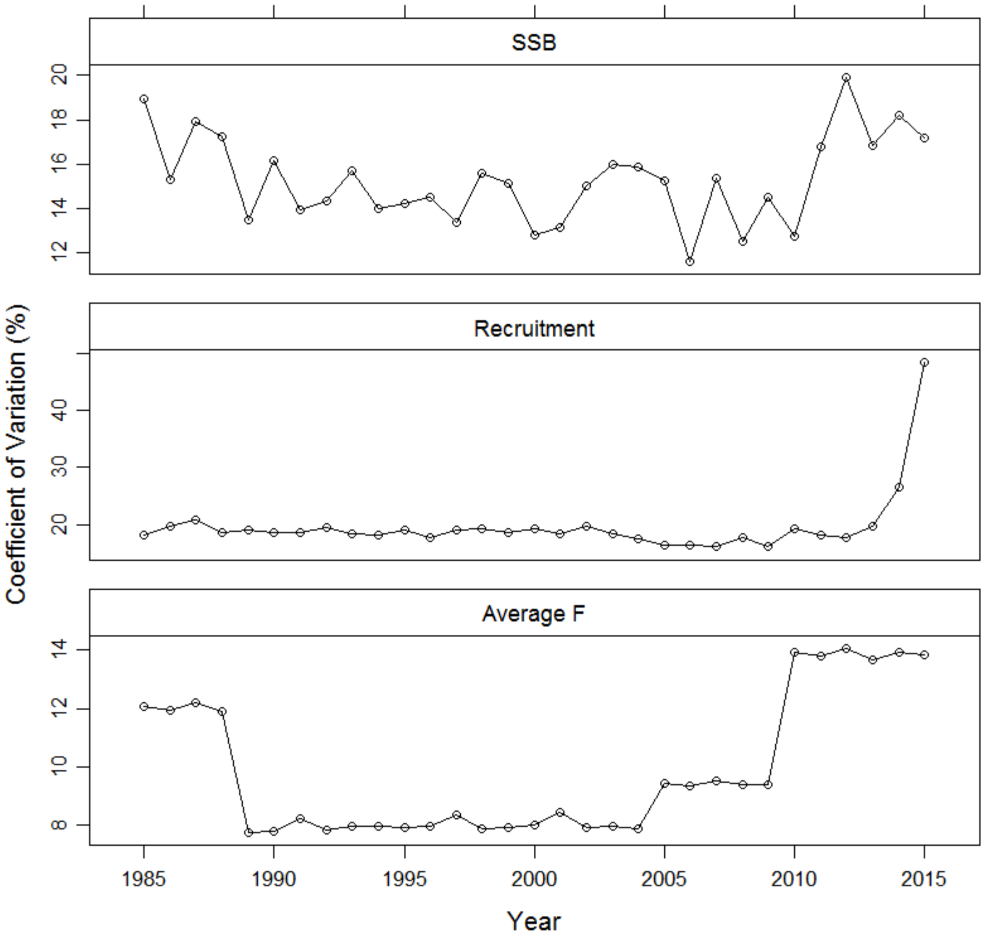


Figure. 2.2.7.1.4. CV of SSB, recruitment and F.

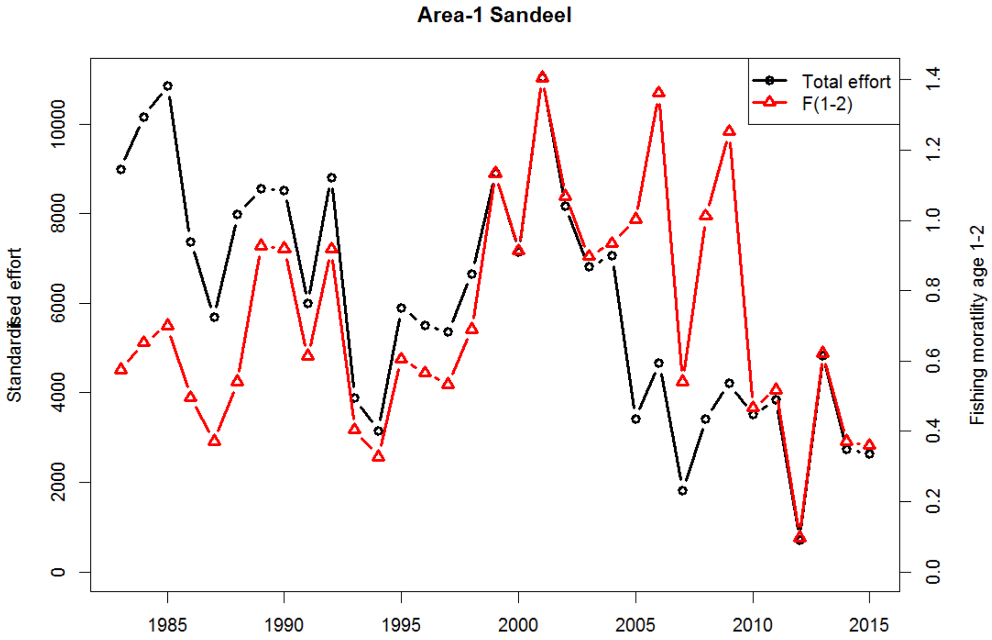


Figure. 2.2.7.1.5. Effort and estimated F.

Table 2.2.7.1.1 Assessment fit summary.

```
Date: 11/03/16  Start time:21:23:18 run time:0 seconds


objective function (negative log likelihood):  2.07333

Number of parameters: 74

Maximum gradient: 7.29481e-005

Akaike information criterion (AIC):   152.147

Number of observations used in the likelihood:

                   Catch    CPUE     S/R Stomach     Sum

                    297      54      33       0     384


objective function weight:

                  Catch  CPUE   S/R

                  1.00  1.00  0.05


unweighted objective function contributions (total):

           Catch    CPUE    S/R   Stom.  Stom N.  Penalty     Sum

           6.8    -5.2    10.5     0.0     0.0      0.00      12



unweighted objective function contributions (per observation):

           Catch   CPUE     S/R   Stomachs

          0.02   -0.10    0.32    0.00



contribution by fleet:

----------------------

Dredge survey 2004-2015     total:  -1.359   mean:  -0.057

RTM  total:  -3.872   mean:  -0.129


F, season effect:

-----------------

age: 0

   1983-1988:   0.000 1.000

   1989-1998:   0.000 1.000
```

```
   1999-2004:   0.000 1.000
   2005-2009:   0.000 1.000
   2010-2015:   0.000 1.000
age: 1 - 4
   1983-1988:   0.437 0.500
   1989-1998:   0.462 0.500
   1999-2004:   0.379 0.500
   2005-2009:   0.279 0.500
   2010-2015:   0.398 0. 500

F, age effect:
--------------
              0      1      2      3      4
1983-1988:  0.020  0.215  0.838  1.317  1.317
1989-1998:  0.011  0.499  0.671  0.705  0.705
1999-2004:  0.072  1.101  1.196  1.155  1.155
2005-2009:  0.006  1.268  2.009  2.091  2.091
2010-2015:  0.009  0.254  0.686  1.082  1.082


Exploitation pattern (scaled to mean F=1)
-----------------------------------------
                     0      1      2      3      4
1983-1988 season 1:      0  0.304  1.187  1.866  1.866
          season 2:  0.019  0.104  0.405  0.636  0.636

1989-1998 season 1:      0  0.820  1.101  1.158  1.158
          season 2:  0.001  0.034  0.045  0.048  0.048

1999-2004 season 1:      0  0.818  0.889  0.858  0.858
          season 2:  0.018  0.140  0.153  0.147  0.147

2005-2009 season 1:      0  0.725  1.149  1.195  1.195
          season 2:  0.000  0.049  0.078  0.081  0.081
```

```
2010-2015 season 1:      0  0.510  1.380  2.175  2.175
          season 2:  0.002  0.030  0.080  0.126  0.126


sqrt(catch variance) ~ CV:
--------------------------

            season
----------------------
age       1       2

 0              1.657
 1      0.336   0.593
 2      0.336   0.593
 3      0.602   0.876
 4      0.602   0.876


Survey catchability:
--------------------
                        age 0    age 1    age 2    age 3
 Dredge survey 2004-2015      181.149   81.221
 RTM            8.338   12.214   15.118

sqrt(Survey variance) ~ CV:
---------------------------
                        age 0    age 1    age 2    age 3
 Dredge survey 2004-2015        0.46     0.72
 RTM             0.51     0.44     0.67



Recruit-SSB                         alfa      beta        recruit s2     recruit s
Area-1      Hockey stick -break.:      935.497   1.600e+005   0.696           0.834
```

2.2.8 Final assessment

The output from the assessment is presented in Tables 2.2.8.1 (fishing mortality at age by year), 2.2.8.2 (fishing mortality at age by half year), 2.2.8.3 (stock numbers at age) and 2.2.8.4 (stock summary).

Table 2.2.8.1. Sandeel SA 1r. Annual fishing mortality (F) at age.

Year/Age	Age 0	Age 1	Age 2	Age 3	Age 4	Avg. 1-2
1983	0.009	0.239	0.912	1.415	1.415	0.576
1984	0.010	0.271	1.033	1.601	1.601	0.652
1985	0.011	0.291	1.109	1.718	1.718	0.700
1986	0.004	0.207	0.784	1.206	1.205	0.495
1987	0.006	0.153	0.589	0.919	0.918	0.371
1988	0.004	0.226	0.856	1.313	1.312	0.541
1989	0.001	0.802	1.054	1.090	1.090	0.928
1990	0.002	0.796	1.044	1.081	1.081	0.920
1991	0.005	0.529	0.699	0.731	0.731	0.614
1992	0.003	0.796	1.040	1.080	1.080	0.918
1993	0.001	0.351	0.458	0.475	0.475	0.404
1994	0.001	0.284	0.371	0.385	0.385	0.328
1995	0.002	0.525	0.686	0.712	0.712	0.605
1996	0.002	0.492	0.640	0.665	0.665	0.566
1997	0.005	0.462	0.606	0.633	0.633	0.534
1998	0.002	0.603	0.777	0.806	0.805	0.690
1999	0.018	1.105	1.163	1.112	1.112	1.134
2000	0.017	0.889	0.937	0.898	0.898	0.913
2001	0.052	1.362	1.448	1.394	1.394	1.405
2002	0.004	1.048	1.089	1.032	1.032	1.068
2003	0.016	0.879	0.916	0.873	0.873	0.898
2004	0.008	0.918	0.952	0.902	0.902	0.935
2005	0.000	0.805	1.201	1.226	1.226	1.003
2006	0.001	1.095	1.629	1.666	1.661	1.362
2007	0.000	0.435	0.647	0.659	0.656	0.541
2008	0.000	0.813	1.212	1.243	1.238	1.012
2009	0.001	1.004	1.502	1.546	1.546	1.253
2010	0.001	0.264	0.669	1.029	1.029	0.467
2011	0.000	0.295	0.741	1.133	1.133	0.518
2012	0.000	0.055	0.140	0.217	0.217	0.098
2013	0.000	0.356	0.889	1.355	1.355	0.622
2014	0.000	0.210	0.532	0.818	0.818	0.371
2015	0.000	0.204	0.514	0.789	0.789	0.359
arith. mean	0.006	0.569	0.874	1.022	1.021	0.721

Table 2.2.8.2. Sandeel SA 1r. Seasonal fishing mortality (F) at age.

Year/Age	Age 0, 2nd half	Age 1, 1st half	Age 1, 2nd half	Age 2, 1st half	Age 2, 2nd half	Age 3, 1st half	Age 3, 2nd half	Age 4+, 1st half	Age 4+, 2nd half
1983	0.009	0.153	0.052	0.597	0.204	0.938	0.320	0.938	0.320
1984	0.010	0.175	0.057	0.682	0.222	1.071	0.349	1.071	0.349
1985	0.011	0.186	0.061	0.728	0.239	1.143	0.375	1.143	0.375
1986	0.004	0.145	0.020	0.566	0.079	0.890	0.125	0.890	0.125
1987	0.006	0.095	0.035	0.370	0.137	0.581	0.216	0.581	0.216
1988	0.004	0.158	0.020	0.618	0.080	0.972	0.125	0.972	0.125
1989	0.001	0.611	0.025	0.820	0.034	0.862	0.035	0.862	0.035
1990	0.002	0.593	0.042	0.797	0.056	0.838	0.059	0.838	0.059
1991	0.005	0.340	0.112	0.457	0.151	0.480	0.159	0.480	0.159
1992	0.003	0.587	0.070	0.789	0.095	0.829	0.099	0.829	0.099
1993	0.001	0.259	0.032	0.348	0.043	0.366	0.045	0.366	0.045
1994	0.001	0.211	0.024	0.284	0.032	0.298	0.034	0.298	0.034
1995	0.002	0.392	0.048	0.527	0.065	0.554	0.068	0.554	0.068
1996	0.002	0.356	0.055	0.478	0.074	0.503	0.078	0.503	0.078
1997	0.005	0.296	0.110	0.398	0.147	0.418	0.155	0.418	0.155
1998	0.002	0.451	0.045	0.606	0.061	0.638	0.064	0.638	0.064
1999	0.018	0.803	0.138	0.873	0.150	0.843	0.145	0.843	0.145
2000	0.017	0.631	0.129	0.685	0.140	0.662	0.136	0.662	0.136
2001	0.052	0.820	0.401	0.891	0.436	0.860	0.421	0.860	0.421
2002	0.004	0.810	0.030	0.881	0.032	0.850	0.031	0.850	0.031
2003	0.016	0.602	0.121	0.655	0.131	0.632	0.127	0.632	0.127
2004	0.008	0.673	0.061	0.731	0.067	0.706	0.064	0.706	0.064
2005	0.000	0.598	0.040	0.948	0.064	0.986	0.067	0.986	0.067
2006	0.001	0.812	0.066	1.286	0.104	1.339	0.109	1.339	0.109
2007	0.000	0.330	0.000	0.522	0.000	0.543	0.000	0.543	0.000
2008	0.000	0.602	0.033	0.954	0.052	0.993	0.054	0.993	0.054
2009	0.001	0.728	0.064	1.154	0.102	1.201	0.106	1.201	0.106
2010	0.001	0.186	0.011	0.503	0.029	0.793	0.046	0.793	0.046
2011	0.000	0.208	0.005	0.563	0.012	0.888	0.019	0.888	0.019
2012	0.000	0.039	0.000	0.106	0.000	0.167	0.000	0.167	0.000
2013	0.000	0.255	0.000	0.690	0.000	1.087	0.000	1.087	0.000
2014	0.000	0.146	0.006	0.395	0.017	0.623	0.028	0.623	0.028
2015	0.000	0.145	0.000	0.393	0.000	0.620	0.000	0.620	0.000
arith. mean	0.006	0.406	0.058	0.645	0.093	0.763	0.111	0.763	0.111

Table 2.2.8.3. Sandeel SA 1r. Stock numbers (millions). Age 0 at start of 2nd half-year, age 1+ at start of the year.

Year/Age	Age 0	Age 1	Age 2	Age 3	Age 4
1983	365913	16440	55268	3075	237
1984	98531	199118	5102	10368	456
1985	717577	54981	60836	860	1262
1986	108295	383656	16500	9603	222
1987	67550	55599	122403	3469	1642
1988	274191	34174	17890	28829	1045
1989	125419	136333	10171	3402	4466
1990	172883	64365	25906	1671	1464
1991	183495	88659	12362	4369	593
1992	41438	98130	21209	2818	1274
1993	160148	23199	19937	3900	829
1994	220055	92732	7102	6404	1701
1995	57678	128104	30680	2511	3198
1996	379686	34322	35135	8337	1705
1997	58381	220287	9722	10010	3114
1998	110564	33455	62188	2824	4167
1999	150528	60257	8079	15715	1933
2000	248330	79687	9168	1421	3675
2001	393903	131218	14432	1945	1273
2002	25556	197677	15285	1856	493
2003	142235	12858	30933	2801	517
2004	62223	68557	2131	6170	809
2005	171057	30135	10798	415	1688
2006	90186	84320	5371	1736	390
2007	218626	43565	11692	598	267
2008	86372	103582	10461	3058	261
2009	658457	41197	18310	1683	588
2010	49731	312715	6441	2285	301
2011	62858	22107	81897	1580	519
2012	149477	26169	5084	17726	373
2013	105174	62561	6804	1701	6634
2014	381470	44019	13107	1270	1217
2015	23476	159585	10216	3226	562
2016		9825	37308	2565	883

Table 2.2.8.4. Sandeel SA 1r. Estimated recruitment, total stock biomass (TBS), spawning stock biomass (SSB), catch weight (Yield) and average fishing mortality.

Year	Recruits	TSB	SSB	Yield	Mean F
(million)	(tonnes)	(tonnes)	(tonnes)	ages 1–2	
1983	365913	646945	451221	378793	0.576
1984	98531	1205180	245419	470081	0.652
1985	717577	944202	527718	482798	0.700
1986	108295	2260660	321473	354664	0.495
1987	67550	1790040	1216250	386145	0.371
1988	274191	983098	699586	453202	0.541
1989	125419	1073640	235034	561996	0.928
1990	172883	576986	218308	253549	0.920
1991	183495	777425	179133	287579	0.614
1992	41438	1197160	386880	585653	0.918
1993	160148	502134	277299	144728	0.404
1994	220055	888287	205151	243284	0.328
1995	57678	1065070	322351	311010	0.605
1996	379686	808206	472013	344724	0.566
1997	58381	1487910	267058	335927	0.534
1998	110564	844179	504177	373101	0.690
1999	150528	659600	270740	487491	1.134
2000	248330	556927	126568	267818	0.913
2001	393903	992539	159503	626191	1.405
2002	25556	1055980	154517	499797	1.068
2003	142235	341270	220158	198921	0.898
2004	62223	334242	85841	156709	0.935
2005	171057	263248	96090	103452	1.003
2006	90186	617780	71556	257364	1.362
2007	218626	379997	106323	113400	0.541
2008	86372	718992	135621	205683	1.012
2009	658457	488807	195967	325995	1.253
2010	49731	2021820	120353	285691	0.467
2011	62858	1183400	845150	442607	0.518
2012	149477	413491	266250	50163	0.098
2013	105174	580022	175314	285375	0.622
2014	381470	317922	99083	77834	0.371
2015	23476	864276	110407	141199	0.359
2016			246221		
arith. mean	186711	873983	294551	317967	0.721
geo. mean	140321				

2.2.9 Historic Stock Trends

The stock summary (Figure 2.2.9.1 and Table 2.2.8.4) shows that SSB have been at or below B_{lim} from 2004 to 2007 and again in 2014 and 2015. Since 2008, SSB has been above B_{lim} but below B_{pa} in 2009-2010 and 2014–2015. SSB is estimated above B_{pa} in 2016. $F_{(1-2)}$ is estimated to have been below the long-time average since 2010. Recruitment in 2015 is estimated to be the lowest observed in the time series.

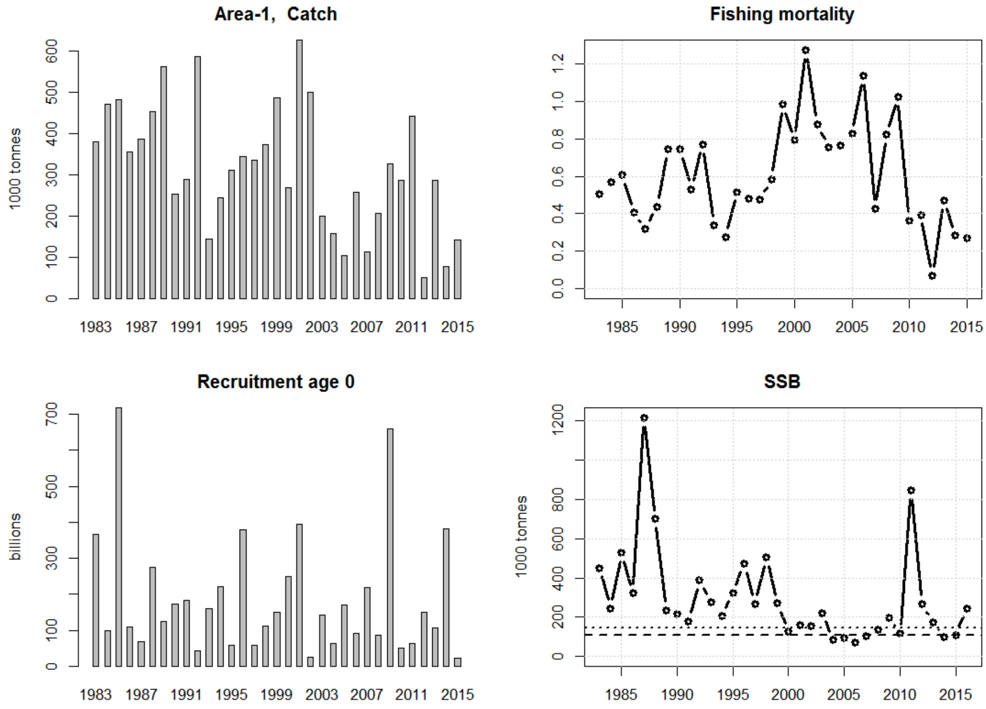


Fig. 2.2.9.1. Stock summary for sandeel in area 1r.

2.3 Short term projections

Weight at age shows no recent trends and should be set at 5 years.

Selection pattern is taken as the last year estimated in SMS. Natural mortality is also taken from the final year, as this is already a 3 year average. Maturity is set at the long term average, similar to the assessment. Recruitment shows no trend and a geometric average of the full period should be used.

2.4 Appropriate Reference Points (MSY)

Examining the stock recruitment relation, there appeared to be a decrease at low SSBs but no relationship at higher SSBs. After examining time patterns in recruitment and SSB, it was decided that the recruitment was of type ‘spasmodic’ and accordingly, Blim was set at the lowest SSB which provided a high recruitment, in this case 2014, which led to a Blim of 110 000 t. With an average CV of the SSB in the last assessment year of 0.17 this results in a Bpa of 145 000 t.

3 Stock SA 2r

Sandeel (*Ammodytes* spp.) in divisions 4.b and 4.c, Sandeel Area 2r (central and southern North Sea); ICES statistical rectangles 35 F7-F8; 36 F7-F9; 37 F7-F8; 38-41 F6-F8; 42 F6-F9; 43 F7-F9; 44 F9-G0; 45 G0-G1; 46 G1.

3.1 Ecosystem drivers

There is strong evidence that sandeel stocks are affected by bottom-up processes involving climate and changing plankton stocks. Sandeel are high quality food for many predatory fish, seabirds and marine mammals. Given the semi-sedentary behaviour of sandeel after settling, local depletion of sandeel aggregations at a distance less than 100 km from seabird colonies may affect some species of birds, especially black-legged kittiwake and sandwich tern, whereas the more mobile marine mammals and fish are likely to be less vulnerable to local sandeel depletion.

Section 1.5 contains a comprehensive description of ecosystem aspects.

3.2 Stock Assessment

General information about the sandeel fishery can be found in Section 1.6.

Catches in the new SA2, SA2r, over time are shown in Table 3.2.1 and Figure 3.2.1.

Table 3.2.1. SA 2r Sandeel. Catch at age numbers (millions) by half year.

Year/Age	Age 0, 2nd half	Age 1, 1st half	Age 1, 2nd half	Age 2, 1st half	Age 2, 2nd half	Age 3, 1st half	Age 3, 2nd half	Age 4+, 1st half	Age 4+, 2nd half
1983	12882	4162	476	6190	877	203	104	67	0
1984	0	10284	3846	912	186	1154	193	38	10
1985	1827	1411	392	5501	768	473	387	109	50
1986	1443	24479	3495	3144	208	436	95	6	7
1987	45	831	512	2621	591	131	17	20	4
1988	5602	1030	545	3379	226	3163	775	478	31
1989	2819	23364	3809	1666	273	938	10	909	34
1990	5046	7332	854	3967	196	587	29	177	9
1991	10053	14203	3628	2099	110	451	35	156	1
1992	6830	12016	886	4066	85	475	34	298	7
1993	14083	4814	873	1294	660	642	226	475	56
1994	0	25596	4477	3619	919	341	275	199	118
1995	1798	4897	1316	1598	1777	209	211	88	159
1996	26463	2472	7161	1573	475	905	278	260	186
1997	284	29071	8330	1640	193	628	83	207	47
1998	1070	645	106	4749	1424	437	136	348	144
1999	4130	841	1113	177	102	855	501	186	149
2000	519	8160	1066	566	164	217	98	518	134
2001	5767	2625	2414	1010	563	129	73	367	228
2002	4	15855	1379	891	185	393	35	85	28
2003	3711	267	79	1723	453	136	43	67	17

2004	755	10761	2034	711	212	537	297	174	55
2005	15	2171	490	513	336	48	32	116	91
2006	8	2441	1030	276	125	100	64	27	39
2007	0	6431	0	240	0	32	0	5	0
2008	1	4621	187	434	64	90	36	15	5
2009	103	2817	1867	671	145	42	25	4	1
2010	2	6490	1308	193	35	374	27	60	4
2011	0	404	19	1474	91	236	17	59	3
2012	0	168	6	194	51	293	6	60	10
2013	0	4824	431	1158	47	296	16	99	5
2014	301	2987	141	2371	28	340	3	119	5
2015	0	1874	42	713	9	559	2	195	2
arith. mean	3199	7283	1646	1859	351	480	126	182	50

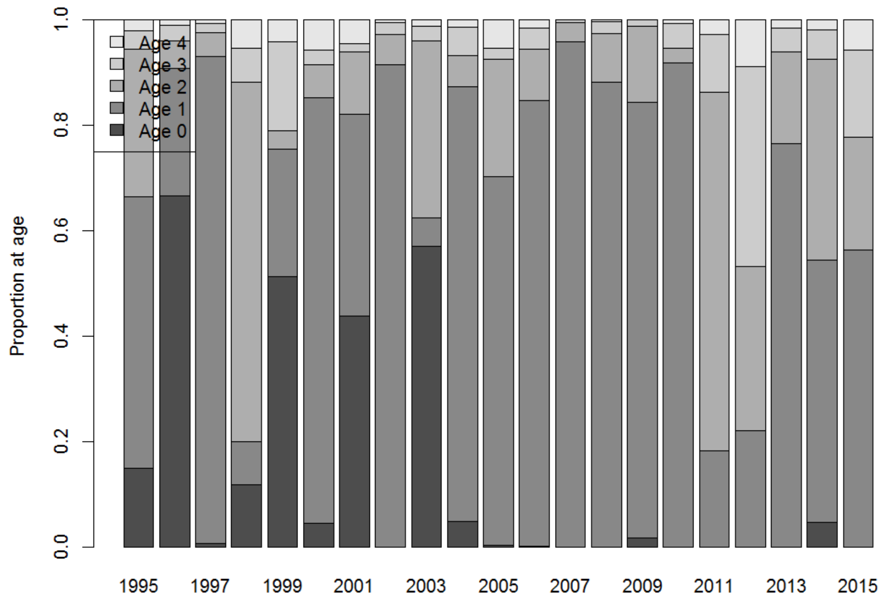


Fig. 3.2.1. Distribution of catches on ages in area 2r.

3.2.1 Surveys

Dredge survey catches are given in Table 3.2.1.1. Only the period from 2010 onwards is used due to limited coverage in previous years. Age 2+ is not used.

Table 3.2.1.1. Dredge survey index.

Year	Age 0	Age 1	Age 2+
2010	716	1424	202
2011	1043	262	266

2012	7850	56	
2013	5301	1808	609
2014	4891	1017	
2015	563	169	117

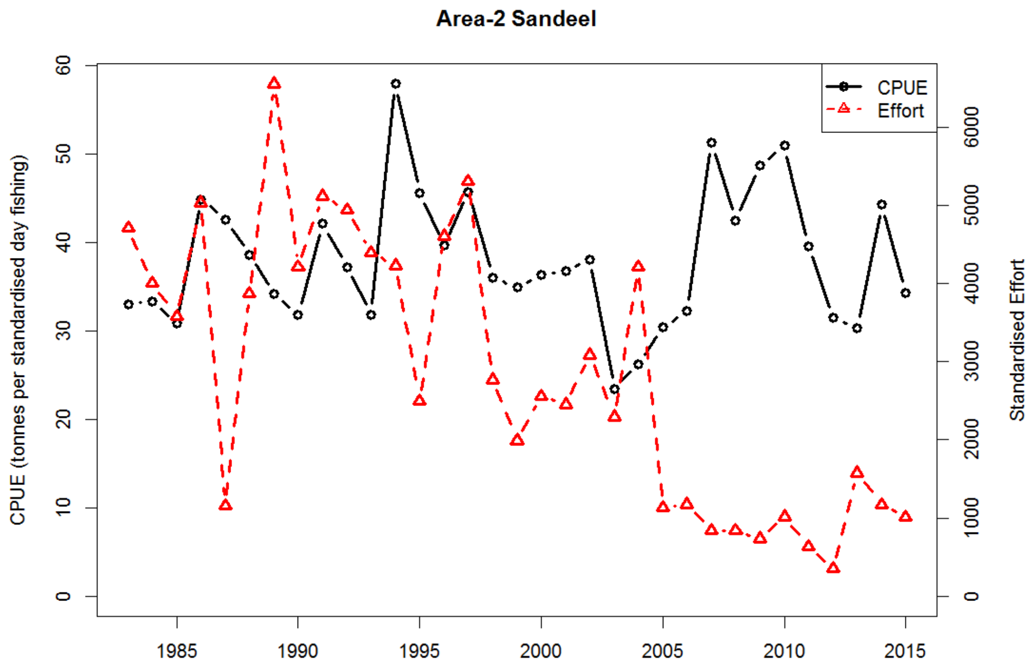


Figure 3.2.1.1. CPUE and effort series.

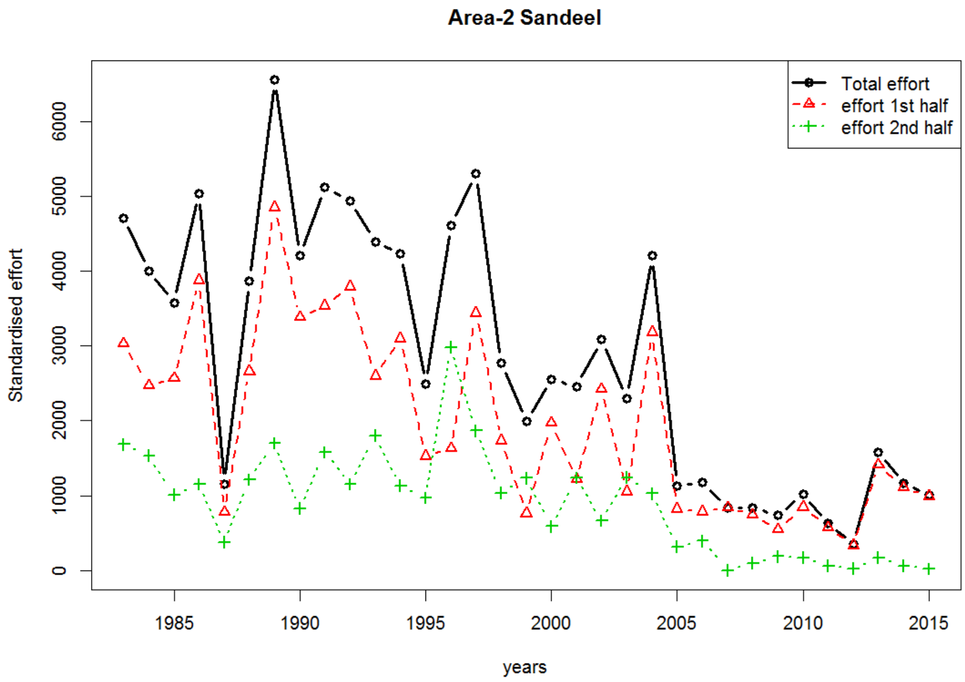


Figure 3.2.1.2. Effort in the first and second half year.

3.2.2 Maturity

Average maturity at age from dredge survey catches in sandeel area 3 were used. Values are given in Table 3.2.2.1.

Table 3.2.2.1 Maturity at age in area 2r.

Age	0	1	2	3	4+
	0.00	0.02	0.83	1.00	1.00

3.2.3 Natural mortality

Long term average natural mortality at age from multispecies modelling of southern and northern sandeel (SMS, WGSAM 2015) were used, weighing the values by the estimated northern and southern sandeel abundance derived from multispecies modelling (Table 3.2.3.1).

Table 3.2.3.1 Annual natural mortality at age in area 2r.

	Age 0	Age 1	Age 2	Age 3	Age 4
Season 1	0	0.571	0.437	0.317	0.311
Season 2	0.925	0.586	0.491	0.419	0.409

3.2.4 Weight at age

Weight at age in the stock and catch was estimated from catch samples. Table 3.2.4.1 show the individual mean weight in catch and stock by year, age and season.

Table 3.2.4.1 SA 2 Sandeel. Individual mean weight(g) at age in the catch and in the stock.

Year/Age	Age 0, 2nd half	Age 1, 1st half	Age 1, 2nd half	Age 2, 1st half	Age 2, 2nd half	Age 3, 1st half	Age 3, 2nd half	Age 4+, 1st half	Age 4+, 2nd half
1983	3.3	5.2	9.9	10.8	16.5	12.8	22.9	15.0	27.3
1984	5.9	5.6	10.2	11.1	14.1	15.6	25.8	18.8	30.1
1985	4.6	6.7	10.7	9.9	16.8	17.5	23.3	24.1	27.5
1986	3.2	5.9	9.9	10.4	15.8	12.7	15.0	15.0	17.0
1987	2.8	5.8	8.7	11.1	12.9	16.4	21.1	14.6	19.4
1988	3.5	5.5	7.2	11.1	15.3	16.1	21.0	23.1	30.6
1989	4.8	5.7	9.4	9.1	13.4	10.1	14.4	12.1	18.0
1990	4.4	7.1	8.1	9.7	11.8	14.4	17.4	17.3	20.8
1991	3.8	7.7	5.7	12.1	11.0	35.8	32.6	21.2	20.1
1992	4.7	6.9	15.0	9.9	20.6	13.5	29.3	17.9	29.2
1993	2.7	7.7	9.3	15.1	14.8	16.9	17.5	22.3	22.0
1994	3.6	5.4	7.6	10.5	18.8	15.3	23.0	19.5	20.7
1995	5.2	7.6	8.9	12.4	13.2	16.0	17.6	19.2	21.1
1996	2.7	7.0	4.9	12.4	13.2	17.0	15.8	28.0	24.5
1997	3.2	5.3	7.1	8.0	11.2	13.1	13.8	15.9	14.9
1998	3.4	6.2	6.7	11.4	14.0	14.7	16.5	17.4	18.3
1999	5.3	8.1	9.1	11.8	12.8	15.4	15.3	19.1	19.6
2000	3.1	6.8	10.2	9.9	13.0	15.2	17.9	18.0	19.5
2001	4.0	6.0	5.0	12.9	16.1	16.6	21.7	20.4	26.2
2002	3.2	5.7	8.3	8.4	13.2	9.6	15.3	17.3	17.7
2003	5.4	6.0	8.1	11.3	16.0	15.1	21.4	18.2	27.2
2004	4.8	6.5	7.4	9.4	10.9	12.4	12.2	13.1	13.7
2005	3.4	7.5	7.4	11.8	11.9	14.4	15.4	14.8	17.5
2006	4.6	7.5	9.9	11.5	15.9	13.9	20.6	14.8	23.4
2007	5.7	6.2	6.2	12.4	12.4	15.4	15.4	17.8	17.8
2008	3.4	5.5	7.5	12.5	12.0	16.1	15.6	18.0	17.7
2009	6.0	6.1	5.0	8.6	10.9	16.5	18.6	12.2	11.0
2010	2.4	5.7	5.3	10.3	8.4	11.5	11.0	13.2	12.4
2011	3.5	6.9	7.6	11.1	12.2	13.8	15.8	14.6	18.0
2012	4.3	9.4	9.4	13.4	15.1	15.1	19.6	21.5	22.3
2013	3.8	5.9	8.8	7.9	11.6	14.2	14.4	14.1	16.5
2014	3.3	6.1	7.1	10.4	11.4	11.9	14.8	18.5	16.8
2015	5.3	6.9	11.4	12.8	18.4	15.3	23.8	17.2	27.1
arith. mean	4.0	6.5	8.3	11.0	13.8	15.2	18.7	17.7	20.8

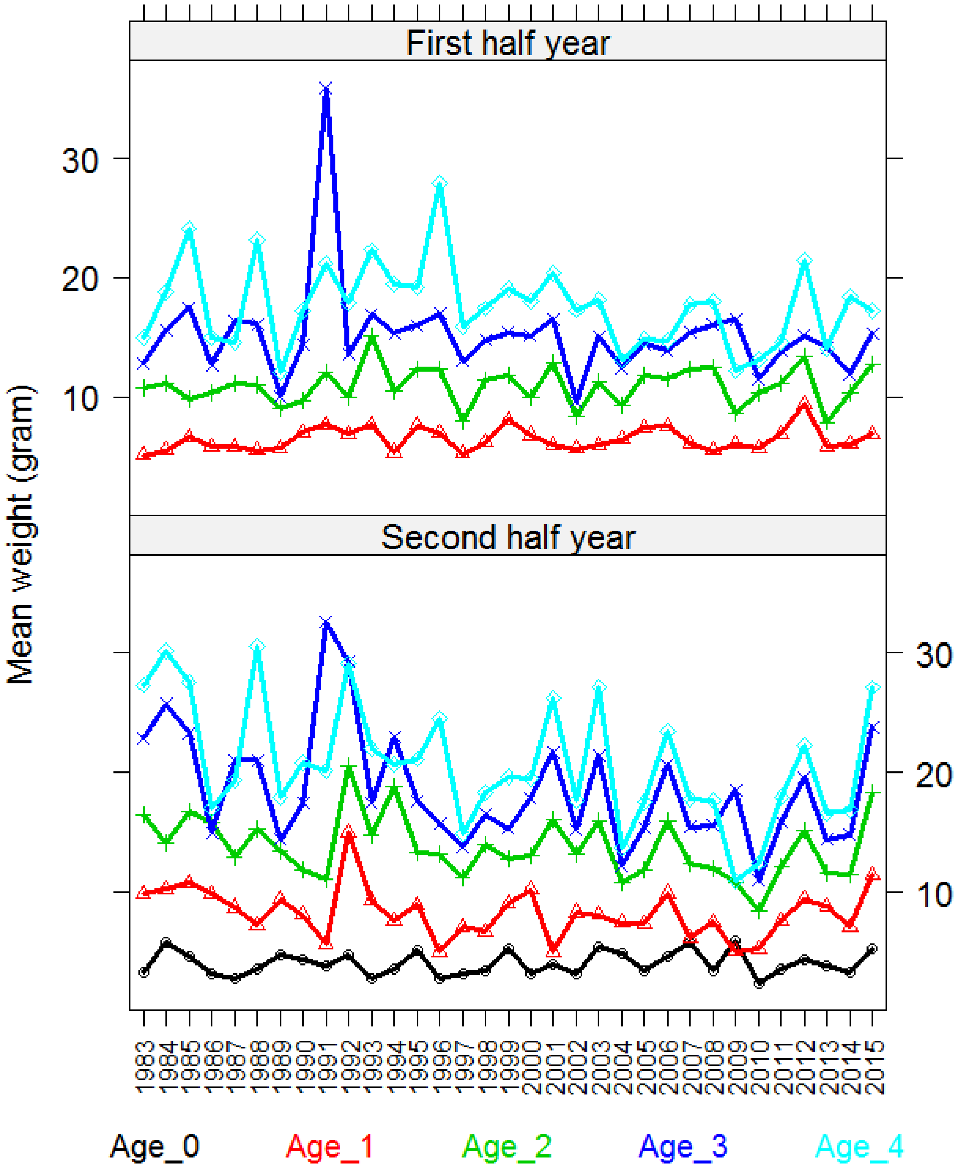


Figure 3.2.4.1. Weight at age in the catch and in the stock.

3.2.5 Commercial data

Catch at age is given in Table 3.2.5.1 and input effort is given in Table 3.2.5.2.

Table 3.2.5.1 SA 2 Sandeel. Catch at age numbers (millions) by half year

Year/Age	Age 0, 2nd half	Age 1, 1st half	Age 1, 2nd half	Age 2, 1st half	Age 2, 2nd half	Age 3, 1st half	Age 3, 2nd half	Age 4+, 1st half	Age 4+, 2nd half
1983	12882	4162	476	6190	877	203	104	67	0
1984	0	10284	3846	912	186	1154	193	38	10
1985	1827	1411	392	5501	768	473	387	109	50

1986	1443	24479	3495	3144	208	436	95	6	7
1987	45	831	512	2621	591	131	17	20	4
1988	5602	1030	545	3379	226	3163	775	478	31
1989	2819	23364	3809	1666	273	938	10	909	34
1990	5046	7332	854	3967	196	587	29	177	9
1991	10053	14203	3628	2099	110	451	35	156	1
1992	6830	12016	886	4066	85	475	34	298	7
1993	14083	4814	873	1294	660	642	226	475	56
1994	0	25596	4477	3619	919	341	275	199	118
1995	1798	4897	1316	1598	1777	209	211	88	159
1996	26463	2472	7161	1573	475	905	278	260	186
1997	284	29071	8330	1640	193	628	83	207	47
1998	1070	645	106	4749	1424	437	136	348	144
1999	4130	841	1113	177	102	855	501	186	149
2000	519	8160	1066	566	164	217	98	518	134
2001	5767	2625	2414	1010	563	129	73	367	228
2002	4	15855	1379	891	185	393	35	85	28
2003	3711	267	79	1723	453	136	43	67	17
2004	755	10761	2034	711	212	537	297	174	55
2005	15	2171	490	513	336	48	32	116	91
2006	8	2441	1030	276	125	100	64	27	39
2007	0	6431	0	240	0	32	0	5	0
2008	1	4621	187	434	64	90	36	15	5
2009	103	2817	1867	671	145	42	25	4	1
2010	2	6490	1308	193	35	374	27	60	4
2011	0	404	19	1474	91	236	17	59	3
2012	0	168	6	194	51	293	6	60	10
2013	0	4824	431	1158	47	296	16	99	5
2014	301	2987	141	2371	28	340	3	119	5
2015	0	1874	42	713	9	559	2	195	2
arith. mean	3199	7283	1646	1859	351	480	126	182	50

Table 3.2.5.2. SA 2 Sandeel. Standardised effort (fishing days for a 200 GT vessels)

Year/Age	1st half year	2nd half year	Sum
1983	3030	1686	4715
1984	2469	1536	4005
1985	2569	1011	3580
1986	3881	1153	5034
1987	778	374	1152
1988	2658	1215	3873
1989	4856	1701	6557
1990	3383	829	4212
1991	3540	1580	5120
1992	3796	1152	4948
1993	2599	1800	4399

1994	3099	1134	4232
1995	1528	970	2498
1996	1628	2982	4609
1997	3441	1869	5310
1998	1735	1035	2770
1999	757	1235	1992
2000	1972	588	2560
2001	1219	1236	2455
2002	2422	664	3086
2003	1053	1242	2295
2004	3186	1028	4214
2005	818	316	1133
2006	782	392	1175
2007	842	0	842
2008	741	97	838
2009	547	187	733
2010	842	171	1014
2011	569	61	630
2012	331	21	352
2013	1410	168	1578
2014	1104	60	1165
2015	994	19	1012
arith. mean	1957	894	2851

3.2.6 Assessment model

The diagnostics output from SMS are shown in Table 3.2.6.1. The seasonal effect on the relation between effort and F (“F, Season effect” in the table) is rather constant over the five year ranges used. The “age selection” (“F, age effect” in the table) shows a change in the fishery pattern where the fishery was mainly targeting the age 2+ sandeel in the beginning of the assessment period, to a fishery targeting age 1+ in a similar way and back in the most recent period to sandeel of age 2+.

The CV of the dredge survey (“sqrt (Survey variance) ~CV” in the table) is low (0.30) for age 0 and very high (0.84) for age 1. The survey residual plot (Figure 3.2.6.1) shows a tendency to autocorrelation in the age 0 index, but no apparent trends or other patterns.

The model CV of catch at age (“sqrt(catch variance) ~CV”, in Table 3.2.6.1 is low (0.31) for age 1 and age 2 in the first half of the year and high (> 0.6) for the remaining ages and season combinations. The catch at age residuals (Figure 3.2.6.2) show no alarming patterns.

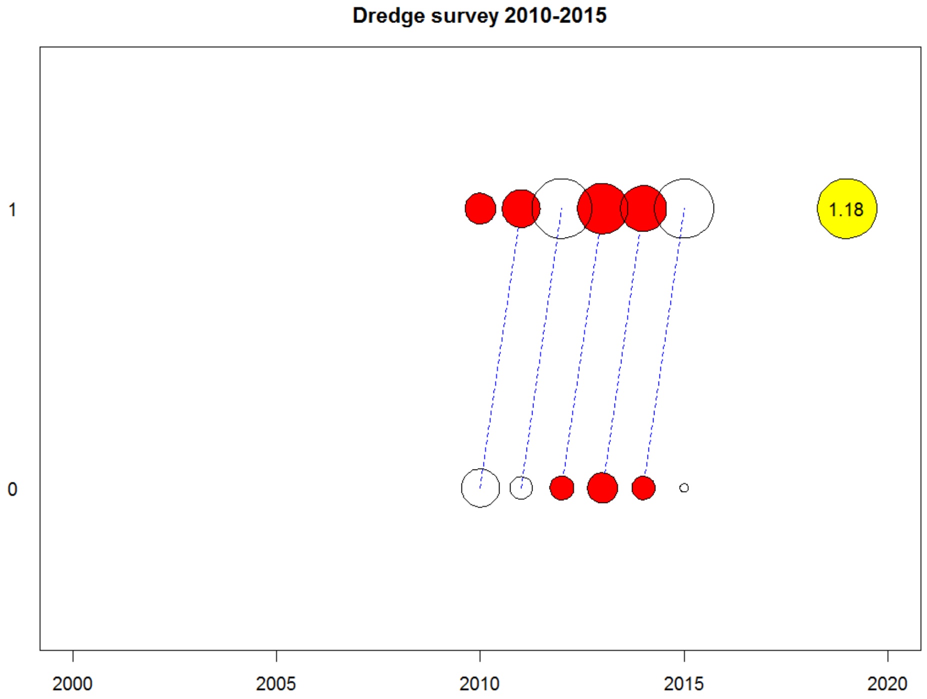


Figure 3.2.6.1 Survey residuals.

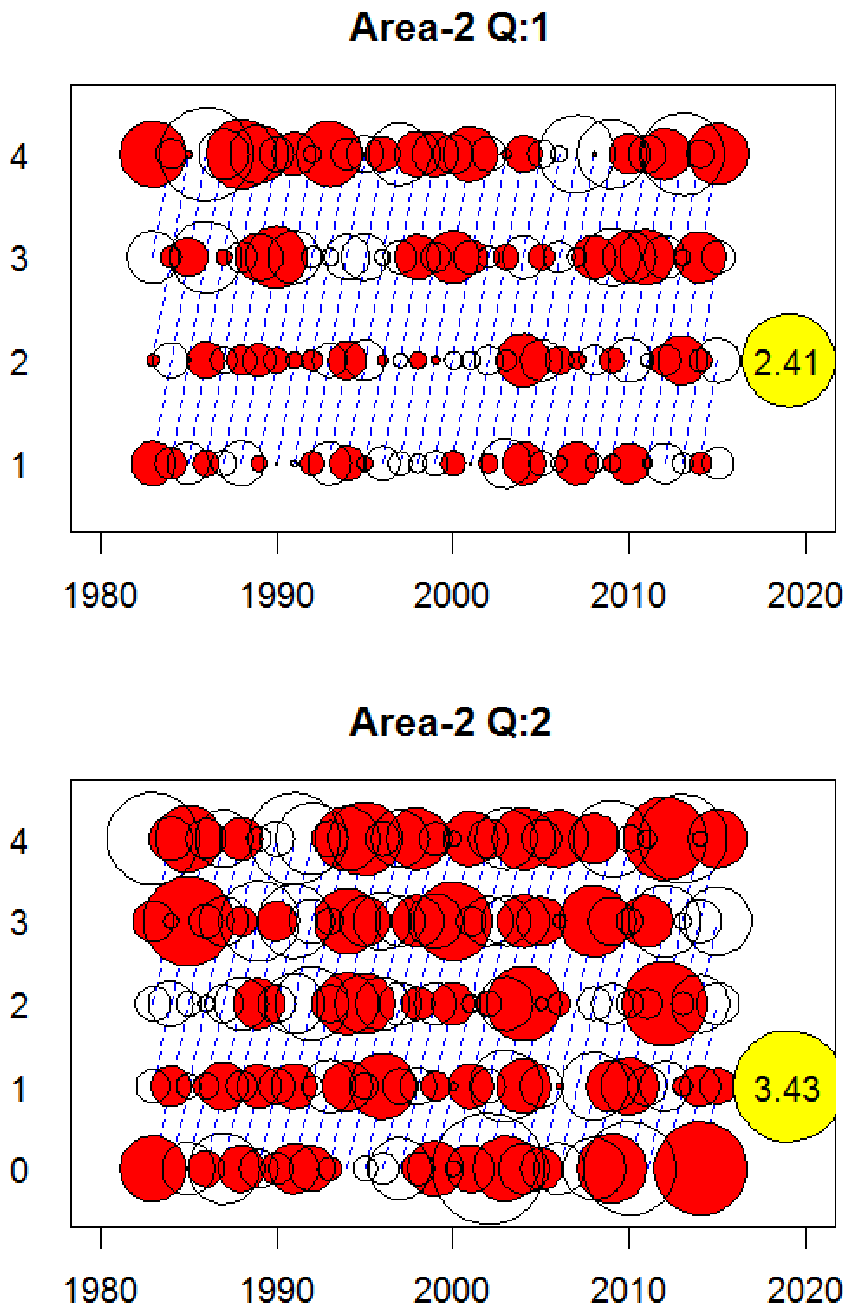


Figure 3.2.6.2 Catch residuals.

The CV of the fitted Stock recruitment relationship (Table 3.2.6.1) is high (0.95), which is also indicated by the stock recruitment plot (Figure 3.2.6.3). The high CV of recruitment is probably due to biological characteristic of the stock and not the quality of the assessment. The *a priori* weight on likelihood contributions from SSR-R observations is therefore set low (0.05 in "objective function weight" in Table 3.2.6.1) such that SSB-R estimates do not contribute much to the overall likelihood and model fit.

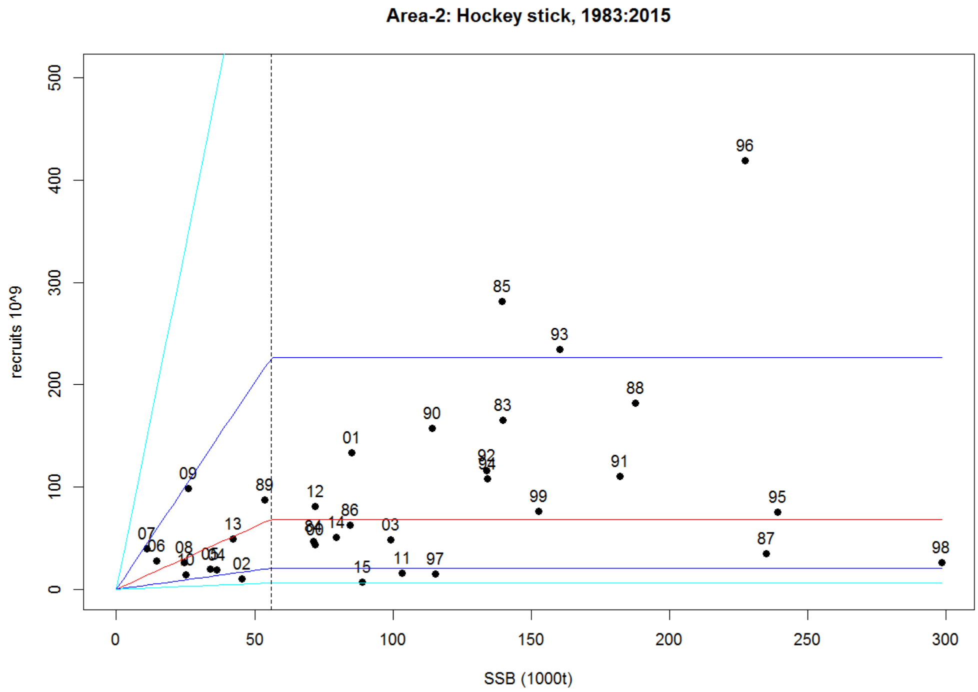


Fig. 3.2.6.3. Stock-recruitment relationship.

The retrospective analysis (Figure 3.2.6.4) shows very consistent assessment results from one year to the next in SSB and F but a large retrospective pattern in recruitment. This is partly due to the assumed robust relationship between effort and F within the defined seperability blocks (where the last block starts in 2010), which is rather insensitive to removal of a few years and the low weight of the dredge survey.

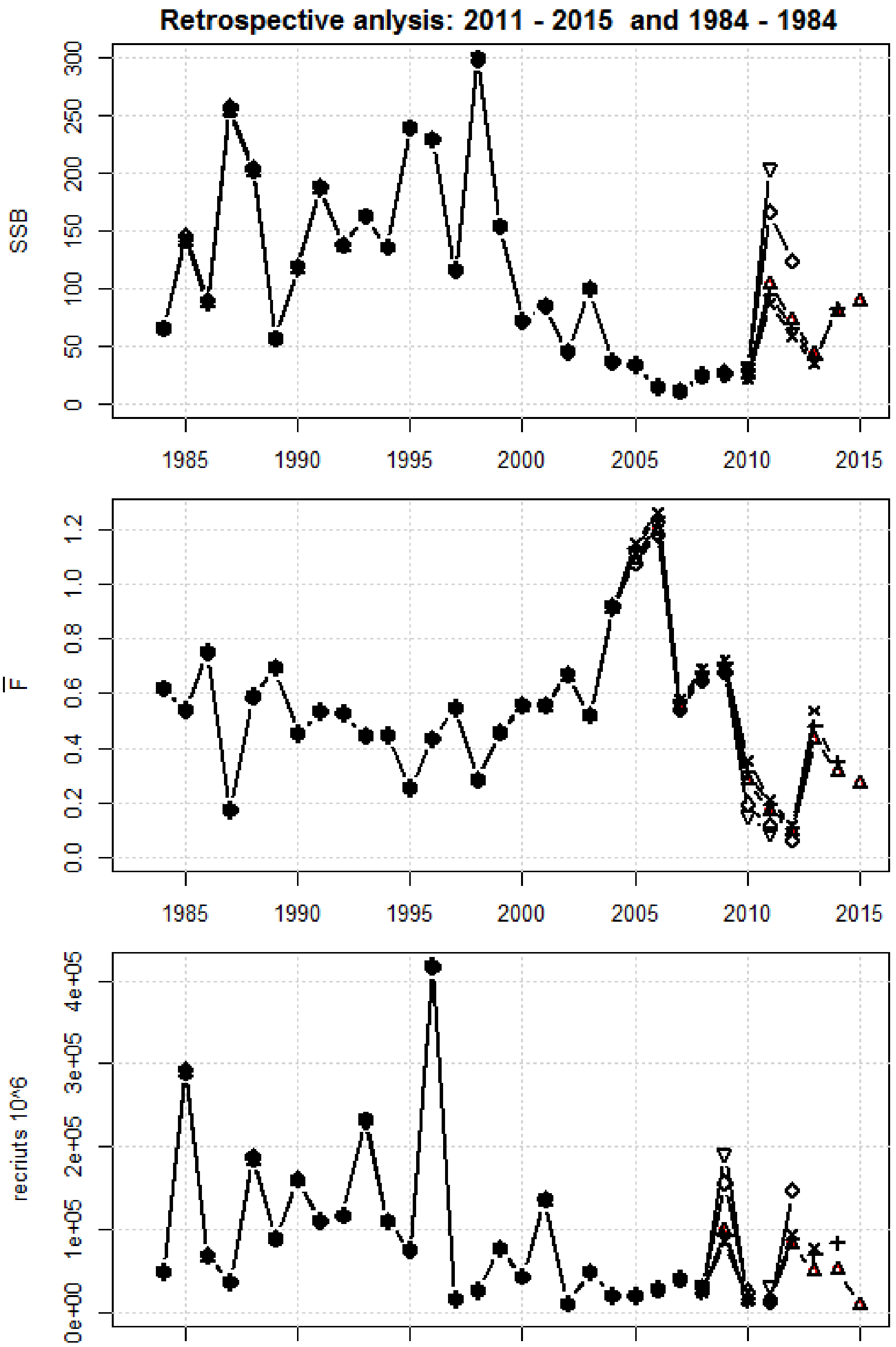


Figure 3.2.6.4. Retrospective analysis.

Uncertainties of the estimated SSB, F and recruitment (Figure 3.2.6.5) are in general small. For F, uncertainties are lowest for the most recent years, which are not normally seen. This is due to the model fit where the most recent effort values estimate F with a small error (Figure 3.2.6.6), while older observations have a larger difference between effort and F (Figure 3.2.6.7).

Table 3.2.6.1. Assessment fit summary.

Date: 11/04/16 Start time:10:50:53 run time:0 seconds

```
objective function (negative log likelihood):  25.086

Number of parameters: 68

Maximum gradient: 2.635e-005

Akaike information criterion (AIC):   186.172

Number of observations used in the likelihood:

                    Catch    CPUE     S/R Stomach     Sum

                     297      12      33       0     342


objective function weight:

                  Catch  CPUE   S/R

                  1.00  1.00  0.10


unweighted objective function contributions (total):

           Catch    CPUE    S/R   Stom.  Stom N.  Penalty     Sum

          26.5    -2.9    14.7     0.0     0.0      0.00      38



unweighted objective function contributions (per observation):

           Catch   CPUE     S/R   Stomachs

          0.09   -0.24    0.44    0.00



contribution by fleet:

----------------------

Dredge survey 2010-2015     total:  -2.906   mean:  -0.242


F, season effect:

-----------------

age: 0

   1983-1988:   0.000 1.000

   1989-1998:   0.000 1.000

   1999-2004:   0.000 1.000

   2005-2009:   0.000 1.000

   2010-2015:   0.000 1.000

age: 1 - 4
```

```
   1983-1988:   0.480 0.500
   1989-1998:   0.672 0.500
   1999-2004:   0.425 0.500
   2005-2009:   0.192 0.500
   2010-2015:   0.399 0.500

F, age effect:
--------------
              0      1      2      3      4
1983-1988:  0.040  0.275  0.888  1.500  1.500
1989-1998:  0.101  0.346  0.416  0.485  0.485
1999-2004:  0.041  0.603  0.736  0.739  0.739
2005-2009:  0.001  1.958  1.650  1.784  1.784
2010-2015:  0.006  0.209  0.432  0.703  0.703



Exploitation pattern (scaled to mean F=1)
----------------------------------------
                     0      1      2      3      4
1983-1988 season 1:      0  0.300  0.967  1.633  1.633
          season 2:  0.051  0.174  0.560  0.946  0.946

1989-1998 season 1:      0  0.720  0.866  1.010  1.010
          season 2:  0.110  0.188  0.226  0.263  0.263

1999-2004 season 1:      0  0.309  0.377  0.378  0.378
          season 2:  0.080  0.592  0.723  0.726  0.726

2005-2009 season 1:      0  0.541  0.456  0.493  0.493
          season 2:  0.001  0.544  0.459  0.496  0.496

2010-2015 season 1:      0  0.520  1.074  1.747  1.747
          season 2:  0.008  0.132  0.274  0.445  0.445
```

```
sqrt(catch variance) ~ CV:
--------------------------


            season
----------------------
age      1      2


 0            1.192
 1      0.310   0.675
 2      0.310   0.675
 3      0.740   1.020
 4      0.740   1.020



Survey catchability:
--------------------
                        age 0    age 1
 Dredge survey 2010-2015      17.918    9.386

sqrt(Survey variance) ~ CV:
---------------------------
                        age 0    age 1
 Dredge survey 2010-2015        0.30     0.84

Recruit-SSB                          alfa      beta       recruit s2     recruit s
Area-2      Hockey stick -break.:     1250.913   5.400e+004   0.894          0.946
```

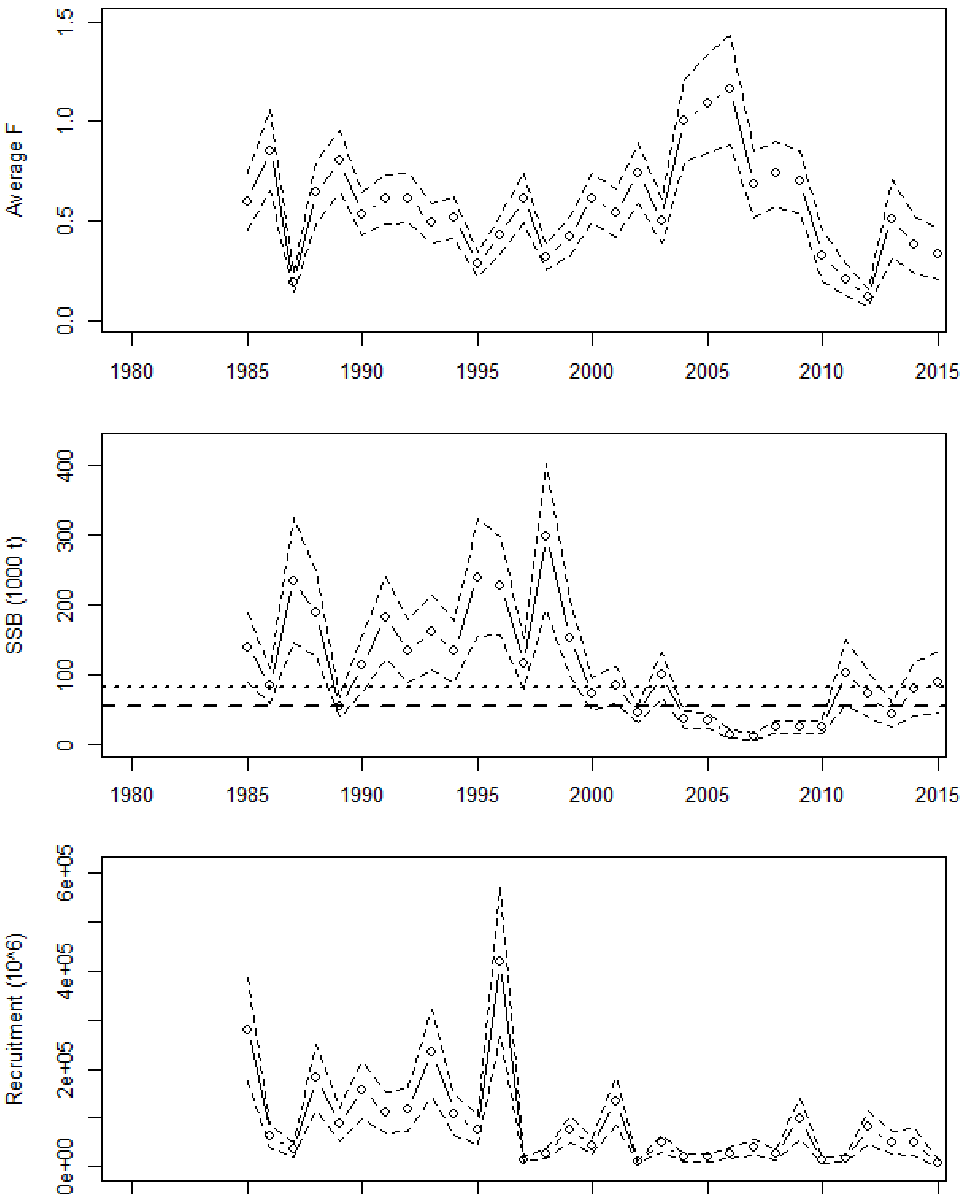


Fig. 3.2.6.5. Predicted stock size, F and recruitment and associated uncertainties.

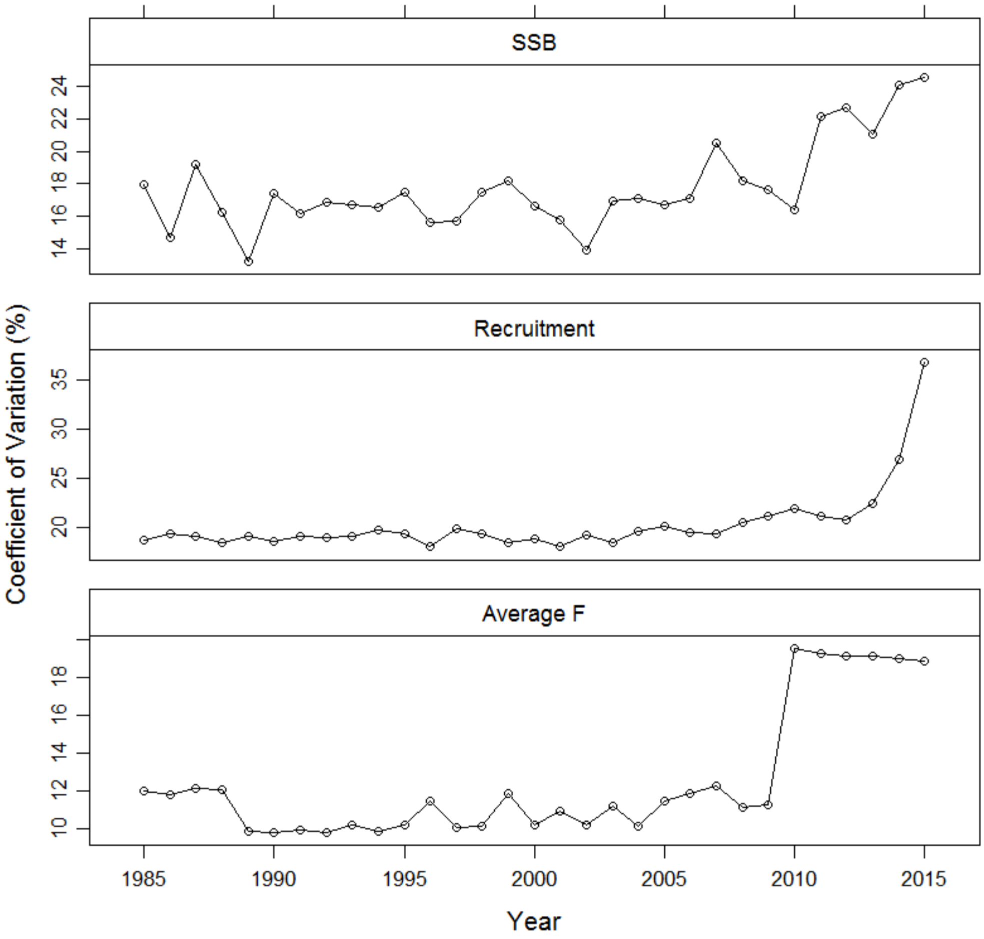


Fig. 3.2.6.6. CV of SSB, recruitment and F.

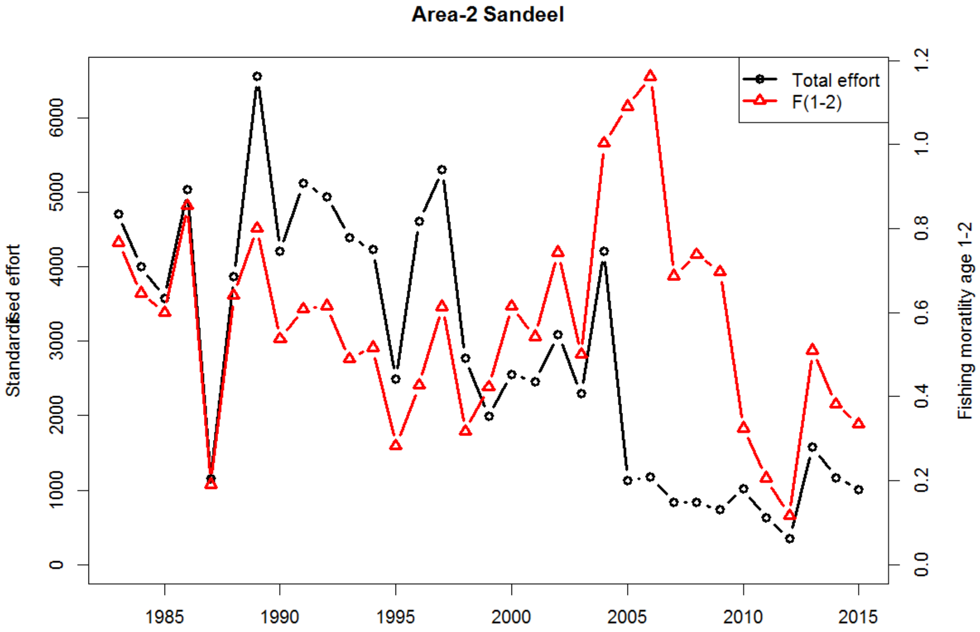


Fig. 3.2.6.7. Effort and estimated F.

3.2.7 Final assessment

The output from the assessment is presented in Tables 3.2.7.1 (fishing mortality at age by year), 3.2.7.2 (fishing mortality at age by half year), 3.2.7.3 (stock numbers at age) and 3.2.7.4 (stock summary).

Table 3.2.7.1. Sandeel SA 2r . Annual fishing mortality (F) at age.

Year/Age	Age 0	Age 1	Age 2	Age 3	Age 4	Avg. 1-2
1983	0.036	0.366	1.168	1.964	1.961	0.767
1984	0.033	0.307	0.984	1.661	1.659	0.646
1985	0.022	0.287	0.911	1.522	1.519	0.599
1986	0.025	0.413	1.296	2.147	2.142	0.854
1987	0.008	0.091	0.291	0.489	0.488	0.191
1988	0.026	0.307	0.975	1.633	1.630	0.641
1989	0.077	0.735	0.867	0.999	0.996	0.801
1990	0.038	0.493	0.580	0.666	0.664	0.537
1991	0.072	0.557	0.660	0.763	0.761	0.609
1992	0.052	0.566	0.666	0.767	0.764	0.616
1993	0.082	0.447	0.533	0.621	0.620	0.490
1994	0.052	0.474	0.560	0.645	0.643	0.517
1995	0.044	0.258	0.308	0.358	0.357	0.283
1996	0.136	0.384	0.471	0.560	0.559	0.428
1997	0.085	0.561	0.667	0.773	0.771	0.614
1998	0.047	0.289	0.344	0.400	0.399	0.317
1999	0.036	0.374	0.470	0.486	0.486	0.422

2000	0.017	0.558	0.672	0.670	0.668	0.615
2001	0.036	0.485	0.601	0.613	0.613	0.543
2002	0.020	0.674	0.811	0.808	0.806	0.743
2003	0.037	0.446	0.555	0.569	0.569	0.501
2004	0.030	0.910	1.097	1.095	1.093	1.003
2005	0.001	1.179	1.002	1.097	1.096	1.090
2006	0.001	1.252	1.071	1.179	1.179	1.162
2007	0.000	0.755	0.619	0.653	0.651	0.687
2008	0.000	0.804	0.670	0.719	0.717	0.737
2009	0.000	0.755	0.640	0.699	0.698	0.697
2010	0.002	0.215	0.435	0.696	0.694	0.325
2011	0.001	0.137	0.274	0.437	0.436	0.206
2012	0.000	0.077	0.155	0.246	0.246	0.116
2013	0.002	0.340	0.681	1.081	1.077	0.510
2014	0.001	0.255	0.509	0.805	0.802	0.382
2015	0.000	0.224	0.445	0.703	0.700	0.335
arith. mean	0.031	0.484	0.666	0.864	0.862	0.575

Table 3.2.7.2. Sandeel SA 2r . Seasonal fishing mortality (F) at age.

Year/Age	Age 0, 2nd half	Age 1, 1st half	Age 1, 2nd half	Age 2, 1st half	Age 2, 2nd half	Age 3, 1st half	Age 3, 2nd half	Age 4+, 1st half	Age 4+, 2nd half
1983	0.036	0.215	0.125	0.693	0.402	1.171	0.679	1.171	0.679
1984	0.033	0.175	0.113	0.565	0.366	0.954	0.618	0.954	0.618
1985	0.022	0.182	0.075	0.588	0.241	0.993	0.407	0.993	0.407
1986	0.025	0.275	0.085	0.888	0.275	1.501	0.464	1.501	0.464
1987	0.008	0.055	0.028	0.178	0.089	0.301	0.151	0.301	0.151
1988	0.026	0.189	0.090	0.608	0.289	1.028	0.489	1.028	0.489
1989	0.077	0.505	0.132	0.607	0.158	0.708	0.185	0.708	0.185
1990	0.038	0.352	0.064	0.423	0.077	0.494	0.090	0.494	0.090
1991	0.072	0.368	0.122	0.443	0.147	0.516	0.172	0.516	0.172
1992	0.052	0.395	0.089	0.475	0.107	0.554	0.125	0.554	0.125
1993	0.082	0.270	0.139	0.325	0.168	0.379	0.195	0.379	0.195
1994	0.052	0.322	0.088	0.387	0.106	0.452	0.123	0.452	0.123
1995	0.044	0.159	0.075	0.191	0.090	0.223	0.105	0.223	0.105
1996	0.136	0.169	0.231	0.204	0.278	0.237	0.324	0.237	0.324
1997	0.085	0.358	0.145	0.430	0.174	0.502	0.203	0.502	0.203
1998	0.047	0.180	0.080	0.217	0.096	0.253	0.112	0.253	0.112
1999	0.036	0.140	0.269	0.171	0.329	0.172	0.330	0.172	0.330
2000	0.017	0.365	0.128	0.446	0.156	0.448	0.157	0.448	0.157
2001	0.036	0.226	0.269	0.276	0.329	0.277	0.330	0.277	0.330
2002	0.020	0.449	0.145	0.548	0.177	0.550	0.177	0.550	0.177
2003	0.037	0.195	0.271	0.238	0.331	0.239	0.332	0.239	0.332
2004	0.030	0.590	0.224	0.721	0.274	0.724	0.275	0.724	0.275
2005	0.001	0.586	0.589	0.494	0.497	0.534	0.537	0.534	0.537
2006	0.001	0.561	0.732	0.472	0.617	0.511	0.667	0.511	0.667

2007	0.000	0.603	0.000	0.508	0.000	0.550	0.000	0.550	0.000
2008	0.000	0.531	0.181	0.448	0.153	0.484	0.165	0.484	0.165
2009	0.000	0.392	0.349	0.330	0.294	0.357	0.318	0.357	0.318
2010	0.002	0.147	0.037	0.303	0.077	0.493	0.126	0.493	0.126
2011	0.001	0.099	0.013	0.205	0.028	0.333	0.045	0.333	0.045
2012	0.000	0.058	0.005	0.119	0.010	0.194	0.016	0.194	0.016
2013	0.002	0.246	0.037	0.508	0.076	0.826	0.123	0.826	0.123
2014	0.001	0.193	0.013	0.398	0.027	0.647	0.044	0.647	0.044
2015	0.000	0.173	0.004	0.358	0.008	0.582	0.014	0.582	0.014
arith. mean	0.031	0.295	0.150	0.417	0.195	0.551	0.245	0.551	0.245

Table 3.2.7.3. Sandeel SA 2r . Stock numbers (millions). Age 0 at start of 2nd half-year, age 1+ at start of the year.

Year/Age	**Age 0**	**Age 1**	**Age 2**	**Age 3**	**Age 4**
1983	165564	16187	14322	701	33
1984	47025	63309	3624	1894	55
1985	281331	18040	14914	565	194
1986	62513	109152	4386	2574	90
1987	34985	24180	23928	542	179
1988	182276	13761	6998	7242	221
1989	87075	70410	3275	1127	785
1990	157318	31959	11710	602	377
1991	110055	60076	6628	2808	263
1992	116229	40617	11566	1453	740
1993	234139	43738	7870	2555	536
1994	108321	85550	9129	1901	836
1995	75260	40796	17850	2205	741
1996	419293	28556	10150	5326	1020
1997	15345	145190	6018	2481	1739
1998	26296	5589	27615	1300	1005
1999	76348	9948	1354	7981	772
2000	43209	29191	2077	325	2541
2001	133303	16839	5604	450	760
2002	9959	50965	3227	1210	319
2003	48415	3872	8853	618	355
2004	19260	18507	764	1982	265
2005	19615	7409	2578	112	397
2006	27510	7772	719	379	85
2007	39728	10899	671	96	68
2008	25952	15754	1875	160	46
2009	98719	10288	2429	407	52
2010	14519	39128	1543	515	112
2011	15473	5744	10232	417	162
2012	81215	6130	1614	3207	191

2013	49115	32195	1811	561	1321
2014	51100	19432	7632	400	353
2015	7206	20246	4974	1973	182
2016		2857	5332	1363	570

Table 3.2.7.4. Sandeel SA 2r. Estimated recruitment, total stock biomass (TBS), spawning stock biomass (SSB), catch weight (Yield) and average fishing mortality.

Year	**Recruits**	**TSB**	**SSB**	**Yield**	**Mean F**
(million)	**(tonnes)**	**(tonnes)**	**(tonnes)**	**ages 1-2**	
1983	165564	247949	139728	155693	0.767
1984	47025	423253	71197	133392	0.646
1985	281331	282615	139444	110527	0.599
1986	62513	719548	84623	225568	0.854
1987	34985	418500	235004	49067	0.191
1988	182276	275571	187774	149443	0.641
1989	87075	455160	53696	223610	0.801
1990	157318	355189	114118	133857	0.537
1991	110055	647436	182001	215565	0.609
1992	116229	429824	133974	184007	0.616
1993	234139	510281	160477	139803	0.490
1994	108321	601506	134121	244944	0.517
1995	75260	582492	239312	113907	0.283
1996	419293	444725	227357	182718	0.428
1997	15345	875453	115368	242187	0.614
1998	26296	385812	298422	99813	0.317
1999	76348	234582	152805	69427	0.422
2000	43209	270654	71924	92940	0.615
2001	133303	195720	85062	90166	0.543
2002	9959	332815	45350	117447	0.743
2003	48415	138861	99181	53687	0.501
2004	19260	154836	36400	110575	1.003
2005	19615	93216	33883	34396	1.090
2006	27510	73462	14552	37860	1.162
2007	39728	78020	10918	43094	0.687
2008	25952	114153	24532	35593	0.737
2009	98719	90714	26031	35685	0.697
2010	14519	246553	25082	51634	0.325
2011	15473	161829	103387	24897	0.206
2012	81215	132221	71787	11079	0.116
2013	49115	230702	42300	47837	0.510
2014	51100	208730	79637	51513	0.382
2015	7206	236272	88914	34697	0.335
2016			87659		
arith. mean	87384	322686	106353	107474	0.575
geo. mean	59162				

3.2.8 Historic Stock Trends

The stock summary (Figure 3.2.8.1 and Table 3.2.7.4) shows that SSB have been at or below B_{lim} from 2004 to 2010 and again in 2013. Since 2010, SSB has been above B_{lim} but below B_{pa} in 2012 and 2014. SSB is estimated just above B_{pa} in 2016. $F_{(1-2)}$ is estimated to have been below the long-time average since 2010. Recruitment in 2015 is estimated to be the lowest observed in the time series.

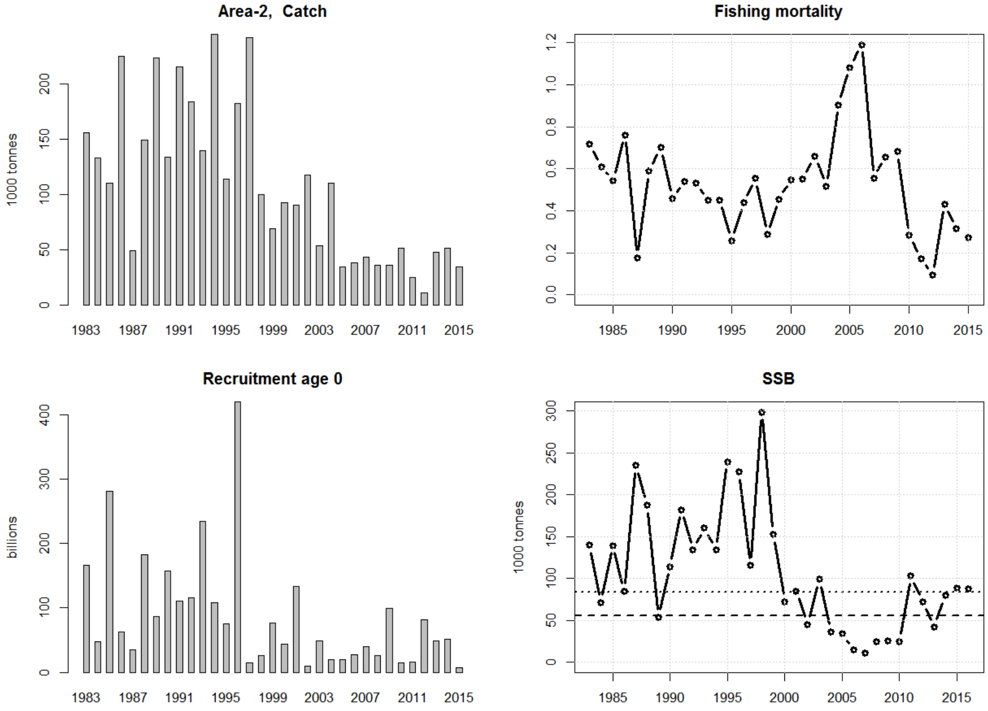


Figure 3.2.8.1. Stock summary for sandeel area 2r.

3.3 Short term projections

Weight at age shows no recent trends and should be set at 5 years.

Selection pattern is taken as the last year estimated in SMS. Natural mortality is also taken from the final year, as this is already a 3 year average. Maturity is set at the long term average, similar to the assessment. Recruitment has declined in the second part of the period, and to respond to such changes, a 10-year geometric average should be used.

3.4 Appropriate Reference Points (MSY)

Examining the stock recruitment relationship, there appeared to be a decrease in recruitment at low stock size and no clear breakpoint of the relationship. Above average cohorts in the low end of the SSB range occurred in 2009 and 2001. The 2009 cohort was 15% above average whereas the 2001 cohort was 57% above average. The average SSB of the two years was 55 546 t, and accordingly, Blim was set at 56 000 t. With a CV of 0.25, this results in a Bpa of 84 000 t.

4 Sandeel Area 3r

Sandeel (*Ammodytes* spp.) in divisions 3.a, 4.a, and 4.b, Sandeel Area 3r (Skagerrak and Kattegat, northern and central North Sea); ICES Statistical Rectangles 41-46 F1-F3; 42-46 F4-F5; 43-46 F6; 44-46 F7-F8; 45-46 F9; 46-48 G0; 47 G1.

4.1 Ecosystem drivers

There is strong evidence that sandeel stocks are affected by bottom-up processes involving climate and changing plankton stocks. Sandeel are high quality food for many predatory fish, seabirds and marine mammals. Given the semi-sedentary behaviour of sandeel after settling, local depletion of sandeel aggregations at a distance less than 100 km from seabird colonies may affect some species of birds, especially black-legged kittiwake and sandwich tern, whereas the more mobile marine mammals and fish are likely to be less vulnerable to local sandeel depletion.

Section 1.5 of the WKSAND report contains a comprehensive description of ecosystem aspects.

4.2 Stock Assessment

4.2.1 Catch – quality, misreporting, discards

General information about the sandeel fishery can be found in Section 1.6 of WKSAND report.

Catches in SA3r over time are shown in Table 4.2.1.1 and Figure 4.2.1.1. Insufficient biological samples were available prior to 1986 and hence this is the first data year.

Table 4.2.1.1. Sandeel Area 3r. Catch at age numbers (millions) by half year.

Year/Age	Age 0, 2nd half	Age 1, 1st half	Age 1, 2nd half	Age 2, 1st half	Age 2, 2nd half	Age 3, 1st half	Age 3, 2nd half	Age 4+, 1st half	Age 4+, 2nd half
1986	7965	18939	7987	2063	533	161	2	0	0
1987	5	33760	65	14020	4	453	0	200	0
1988	8769	6584	853	17321	233	893	144	19	13
1989	159	47004	190	1844	13	2806	0	4	0
1990	9793	9302	1377	2791	286	413	43	125	13
1991	14442	24009	942	1391	30	526	9	184	3
1992	525	7100	87	2862	8	342	3	215	1
1993	9663	15164	851	558	155	211	71	1336	12
1994	0	23742	615	4818	684	938	78	386	10
1995	1020	25037	484	1894	78	238	13	156	17
1996	6263	4319	3111	3394	97	465	33	399	248
1997	2975	66856	10388	2912	134	607	13	194	9
1998	30136	3954	992	28137	740	2553	192	290	32
1999	6444	5182	1835	1554	118	1979	401	421	169
2000	0	18793	344	3286	4	541	1	533	9
2001	18263	5327	3968	992	9	163	2	160	6
2002	0	9075	21	2680	3	387	1	135	0

2003	2755	939	61	808	53	130	2	78	1
2004	1091	1976	737	256	16	74	6	92	1
2005	0	1404	1	146	0	21	0	12	0
2006	0	769	3	47	1	27	0	4	0
2007	0	8600	0	571	0	86	0	19	0
2008	0	4077	0	2012	0	460	0	73	0
2009	1	827	12	69	2	8	0	0	0
2010	0	3042	51	740	1	1006	1	173	0
2011	0	1304	0	5224	0	825	0	24	0
2012	0	32	0	186	0	1157	0	356	0
2013	0	648	0	211	0	55	0	42	0
2014	0	5384	0	2373	0	643	0	319	0
2015	0	6426	0	2337	0	955	0	98	0
arith. mean	4009	11986	1166	3583	107	638	34	202	18

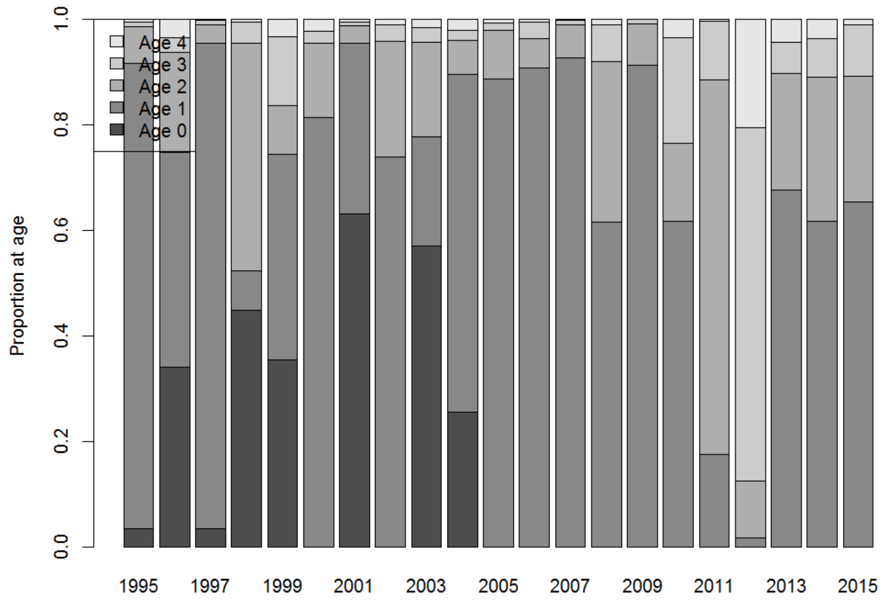


Figure. 4.2.1.1 Distribution of catches on ages.

4.2.2 Surveys

Dredge survey catches are given in Table 4.2.2.1 The coverage of the survey varied prior to 2014. Acoustic survey indices are shown in Table 4.2.2.2.

Table 4.2.2.1 Dredge survey index.

Year	Age 0	Age 1
2005	64.85	-0.01
2006	50.60	1.19

2007	9.69	3.13
2008	15.11	1.13
2009	28.25	14.34
2010	1.36	3.61
2011	0.86	1.71
2012	36.25	0.69
2013	144.90	0.81
2014	78.48	5.07
2015	2.49	8.30

Table 4.2.2.2. Acoustic survey indices (*10^{-3}).

Year	Age 1	Age 2	Age 3	Age 4
2007	16073	3924	998	337
2008	3303	4153	208	46
2009	12660	4298	868	118
2010	16584	9675	1582	974
2011	410	8696	987	368
2012	892	372	3309	660
2013	2634	334	100	698
2014	23630	2062	184	2681
2015	9651	1894	668	943

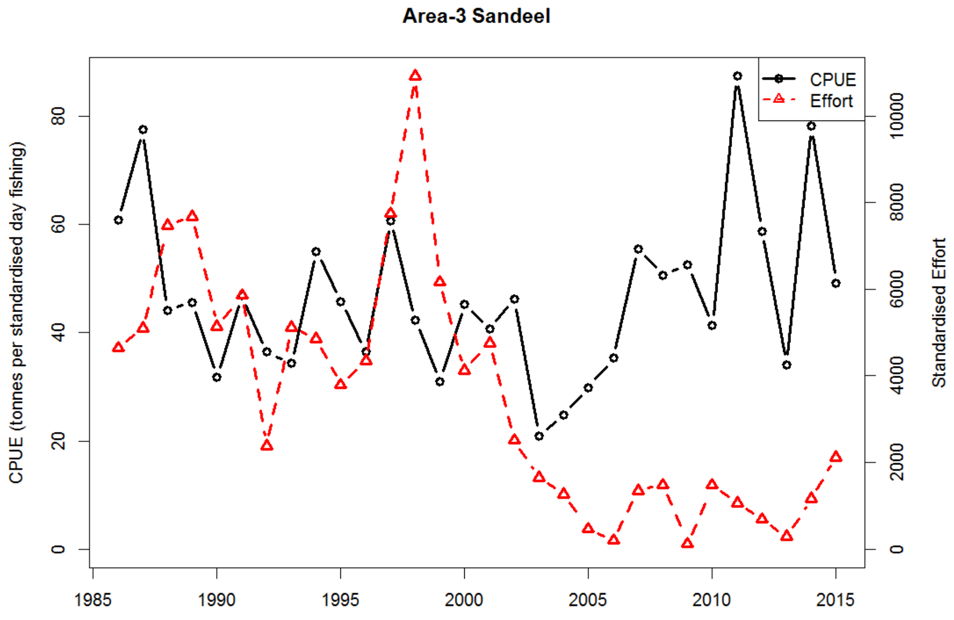


Figure 4.2.2.1. CPUE and effort series.

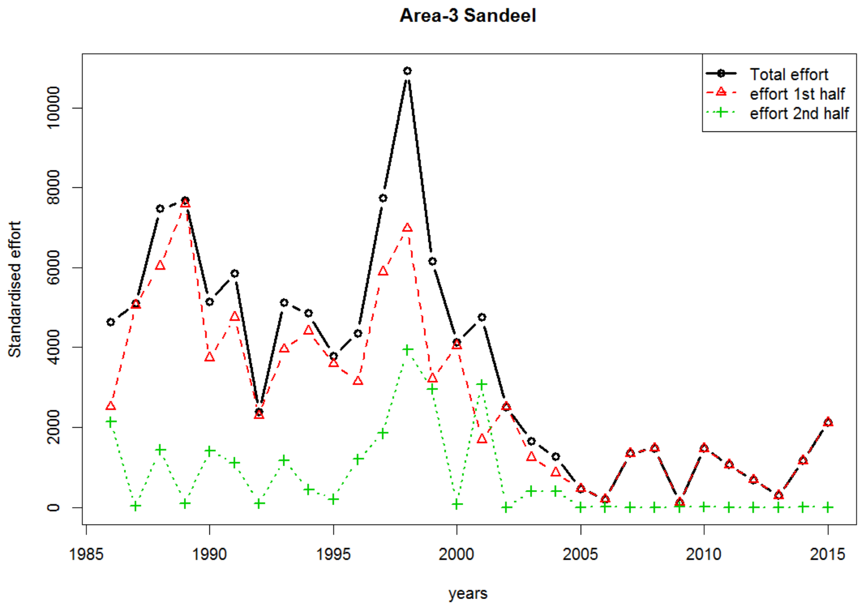


Figure 4.2.2.2. Effort in the first and second half year.

4.2.3 Maturity

Average maturity at age from dredge survey catches in Sandeel Area 3 were used. Values are given in Table 4.2.3.1.

Table 4.2.3.1. Maturity at age in area 3r.

Age	0	1	2	3	4+
	0.000	0.036	0.77	1.00	1.00

4.2.4 Natural mortality

Long term average natural mortality at age from multispecies modelling of southern sandeel (SMS, WGSAM 2015) were used (Table 4.2.4.1).

Table 4.2.4.1. Annual natural mortality at age in area 3r.

YEAR/AGE	AGE 0	AGE 1	AGE 2	AGE 3	AGE 4
1986	1.340	1.330	1.044	0.771	0.690
1987	1.430	1.185	0.926	0.696	0.627
1988	1.540	1.154	0.891	0.665	0.616
1989	1.330	1.006	0.779	0.621	0.583
1990	1.280	1.045	0.790	0.603	0.563
1991	1.220	1.011	0.768	0.570	0.531
1992	1.190	1.111	0.831	0.591	0.561
1993	1.140	1.111	0.843	0.625	0.596
1994	1.110	1.154	0.889	0.640	0.603
1995	1.010	1.167	0.926	0.708	0.669
1996	0.990	1.162	0.938	0.712	0.672

1997	0.900	1.053	0.847	0.704	0.668
1998	0.970	1.039	0.809	0.671	0.616
1999	1.040	1.243	0.930	0.636	0.582
2000	1.120	1.258	0.948	0.672	0.628
2001	1.190	1.588	1.309	0.984	0.921
2002	1.220	1.481	1.217	1.062	1.005
2003	1.220	1.533	1.287	1.134	1.075
2004	1.210	1.513	1.240	1.073	1.003
2005	1.150	1.464	1.192	0.947	0.898
2006	1.120	1.420	1.139	0.892	0.842
2007	1.050	1.285	1.010	0.796	0.758
2008	0.990	1.118	0.885	0.754	0.716
2009	0.990	1.055	0.865	0.706	0.666
2010	1.110	1.028	0.801	0.676	0.629
2011	1.210	1.160	0.915	0.765	0.698
2012	1.190	1.208	0.965	0.829	0.780
2013	1.190	1.226	0.985	0.847	0.797
2014	1.190	1.187	0.941	0.808	0.761
2015	1.190	1.147	0.898	0.770	0.723
arith. mean	1.161	1.215	0.960	0.764	0.716

4.2.5 Natural mortality estimated from acoustic surveys

The natural mortality used in the sandeel assessment for SA1–3 are obtained from a multispecies models. An alternative method is to estimate the natural mortality directly from the acoustic surveys (Annex 2 WD 08), and the main purpose of this study is to investigate age dependent mortalities.

These analyses are using the abundance estimates (Table 4.2.5.1) from the Norwegian acoustic survey carried out in Sandeel Assessment area 3. The survey methodology is described in 1.7.2. Figure 4.2.5.1 shows the abundance by age estimated from acoustic surveys in the NEEZ in the North Sea.

In this analyses the abundance estimates are regarded to be absolute numbers when compared to the catch by age numbers (Table 4.2.5.2).

Table 4.2.5.1. Abundance estimate (in millions) by age

	Age1	Age2	Age3	Age4
2009	7541.71080	5040.7820	968.5602	79.01315
2010	18067.66996	6274.0779	1176.6438	696.50248
2011	799.12644	8640.0734	960.6569	226.66163
2012	1122.55252	203.8531	3219.4770	407.70364
2013	2441.31576	753.9432	104.8557	549.14953
2014	21977.70223	1781.9049	199.4293	95.14195
2015	9286.79308	2393.7483	1333.6447	80.91575
2016	64.75249	6126.0157	729.3264	337.18480

Table 4.2.5.2. Estimated catch numbers by age (in millions)

	1	2	3
2009	0	0	0
2010	1432.697	1580.41	175.4877
2011	117.1487	4831.122	390.4486
2012	2.648302	62.14643	1115.373
2013	367.368	89.82966	17.46682
2014	5080.551	162.0751	0
2015	5986.03	1935.999	156.8619

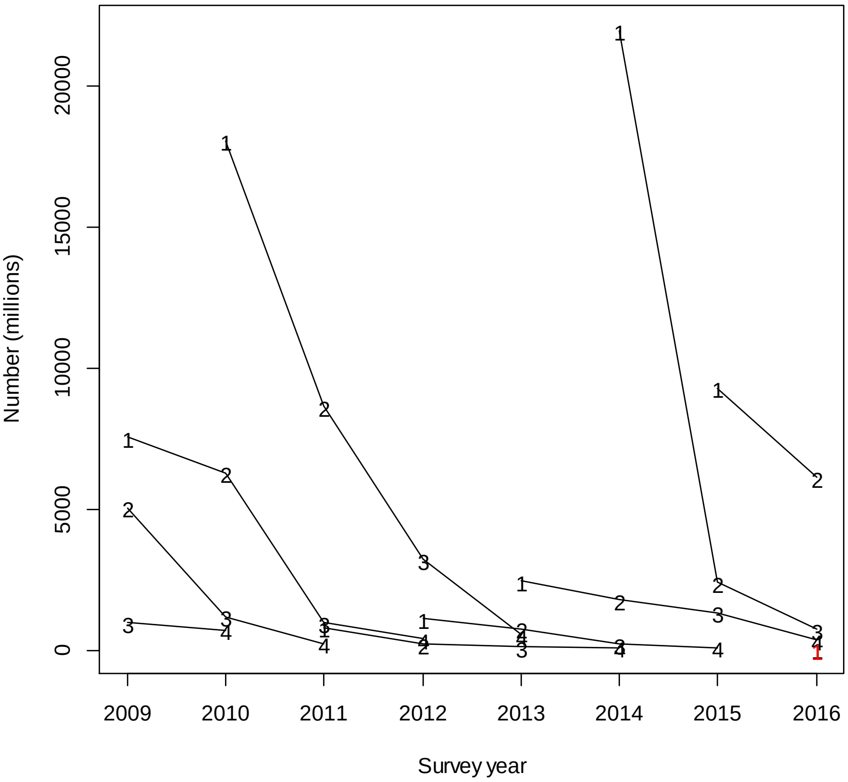


Figure 4.2.5.1. Abundance of sandeel by age (indicated on the lines) by survey year. Red number (bottom right cornes) shows abundance of age 1 in 2016.

The internal consistency between age 1 and age 2, age 2 and age 3, and age 3 and age 4 is high (Annex 2 WD 05) and the Z can be estimated by Z = ln(Ny/Ny+1). When regarding the survey estimates as absolute numbers (Na,y), the natural mortality can be estimated by subtracting the catch numbers (Ca,y) from the survey abundance. Here, it is assumed that the survey estimate represent the abundance prior to the fishing season, however, the fishing season can start as early as 15 April and the survey in SA3 has ended early in May.

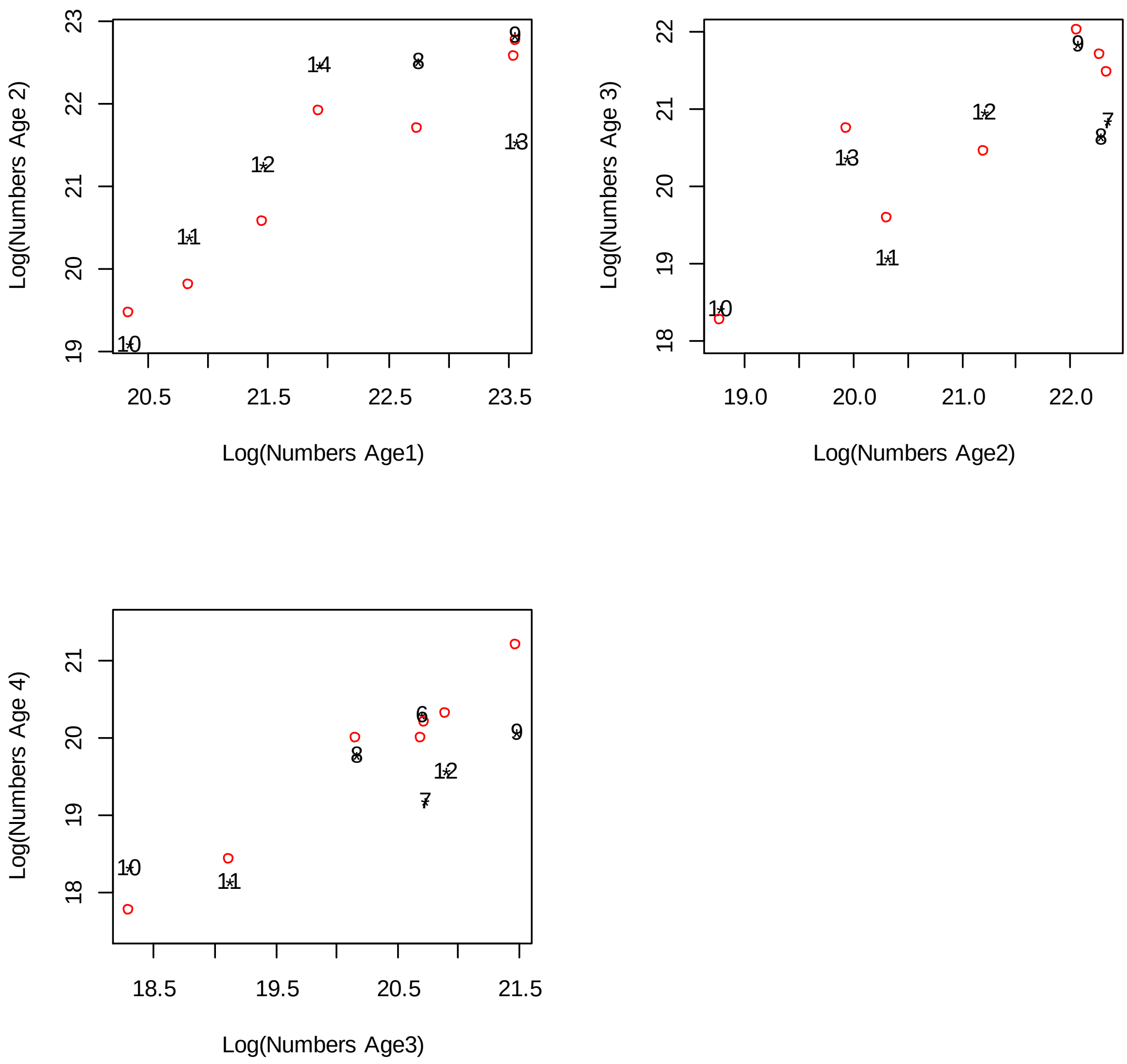


Figure 4.2.5.2. Na,y – Ca,y versus Na+1, y+1 where N is survey abundance and C is catch numbers. Red circles (x-axis) is (Na,y – Ca,y)*exp(-M) (Table 1) and Na+1,y+1 (y-axis)

The total mortality was estimated as log(Na,y/Na+1,y+1) and natural mortality where N is survey estimates, The natural mortality was estimated as log((Na,y-Ca,y/Na+1,y+1) (Table 4.2.5.3)

Table 4.2.5.3 Estimated Total mortality and Natural mortality using survey estimates as absolute abundance estimates

	09-10	10-11	11-12	12-13	13-14	14-15	15-16	Mean
Z1_2	0.18	0.74	1.37	0.4	0.31	2.22	0.42	0.81
Z2_3	1.45	1.88	0.99	0.66	1.33	0.29	1.19	1.11
Z3_4	0.33	1.65	0.86	1.77	0.1	0.9	1.38	1.00
M1_2	0.18	0.66	1.21	0.4	0.15	1.95	-0.62	**0.56**
M2_3	1.45	1.59	0.17	0.3	1.2	0.19	-0.47	**0.63**
M3_4	0.33	1.49	0.34	1.34	-0.09	0.9	1.25	**0.79**

Despite large variability, and even negative estimates for natural mortality, the estimated natural mortalities (Table 4.2.5.3) for age 2 and age 3 seems to fit reasonable well the values used in the current assessment (see Table 4.2.5.1). However, the natural mortality for age 1 estimated here is significant lower than the values used in the current assessment. There are several problems with the method, the survey uncertainty and by considering natural as independent of year class strength. Still, it seems reasonable to assume that all these sources of uncertainty should be similar for all age classes. Therefore, the combination of high abundance estimates of age 2 in the acoustic time series, and the similarity in mortality between the different age groups suggest that natural mortality values for age 1 derived from the multispecies model for SA3 seems unrealistic high.

The mean length by age is high in NEEZ (Figure 4.2.5.3), and a length dependent survival rate can explain why the natural mortality of age 1 seems to more in line with the older age groups in NEEZ than in southern areas of the North Sea.

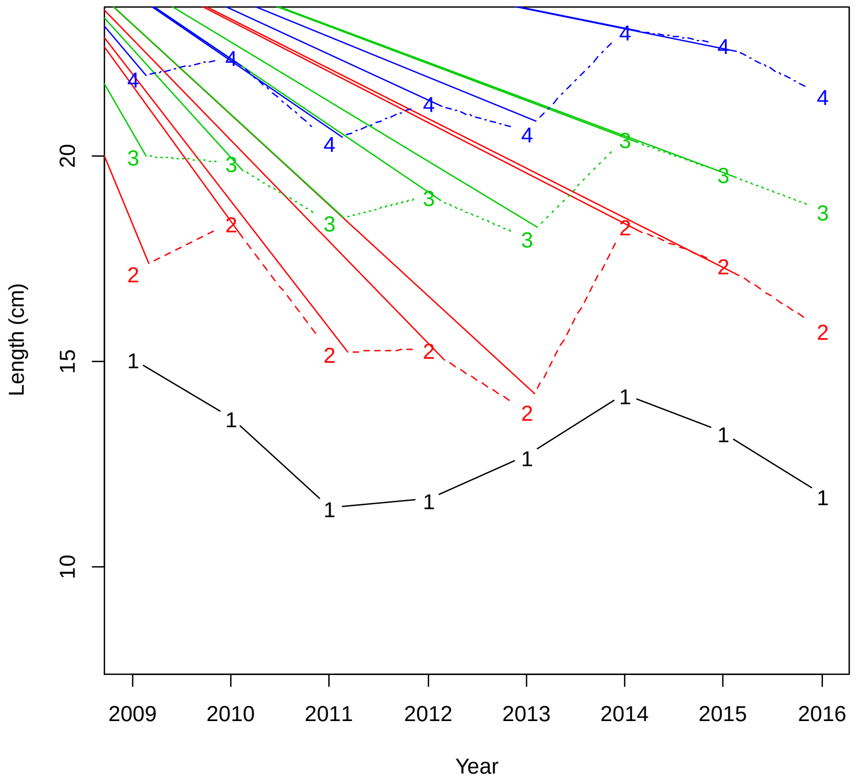


Figure 4.2.5.3. Mean length by age. Data recorded during the acoustic surveys in NEEZ

4.2.6 Weight at age

Weight at age in the stock and catch was estimated from catch samples. Table 4.2.6.1 shows the individual mean weight in catch and stock by year, age and season.

Table 4.2.6.1 Area-3r Sandeel. Individual mean weight(g) at age in the catch and in the stock.

YEAR/AGE	AGE 0, 2ND HALF	AGE 1, 1ST HALF	AGE 1, 2ND HALF	AGE 2, 1ST HALF	AGE 2, 2ND HALF	AGE 3, 1ST HALF	AGE 3, 2ND HALF	AGE 4+, 1ST HALF	AGE 4+, 2ND HALF
1986	4.0	6.1	12.7	9.7	21.0	12.4	18.8	15.7	20.2
1987	6.9	6.4	12.8	11.7	20.4	20.5	31.6	22.2	29.4
1988	4.1	5.1	6.4	13.1	16.1	23.0	22.5	36.2	31.5
1989	4.8	6.1	9.3	10.5	12.7	14.3	14.0	18.8	17.5
1990	4.4	7.5	7.5	9.8	11.0	15.2	16.2	20.2	19.4
1991	3.7	7.3	5.7	11.4	13.8	36.4	27.5	26.0	16.2
1992	4.6	6.1	13.4	10.3	26.7	14.7	28.7	23.0	30.9
1993	3.5	5.8	7.3	16.4	16.7	17.9	20.8	23.3	22.4
1994	3.6	6.1	13.0	14.6	20.8	20.6	35.2	21.1	27.1
1995	4.7	5.6	8.2	9.7	10.2	13.8	13.7	16.5	16.1
1996	2.5	8.8	8.0	13.3	14.0	26.1	15.7	38.5	24.0
1997	2.9	5.2	6.7	10.1	10.2	13.7	14.2	18.3	14.4
1998	3.2	5.0	7.0	10.1	15.2	13.7	17.3	20.3	20.7
1999	8.7	7.4	14.5	10.1	19.4	14.1	21.1	26.3	30.7
2000	5.3	6.9	10.9	10.5	17.6	15.3	23.3	20.5	25.1
2001	5.6	6.8	8.9	13.7	16.0	17.8	15.9	23.2	25.5
2002	9.6	8.1	19.7	12.7	31.9	14.6	42.4	19.2	45.6
2003	4.3	5.3	5.4	14.6	15.3	20.3	24.1	26.9	26.7
2004	5.8	7.3	7.3	9.5	14.1	14.5	18.4	15.1	12.7
2005	3.4	7.8	7.0	16.5	11.3	19.9	15.1	22.6	16.2
2006	11.2	7.5	23.2	13.5	37.5	17.1	49.8	26.9	53.6
2007	8.8	7.5	14.2	15.1	18.8	21.7	20.3	14.6	25.0
2008	8.8	8.0	14.2	15.0	18.8	22.0	20.3	25.8	25.0
2009	4.3	6.3	8.8	10.4	14.2	19.9	18.9	12.1	20.3
2010	2.5	7.5	5.2	17.7	8.4	20.7	11.2	24.3	12.1
2011	8.8	7.7	14.2	12.6	18.8	19.4	20.3	36.2	25.0
2012	8.8	10.0	14.2	15.2	18.8	22.7	20.3	30.0	25.0
2013	8.8	9.1	14.2	11.6	18.8	14.3	20.3	16.2	25.0
2014	8.8	8.6	14.2	12.7	18.8	13.9	20.3	18.3	25.0
2015	4.3	8.3	8.8	12.7	14.2	19.3	18.8	30.1	20.3
arith. mean	5.7	7.0	10.8	12.5	17.4	18.3	21.9	22.9	24.3

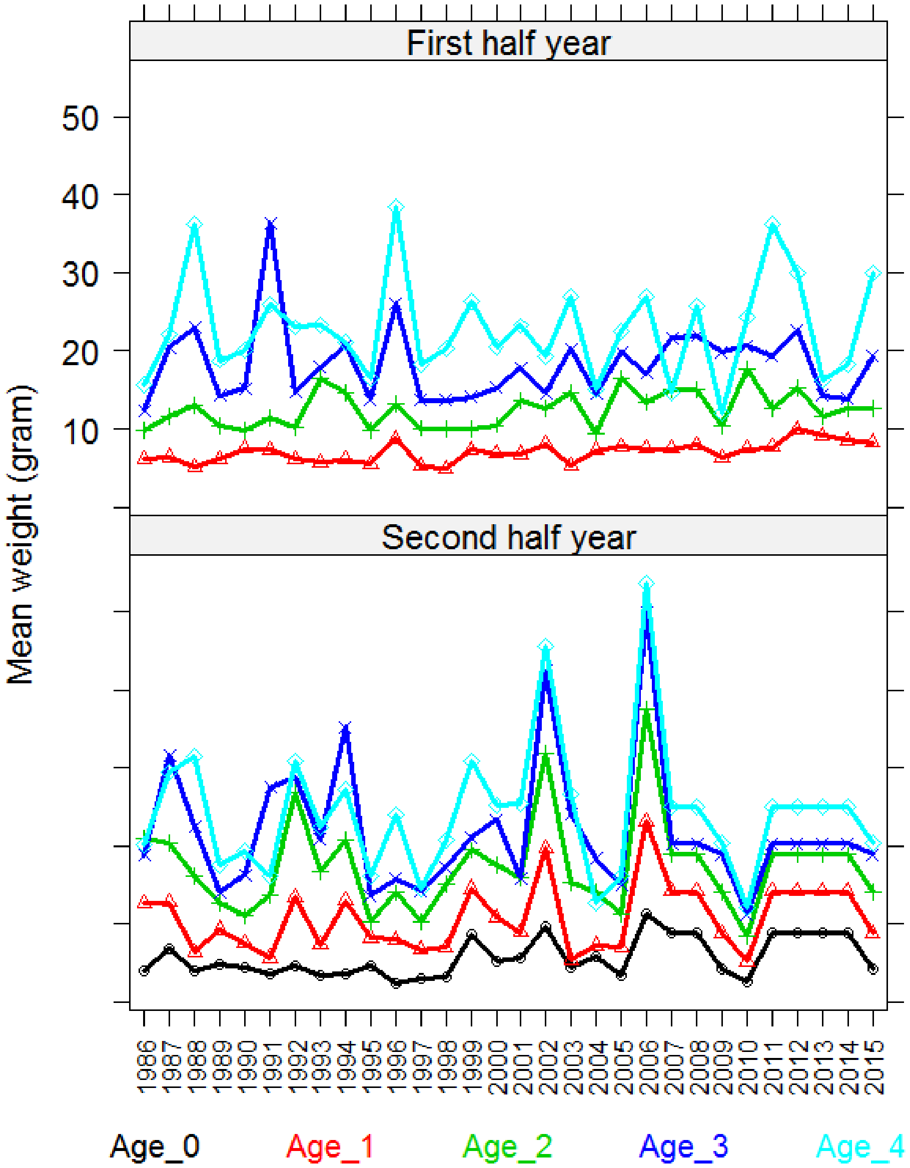


Figure 4.2.6.1. Weight at age in the catch and in the stock.

4.2.7 Commercial data

Catch at age is given in Table 4.2.7.1 and input effort is given in Table 4.2.7.2. Appropriate sampling is not present until 1986 and hence this is the start year of the assessment.

Table 4.2.7.1. Area-3r Sandeel. Catch at age numbers (millions) by half year

YEAR/AGE	AGE 0, 2ND HALF	AGE 1, 1ST HALF	AGE 1, 2ND HALF	AGE 2, 1ST HALF	AGE 2, 2ND HALF	AGE 3, 1ST HALF	AGE 3, 2ND HALF	AGE 4+, 1ST HALF	AGE 4+, 2ND HALF
1986	7965	18939	7987	2063	533	161	2	0	0

1987	5	33760	65	14020	4	453	0	200	0
1988	8769	6584	853	17321	233	893	144	19	13
1989	159	47004	190	1844	13	2806	0	4	0
1990	9793	9302	1377	2791	286	413	43	125	13
1991	14442	24009	942	1391	30	526	9	184	3
1992	525	7100	87	2862	8	342	3	215	1
1993	9663	15164	851	558	155	211	71	1336	12
1994	0	23742	615	4818	684	938	78	386	10
1995	1020	25037	484	1894	78	238	13	156	17
1996	6263	4319	3111	3394	97	465	33	399	248
1997	2975	66856	10388	2912	134	607	13	194	9
1998	30136	3954	992	28137	740	2553	192	290	32
1999	6444	5182	1835	1554	118	1979	401	421	169
2000	0	18793	344	3286	4	541	1	533	9
2001	18263	5327	3968	992	9	163	2	160	6
2002	0	9075	21	2680	3	387	1	135	0
2003	2755	939	61	808	53	130	2	78	1
2004	1091	1976	737	256	16	74	6	92	1
2005	0	1404	1	146	0	21	0	12	0
2006	0	769	3	47	1	27	0	4	0
2007	0	8600	0	571	0	86	0	19	0
2008	0	4077	0	2012	0	460	0	73	0
2009	1	827	12	69	2	8	0	0	0
2010	0	3042	51	740	1	1006	1	173	0
2011	0	1304	0	5224	0	825	0	24	0
2012	0	32	0	186	0	1157	0	356	0
2013	0	648	0	211	0	55	0	42	0
2014	0	5384	0	2373	0	643	0	319	0
2015	0	6426	0	2337	0	955	0	98	0
arith. mean	4009	11986	1166	3583	107	638	34	202	18

Table 4.2.7.3. Area-1 Sandeel. Standardised effort (fishing days for a 200 GT vessels)

Year/Age	**1st half year**	**2nd half year**	**Sum**
1986	2509	2133	4642
1987	5064	31	5095
1988	6031	1442	7473
1989	7585	92	7677
1990	3738	1404	5142
1991	4750	1113	5863
1992	2290	93	2383
1993	3949	1174	5123
1994	4410	443	4853
1995	3589	201	3790
1996	3146	1205	4351
1997	5894	1854	7748

1998	6980	3940	10920
1999	3208	2961	6169
2000	4046	78	4124
2001	1687	3069	4756
2002	2516	0	2516
2003	1248	406	1654
2004	863	402	1265
2005	468	0	468
2006	196	5	201
2007	1349	0	1349
2008	1481	0	1481
2009	117	2	119
2010	1468	11	1479
2011	1057	0	1057
2012	682	0	682
2013	289	0	289
2014	1162	3	1165
2015	2118	0	2118
arith. mean	2796	735	3532

4.2.8 Assessment model

The diagnostics output from SMS are shown in Table 4.2.8.1. The seasonal effect on the relation between effort and F ("F, Season effect" in the table) is rather constant over the five year ranges used. The "age selection" ("F, age effect" in the table) shows a change in the fishery pattern where the fishery was mainly targeting the age 2+ sandeel in the beginning of the assessment period, to a fishery targeting age 1+ in a similar way.

The CV of the acoustic survey is low (0.45 for ages 1 and 2), whereas the CV of the dredge survey ("sqrt (Survey variance) ~CV" in the table) is very high (>0.77) for both ages. The survey residual plot (Figure 4.2.8.1) shows some degree of clustering. However, the time series is too short to determine if the clustering is due to a systematic bias or systemic noise.

The model CV of catch at age ("sqrt(catch variance) ~CV", in Table 4.2.8.1 is moderate (0.66) for age 1 and age 2 in the first half of the year and very high (> 1) for the remaining ages and season combinations. The catch at age residuals (Figure 4.2.8.2) show no alarming patterns.

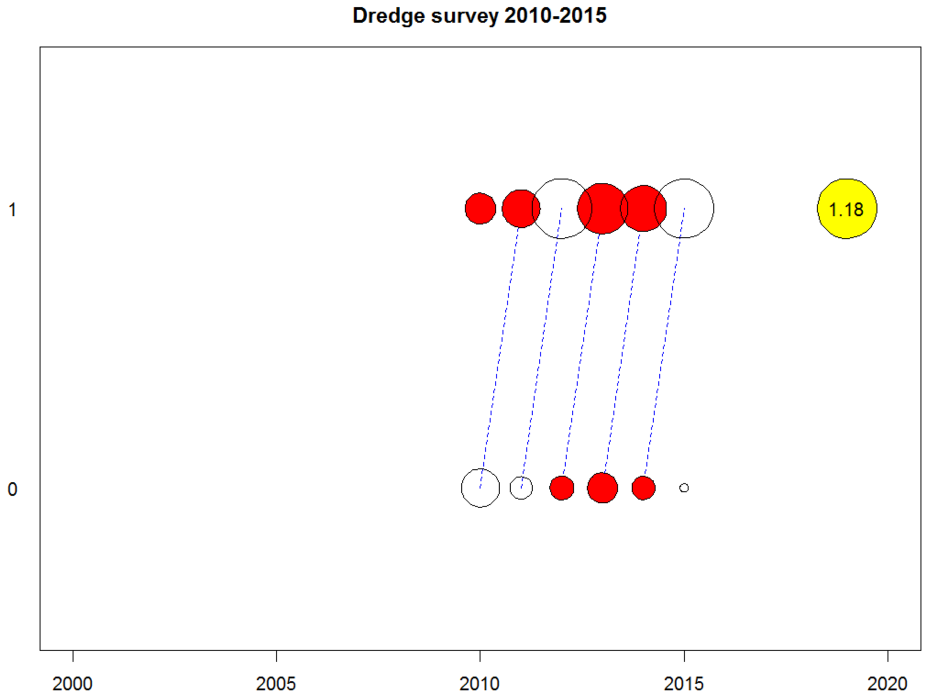


Figure 4.2.8.1 Survey residuals in the SMS model (red is negative)..

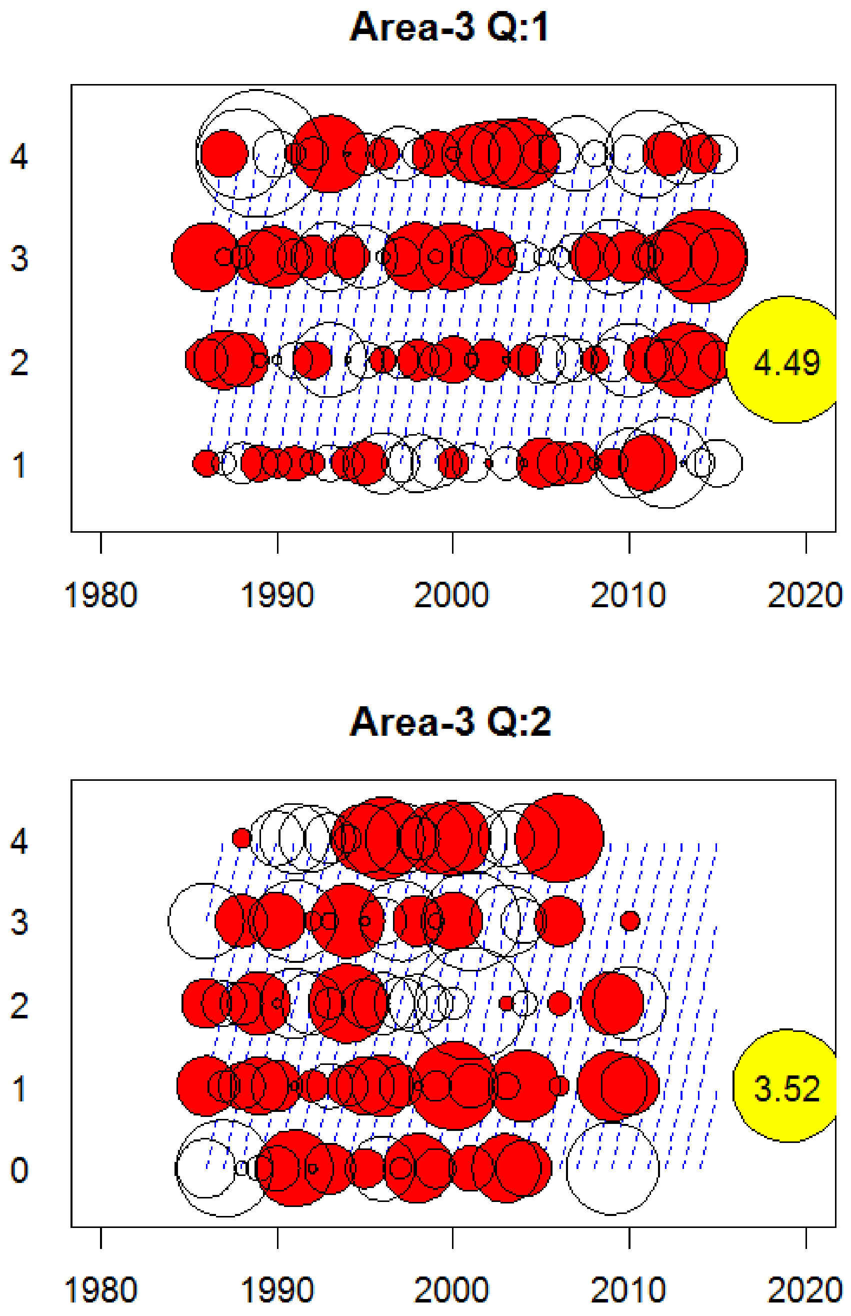


Figure 4.2.8.2 Catch residuals in the SMS model (red is negative).

The CV of the fitted Stock recruitment relationship (Table 4.2.8.1) is high (0.96), which is also indicated by the stock recruitment plot (Figure 4.2.8.3). The high CV of recruitment is probably due to biological characteristic of the stock and not the quality of the assessment. The *a priori* weight on likelihood contributions from SSR-R observations is therefore set low (0.05 in "objective function weight" in Table 4.2.8.1) such that SSB-R estimates do not contribute much to the overall likelihood and model fit.

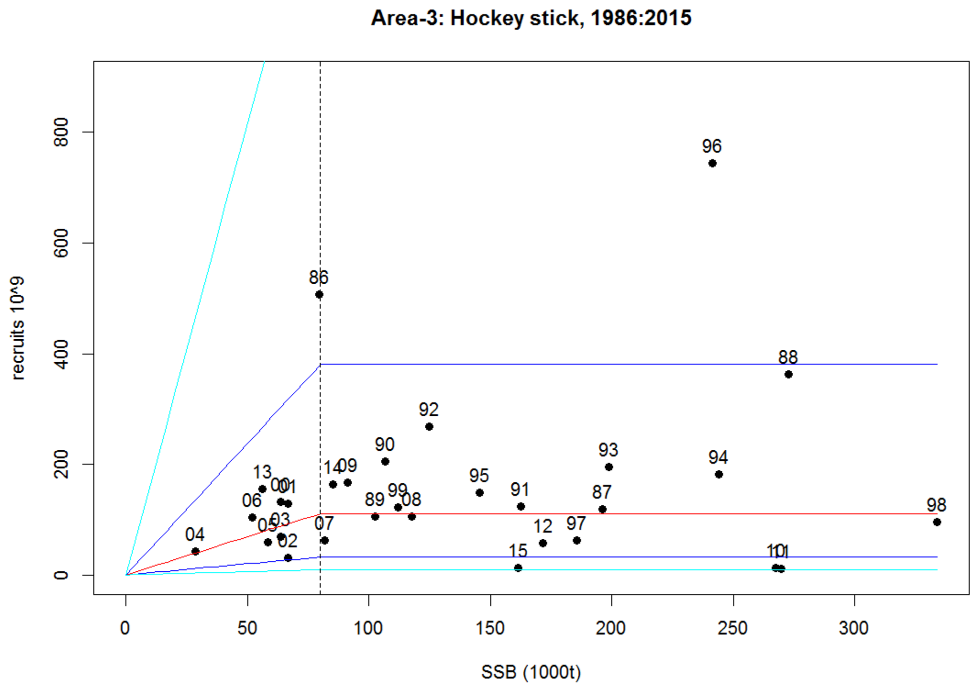


Fig. 4.2.8.3. Stock-recruitment relationship.

The retrospective analysis (Figure 4.2.8.4) shows very consistent assessment results from one year to the next in SSB and F but a large retrospective pattern in recruitment. This is partly due to the assumed robust relationship between effort and F, which is rather insensitive to removal of a few years and the low weight of the dredge survey.

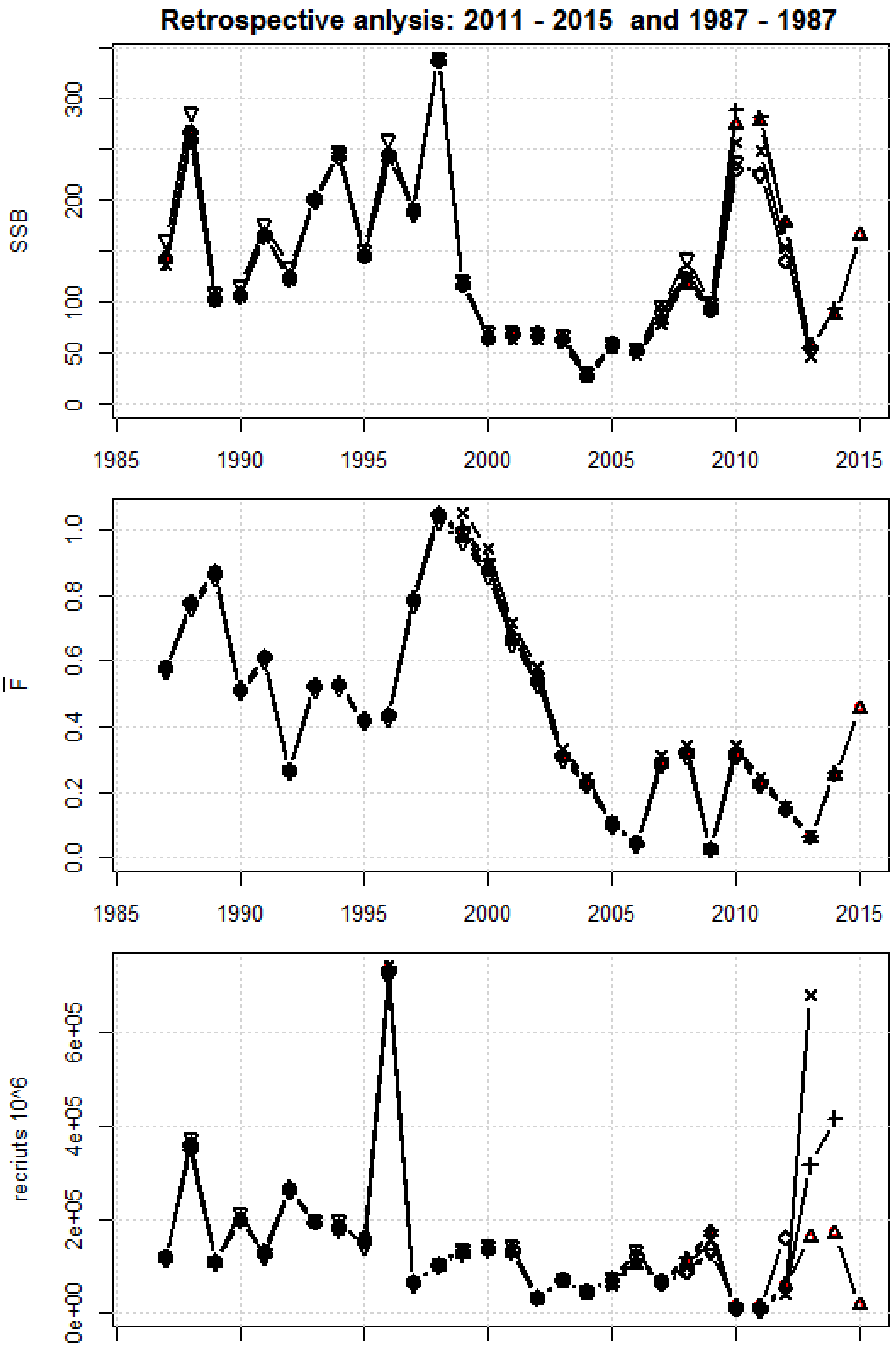


Figure 4.2.8.4. Retrospective analysis.

Uncertainties of the estimated SSB, F and recruitment (Figure 4.2.8.4) are in general small. For F, uncertainties are lowest for the most recent years, which are not normally seen. This is due to the model fit where the most recent effort values estimate F with a small error (Figure 4.2.9.1), while older observations have a larger difference between effort and F (Figure 4.2.9.2).

Table 4.2.8.1. Assessment fit summary.

Date: 11/03/16 Start time:21:14:16 run time:0 seconds

```
objective function (negative log likelihood):  101.831
Number of parameters: 54
Maximum gradient: 2.22563e-005
Akaike information criterion (AIC):   311.661
Number of observations used in the likelihood:
                Catch    CPUE     S/R Stomach     Sum
                 270      49      30       0     349

objective function weight:
               Catch  CPUE   S/R
               1.00  1.00  0.01

unweighted objective function contributions (total):
          Catch    CPUE    S/R   Stom.  Stom N.  Penalty     Sum
         96.0     5.7    13.8    0.0     0.0      0.00     116



unweighted objective function contributions (per observation):
          Catch   CPUE     S/R   Stomachs
         0.36    0.12    0.46    0.00



contribution by fleet:
----------------------
Dredge survey 2004-2015     total:   7.323   mean:   0.349
Acoustic survey             total:  -1.588   mean:  -0.057

F, season effect:
-----------------
age: 0
   1986-1998:   0.000 1.000
   1999-2015:   0.000 1.000
age: 1 - 4
   1986-1998:   0.888 0.500
   1999-2015:   1.074 0.500
```

```
F, age effect:

--------------

               0      1      2      3      4

1986-1998:  0.102  0.370  0.401  0.306  0.306

1999-2015:  0.056  0.207  0.274  0.238  0.238



Exploitation pattern (scaled to mean F=1)

----------------------------------------

                       0      1      2      3      4

1986-1998 season 1:      0  0.649  0.704  0.538  0.538

          season 2:  0.172  0.311  0.337  0.257  0.257


1999-2015 season 1:      0  0.602  0.797  0.694  0.694

          season 2:  0.140  0.259  0.342  0.298  0.298



sqrt(catch variance) ~ CV:

--------------------------


              season

----------------------

age       1       2


 0              1.163

 1      0.663   1.000

 2      0.663   1.000

 3      1.097   1.201

 4      1.097   1.201



Survey catchability:

--------------------

                          age 0    age 1    age 2    age 3    age 4
```

```
 Dredge survey 2004-2015      0.560   0.560
 Acoustic survey               3.829   7.116   7.918   7.918


sqrt(Survey variance) ~ CV:
---------------------------
                   age 0   age 1   age 2   age 3   age 4
 Dredge survey 2004-2015       0.95    0.77
 Acoustic survey                0.45    0.45    0.73    0.73




Recruit-SSB                    alfa    beta      recruit s2   recruit s
Area-3    Hockey stick -break.:   1384.326   8.000e+004   0.925          0.962
```

4.2.9 Final assessment

The output from the assessment is presented in Tables 4.2.9.1 (fishing mortality at age by year), 4.2.9.2 (fishing mortality at age by half year), 4.2.9.3 (stock numbers at age) and 4.2.9.4 (stock summary).

Table 4.2.9.1. Sandeel SA 3r. Annual fishing mortality (F) at age.

Year/Age	Age 0	Age 1	Age 2	Age 3	Age 4	Avg. 1–2
1986	0.075	0.452	0.483	0.368	0.370	0.467
1987	0.001	0.713	0.741	0.553	0.551	0.727
1988	0.051	0.914	0.952	0.719	0.719	0.933
1989	0.003	1.032	1.072	0.819	0.816	1.052
1990	0.050	0.579	0.609	0.464	0.463	0.594
1991	0.039	0.700	0.735	0.557	0.556	0.718
1992	0.003	0.326	0.338	0.249	0.250	0.332
1993	0.042	0.603	0.636	0.479	0.478	0.620
1994	0.016	0.646	0.676	0.499	0.496	0.661
1995	0.007	0.514	0.540	0.401	0.400	0.527
1996	0.043	0.503	0.534	0.399	0.398	0.518
1997	0.066	0.905	0.959	0.730	0.726	0.932
1998	0.139	1.147	1.225	0.936	0.930	1.186
1999	0.139	0.925	1.215	1.041	1.036	1.070
2000	0.004	0.955	1.222	1.018	1.011	1.089
2001	0.144	0.595	0.792	0.687	0.690	0.693
2002	0.000	0.629	0.796	0.690	0.687	0.713
2003	0.019	0.336	0.429	0.376	0.374	0.382
2004	0.019	0.234	0.300	0.264	0.263	0.267
2005	0.000	0.113	0.144	0.123	0.123	0.129

2006	0.000	0.047	0.060	0.051	0.051	0.054
2007	0.000	0.317	0.404	0.344	0.343	0.360
2008	0.000	0.338	0.432	0.375	0.373	0.385
2009	0.000	0.027	0.035	0.030	0.029	0.031
2010	0.001	0.337	0.434	0.372	0.369	0.386
2011	0.000	0.247	0.317	0.273	0.270	0.282
2012	0.000	0.159	0.204	0.178	0.177	0.182
2013	0.000	0.068	0.087	0.076	0.075	0.077
2014	0.000	0.270	0.347	0.302	0.300	0.308
2015	0.000	0.489	0.626	0.547	0.543	0.557
arith. mean	0.029	0.504	0.578	0.464	0.462	0.541

Table 4.2.9.2. Sandeel SA 3r. Seasonal fishing mortality (F) at age.

Year/Age	**Age 0, 2nd half**	**Age 1, 1st half**	**Age 1, 2nd half**	**Age 2, 1st half**	**Age 2, 2nd half**	**Age 3, 1st half**	**Age 3, 2nd half**	**Age 4+, 1st half**	**Age 4+, 2nd half**
1986	0.075	0.285	0.137	0.309	0.148	0.236	0.113	0.236	0.113
1987	0.001	0.576	0.002	0.624	0.002	0.477	0.002	0.477	0.002
1988	0.051	0.686	0.092	0.743	0.100	0.568	0.076	0.568	0.076
1989	0.003	0.862	0.006	0.935	0.006	0.715	0.005	0.715	0.005
1990	0.050	0.425	0.090	0.461	0.097	0.352	0.074	0.352	0.074
1991	0.039	0.540	0.071	0.586	0.077	0.448	0.059	0.448	0.059
1992	0.003	0.260	0.006	0.282	0.006	0.216	0.005	0.216	0.005
1993	0.042	0.449	0.075	0.487	0.081	0.372	0.062	0.372	0.062
1994	0.016	0.501	0.028	0.544	0.031	0.415	0.023	0.415	0.023
1995	0.007	0.408	0.013	0.442	0.014	0.338	0.011	0.338	0.011
1996	0.043	0.358	0.077	0.388	0.084	0.296	0.064	0.296	0.064
1997	0.066	0.670	0.119	0.727	0.129	0.555	0.098	0.555	0.098
1998	0.139	0.793	0.252	0.860	0.273	0.658	0.209	0.658	0.209
1999	0.139	0.600	0.258	0.794	0.341	0.691	0.297	0.691	0.297
2000	0.004	0.756	0.007	1.001	0.009	0.872	0.008	0.872	0.008
2001	0.144	0.315	0.267	0.418	0.354	0.363	0.308	0.363	0.308
2002	0.000	0.470	0.000	0.623	0.000	0.542	0.000	0.542	0.000
2003	0.019	0.233	0.035	0.309	0.047	0.269	0.041	0.269	0.041
2004	0.019	0.161	0.035	0.214	0.046	0.186	0.040	0.186	0.040
2005	0.000	0.087	0.000	0.116	0.000	0.101	0.000	0.101	0.000
2006	0.000	0.037	0.000	0.049	0.001	0.042	0.001	0.042	0.001
2007	0.000	0.252	0.000	0.334	0.000	0.291	0.000	0.291	0.000
2008	0.000	0.277	0.000	0.367	0.000	0.319	0.000	0.319	0.000
2009	0.000	0.022	0.000	0.029	0.000	0.025	0.000	0.025	0.000
2010	0.001	0.274	0.001	0.363	0.001	0.316	0.001	0.316	0.001
2011	0.000	0.198	0.000	0.262	0.000	0.228	0.000	0.228	0.000
2012	0.000	0.127	0.000	0.169	0.000	0.147	0.000	0.147	0.000
2013	0.000	0.054	0.000	0.072	0.000	0.062	0.000	0.062	0.000

2014	0.000	0.217	0.000	0.288	0.000	0.250	0.000	0.250	0.000
2015	0.000	0.396	0.000	0.524	0.000	0.456	0.000	0.456	0.000
arith. mean	0.029	0.376	0.052	0.444	0.062	0.360	0.050	0.360	0.050

Table 4.2.9.3. Sandeel SA 3r. Stock numbers (millions). Age 0 at start of 2nd half-year, age 1+ at start of the year.

YEAR/AGE	AGE 0	AGE 1	AGE 2	AGE 3	AGE 4
1986	507609	88323	6111	256	729
1987	118126	123252	14869	1327	334
1988	362578	28238	18478	2809	484
1989	106208	73863	3571	2924	831
1990	204621	27998	9622	561	898
1991	124323	54135	5514	2377	515
1992	267726	35286	9779	1227	944
1993	195059	81180	8392	3039	949
1994	182340	59845	14623	1913	1331
1995	148191	59157	9895	3059	1056
1996	744112	53592	11016	2283	1372
1997	62535	264953	10141	2529	1223
1998	94765	23810	37370	1668	907
1999	121863	31249	2676	4889	528
2000	132001	37479	3578	313	1018
2001	128972	42912	4099	408	255
2002	30024	33968	4839	501	128
2003	68185	8864	4117	647	110
2004	42137	19750	1368	740	169
2005	58897	12330	3445	293	242
2006	103276	18649	2546	906	188
2007	62362	33689	4300	768	430
2008	105607	21823	6787	1046	388
2009	167284	39241	5084	1819	469
2010	11954	62153	13299	2069	1106
2011	11400	3938	15867	3869	1134
2012	56552	3400	964	4630	1802
2013	155598	17204	866	299	2384
2014	164299	47336	4717	297	1115
2015	12828	49976	11021	1301	484
2016		3903	9734	2400	485

Table 4.2.9.4. Sandeel SA 3r. Estimated recruitment, total stock biomass (TBS), spawning stock biomass (SSB), catch weight (Yield) and average fishing mortality.

Year	**Recruits**	**TSB**	**SSB**	**Yield**	**Mean F**
(million)	(tonnes)	(tonnes)	(tonnes)	ages 1-2	
1986	507609	614797	79627	282315	0.467

1987	118126	1000550	195988	395296	0.727
1988	362578	468372	272583	330358	0.933
1989	106208	547646	102412	350409	1.052
1990	204621	329906	106616	163224	0.594
1991	124323	559671	162519	274839	0.718
1992	267726	356053	124749	86788	0.332
1993	195059	682895	198684	175786	0.620
1994	182340	644411	243907	267281	0.661
1995	148191	485171	145367	173607	0.527
1996	744112	730113	241523	159024	0.518
1997	62535	1544420	185468	470670	0.932
1998	94765	535565	333685	462081	1.186
1999	121863	339633	111911	191253	1.070
2000	132001	320591	63695	186837	1.089
2001	128972	361665	66617	193684	0.693
2002	30024	346048	66822	116298	0.713
2003	68185	123243	63842	34673	0.382
2004	42137	169964	28412	31285	0.267
2005	58897	163810	58299	13991	0.129
2006	103276	194700	51878	7094	0.054
2007	62362	339332	81639	74972	0.360
2008	105607	309946	117532	74933	0.385
2009	167284	343375	91235	6261	0.031
2010	11954	771467	267225	61241	0.386
2011	11400	345451	269744	92452	0.282
2012	56552	207710	171641	40123	0.182
2013	155598	209953	56179	9844	0.077
2014	164299	491860	85069	91235	0.308
2015	12828	593407	161504	104236	0.557
2016			156534		
arith. mean	151714	471058	140739	164070	0.541
geo. mean	107718				

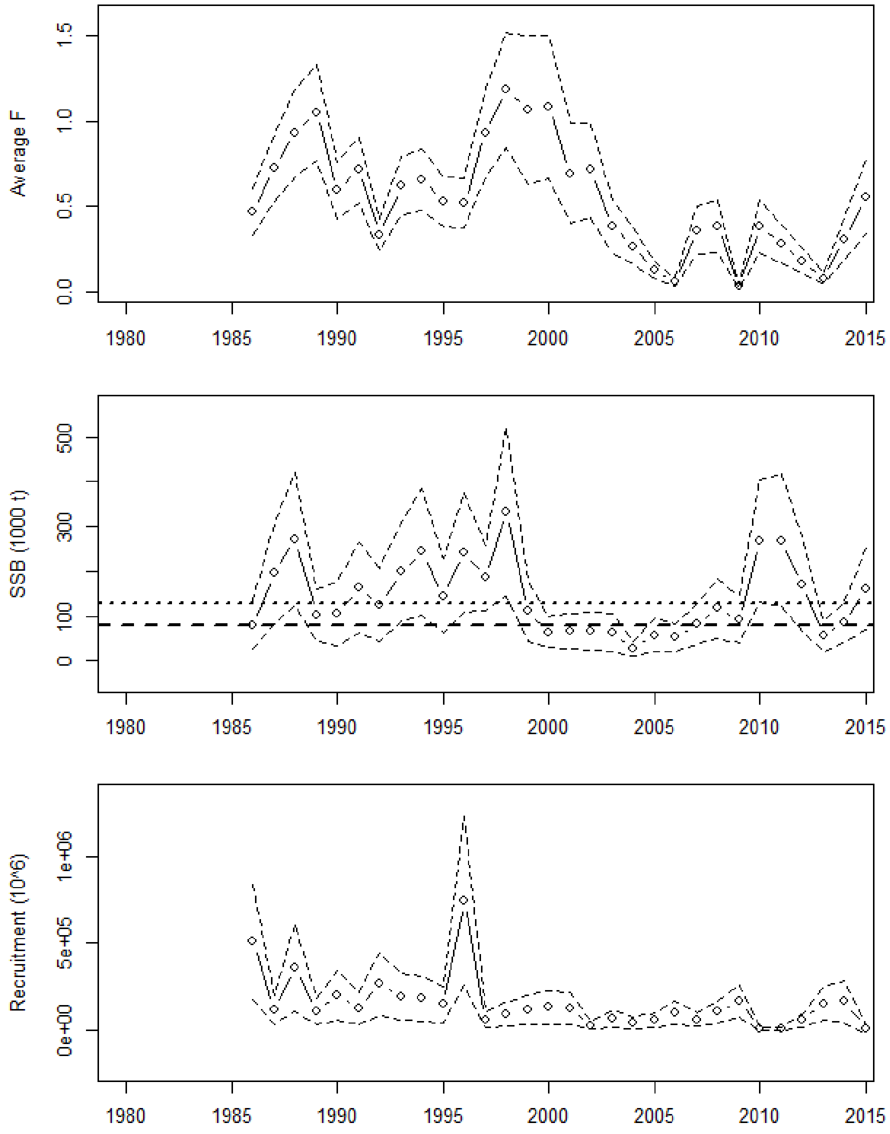


Fig. 4.2.9.1. Predicted stock size, F and recruitment and associated uncertainties.

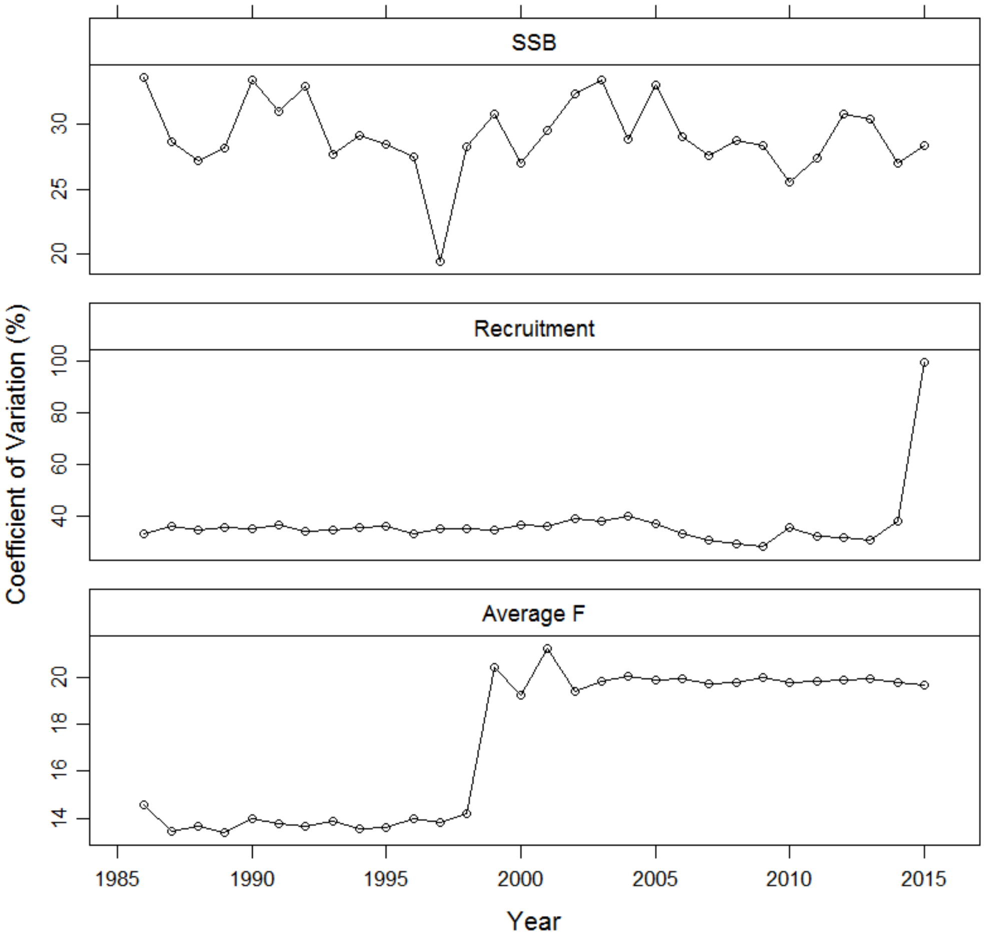


Fig. 4.2.9.2. CV of SSB, recruitment and F.

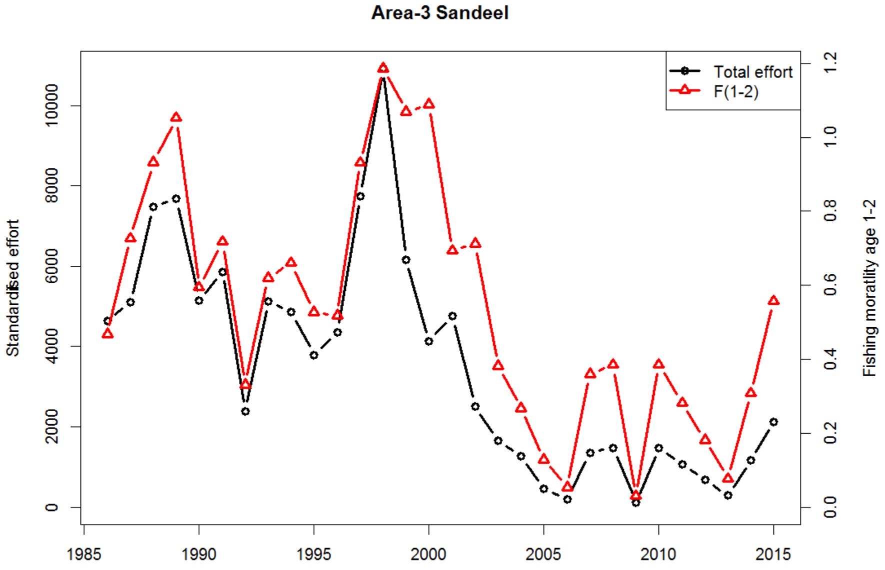


Fig. 4.2.9.3. Effort and estimated F.

4.2.10 Historic Stock Trends

The stock summary (Figure 4.2.10.1 and Table 4.2.9.4) shows that SSB have been at or below B_{lim} from 2000 to 2007 and again in 2013. Since 2008, SSB has been above B_{lim} but below B_{pa} in 2008-2009 and 2014. SSB is estimated above B_{pa} in 2016. $F_{(1-2)}$ is estimated to have been below the long-time average since 2003. Recruitment in 2015 is estimated to be the lowest observed in the time series.

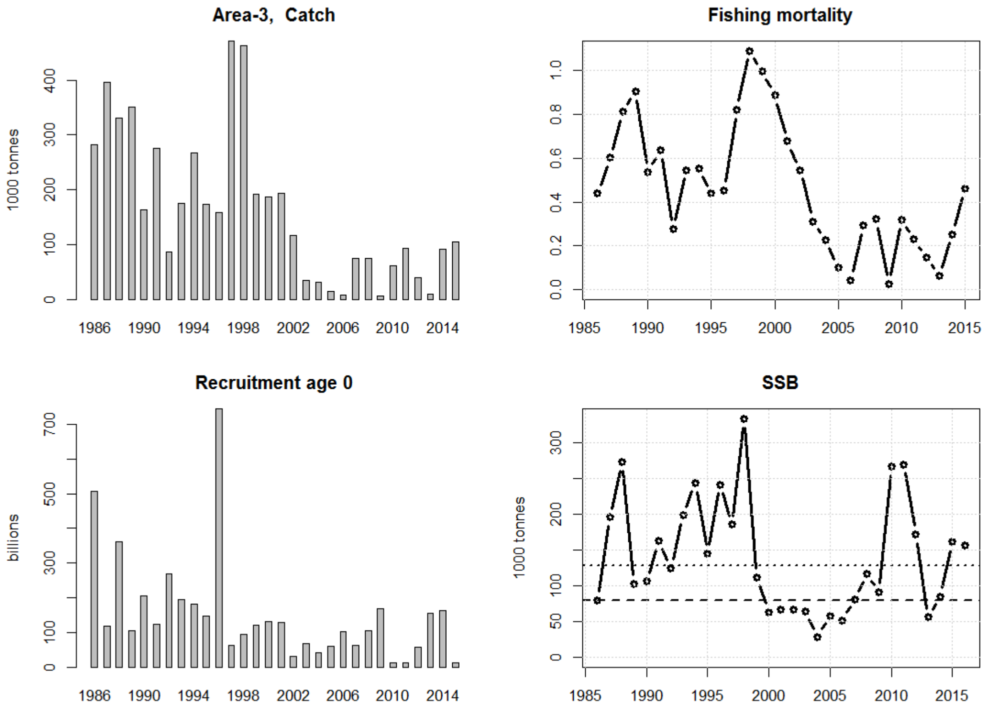


Fig. 4.2.10.1. Stock summary.

4.3 Short term projections

Weight at age shows no recent trends and should be set at 5 years.

Selection pattern is taken as the last year estimated in SMS. Natural mortality is also taken from the final year, as this is already a 3 year average. Maturity is set at the long term average, similar to the assessment. Recruitment has declined in the second part of the period, and to respond to such changes, a 10-year geometric average should be used.

4.4 Appropriate Reference Points (MSY)

The stock recruitment relationship appears to be spasmodic and Blim is set to smallest SSB at which high recruitment was observed (1986, Blim=80 000 t). With a CV of 0.29, this results in a Bpa of 129 000 t.

5 Stock (SA4)

Sandeel (*Ammodytes* spp.) in divisions 4.a and 4.b, Sandeel Area 4 (northern and central North Sea); ICES statistical rectangles 38–40 E7–E9; 41–46 E6–F0. The 2016 benchmark did not alter the definition of this sandeel area.

5.1 Ecosystem drivers

There is strong evidence that sandeel stocks are affected by bottom-up processes involving climate and changing plankton stocks. Sandeel are high quality food for many predatory fish, seabirds and marine mammals. Given the semi-sedentary behaviour of sandeel after settling, local depletion of sandeel aggregations at a distance less than 100 km from seabird colonies may affect some species of birds, especially black-legged kittiwake and sandwich tern, whereas the more mobile marine mammals and fish are likely to be less vulnerable to local sandeel depletion.

Section 1.5 contains a comprehensive description of ecosystem aspects.

5.2 Stock Assessment

General information about the sandeel fishery can be found in Section 1.6.

Catches in the new SA4 over time are shown in Table 5.2.1 and Figure 5.2.1. Insufficient samples were taken in the commercial fishery prior to 1993 and this period was

Table 5.2.1. Area-4 Sandeel. Catch at age numbers (millions) by half year.

Year/Age	Age 0, 2nd half	Age 1, 1st half	Age 1, 2nd half	Age 2, 1st half	Age 2, 2nd half	Age 3, 1st half	Age 3, 2nd half	Age 4+, 1st half	Age 4+, 2nd half
1993	674	1235	149	6337	381	1861	122	534	39
1994	0	1070	256	1522	62	5144	257	2092	159
1995	4	2690	4	1229	1	529	0	30	0
1996	2666	754	2584	2536	3461	476	227	130	1110
1997	0	2879	1369	291	35	1683	43	413	10
1998	0	2159	61	3766	97	235	6	130	3
1999	0	1472	86	1137	46	1543	47	252	11
2000	0	6537	0	376	0	323	0	297	0
2001	0	2048	64	4961	20	601	1	377	0
2002	0	337	0	807	0	511	0	101	0
2003	145	4322	148	1002	10	2721	5	1253	1
2004	0	920	4	220	1	45	0	82	0
2005	0	49	0	145	0	32	0	17	0
2006	0	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	0	0	0
2008	0	0	0	0	0	0	0	0	0
2009	0	0	0	0	0	0	0	0	0
2010	0	0	0	0	0	0	0	0	0
2011	0	0	0	0	0	0	0	0	0
2012	0	83	0	40	0	196	0	3	0
2013	0	182	0	100	0	71	0	133	0

2014	0	346	0	54	0	15	0	47	0
2015	0	864	0	29	0	9	0	14	0
arith. mean	152	1215	205	1067	179	695	31	257	58

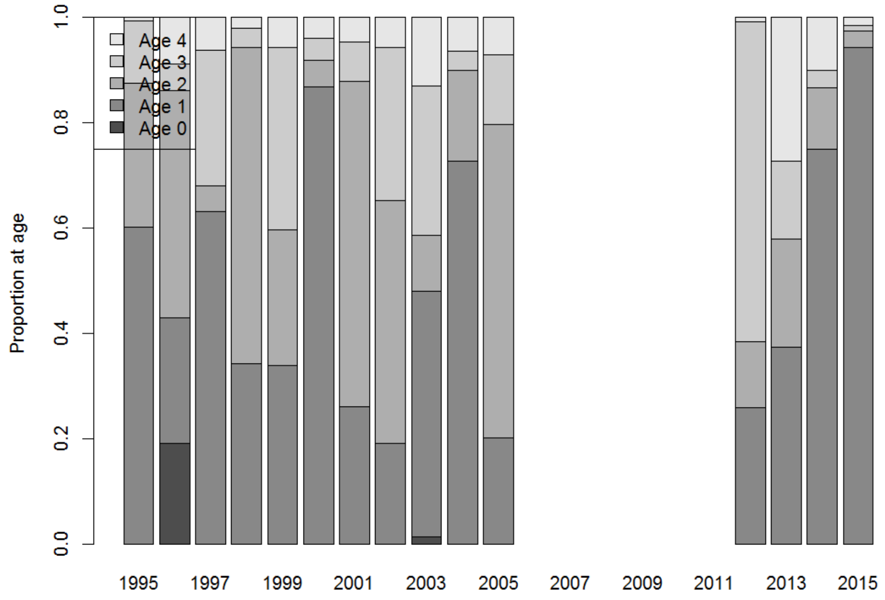


Figure. 5.2.1. Distribution of catches on ages.

5.2.1 Surveys

Dredge survey catches are given in Table 5.2.1.1. The period survey was expanded between the period before and after 2005. Age 2+ is not used.

Table 5.2.1.1. Dredge survey index.

YEAR	AGE 0	AGE 1	AGE 2+
1999	615	494	301
2000	586	3170	258
2001	48	2656	1561
2002	243	404	916
2003	580		
2008	52	24	18
2009	832	87	38
2010	147	1032	67
2011	89	165	407
2012	95	135	23
2013	62	85	35

2014	445	43	12
2015	136	1044	14

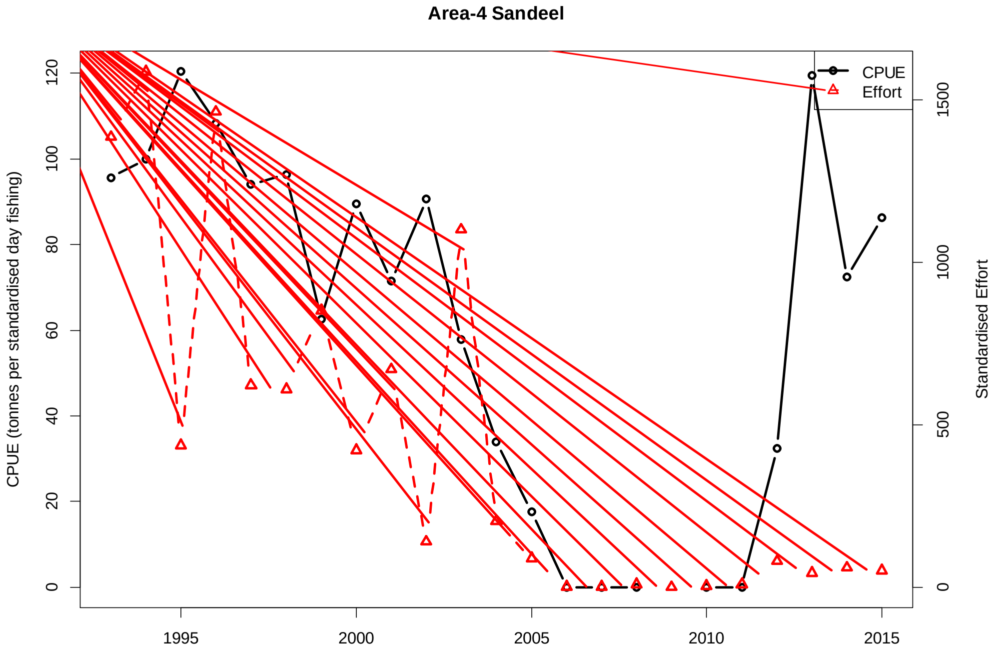


Figure 5.2.1.1 CPUE and effort series.

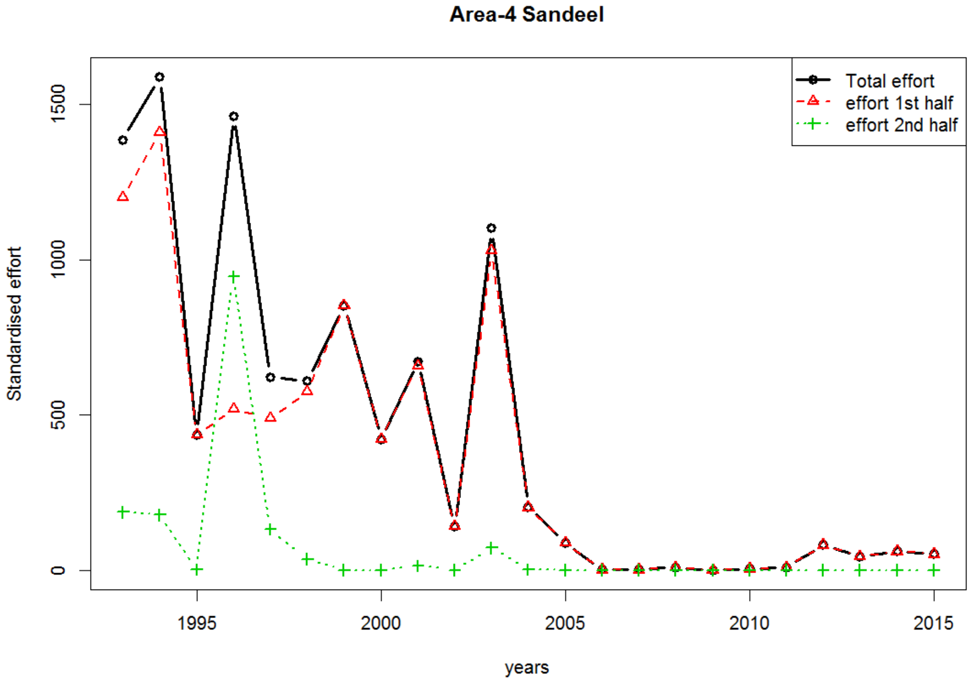


Figure 5.2.1.2. Effort in the first and second half year.

5.2.2 Maturity

Average maturity at age from dredge survey catches in area 4 were used (Boulcott *et al.*, 2007). Values are given in Table 5.2.2.1

Table 5.2.2.1 Maturity at age in area 4.

Age	0	1	2	3	4+
	0.00	0.00	0.79	0.98	1.00

5.2.3 Natural mortality

Long term average natural mortality at age from multispecies modelling of northern sandeel (SMS, WGSAM 2015) were used (Table 5.2.3.1).

Table 5.2.3.1 Annual natural mortality at age in area 4.

	Age 0	Age 1	Age 2	Age 3	Age 4
Season 1	0.00	0.767	0.602	0.431	0.398
Season 2	1.140	0.592	0.488	0.392	0.378

5.2.4 Weight at age

Weight at age in the stock and catch was estimated from catch samples. Table 5.2.4.1 show the individual mean weight in catch and stock by year, age and season.

Table 5.2.4.1 Area-4 Sandeel. Individual mean weight(g) at age in the catch and in the stock.

Year/Age	Age 0, 2nd half	Age 1, 1st half	Age 1, 2nd half	Age 2, 1st half	Age 2, 2nd half	Age 3, 1st half	Age 3, 2nd half	Age 4+, 1st half	Age 4+, 2nd half
1993	3.0	7.4	6.7	11.9	12.0	14.9	14.0	20.1	18.9
1994	3.8	10.9	8.6	11.1	15.5	14.7	18.0	20.5	24.4
1995	4.4	8.4	10.1	15.7	18.0	19.1	21.0	15.5	28.5
1996	6.3	5.3	7.3	12.9	13.1	18.6	18.0	23.0	22.3
1997	3.1	6.7	7.0	7.5	12.4	11.2	14.5	18.1	19.6
1998	2.6	6.1	6.0	10.4	10.7	13.6	12.5	14.6	16.9
1999	3.2	6.1	7.2	10.8	12.9	16.1	15.1	20.2	20.4
2000	4.0	3.9	9.0	8.0	16.2	13.2	18.8	17.3	25.5
2001	1.8	3.4	4.2	6.0	7.5	9.0	8.7	14.2	11.8
2002	4.0	3.8	9.0	5.9	16.2	9.5	18.8	17.9	25.5
2003	3.6	4.6	5.6	6.6	6.2	8.1	7.8	10.9	10.1
2004	1.4	4.0	3.3	7.4	5.8	9.3	6.8	13.8	9.2
2005	4.0	4.2	9.0	6.1	16.2	8.6	18.8	11.0	25.5
2006	0.0	5.5	0.0	10.0	0.0	14.3	0.0	18.1	0.0
2007	4.0	4.8	9.0	8.8	16.2	12.6	18.8	16.0	25.5
2008	4.0	4.8	9.0	8.7	16.2	12.4	18.8	15.7	25.5
2009	4.0	5.8	9.0	10.7	16.2	15.2	18.8	19.3	25.5
2010	4.0	5.1	9.0	9.4	16.2	13.4	18.8	17.0	25.5
2011	4.0	4.9	9.0	8.9	16.2	12.7	18.8	16.1	25.5
2012	4.0	4.0	9.0	8.2	16.2	9.6	18.8	12.2	25.5
2013	4.0	5.3	9.0	9.3	16.2	14.7	18.8	17.1	25.5
2014	4.0	7.1	9.0	12.4	16.2	17.2	18.8	20.0	25.5
2015	4.0	4.4	9.0	9.5	16.2	11.4	18.8	16.2	25.5
arith. mean	3.5	5.5	7.6	9.4	13.4	13.0	15.7	16.7	21.2

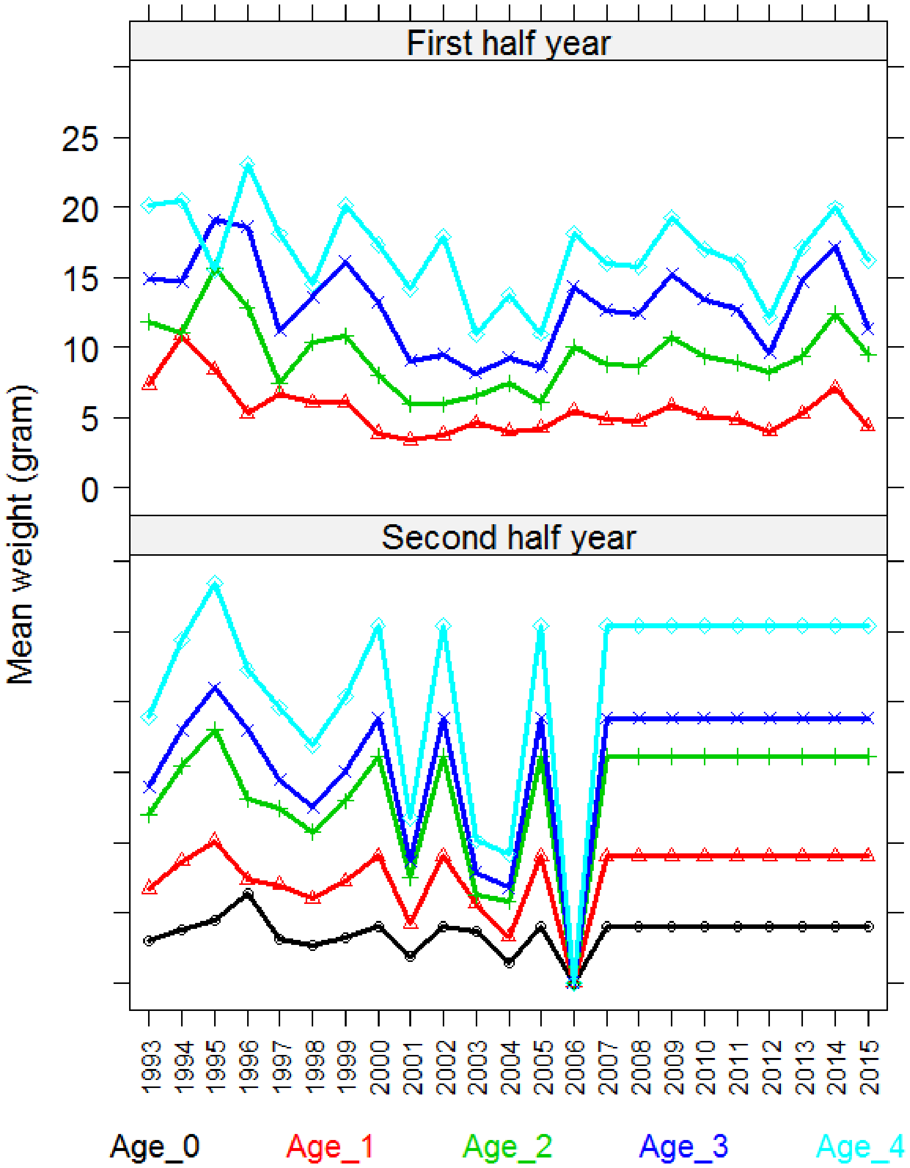


Figure 5.2.4.1. Weight at age in the catch and in the stock. Note that in some years, mean weight is based on very few samples.

5.2.5 Commercial data

Catch at age is given in Table 5.2.5.1 and input effort is given in Table 5.2.5.2.

Table 5.2.5.1. Area-4 Sandeel. Catch at age numbers (millions) by half year

Year/Age	Age 0, 2nd half	Age 1, 1st half	Age 1, 2nd half	Age 2, 1st half	Age 2, 2nd half	Age 3, 1st half	Age 3, 2nd half	Age 4+, 1st half	Age 4+, 2nd half
1993	674	1235	149	6337	381	1861	122	534	39
1994	0	1070	256	1522	62	5144	257	2092	159
1995	4	2690	4	1229	1	529	0	30	0

1996	2666	754	2584	2536	3461	476	227	130	1110
1997	0	2879	1369	291	35	1683	43	413	10
1998	0	2159	61	3766	97	235	6	130	3
1999	0	1472	86	1137	46	1543	47	252	11
2000	0	6537	0	376	0	323	0	297	0
2001	0	2048	64	4961	20	601	1	377	0
2002	0	337	0	807	0	511	0	101	0
2003	145	4322	148	1002	10	2721	5	1253	1
2004	0	920	4	220	1	45	0	82	0
2005	0	49	0	145	0	32	0	17	0
2006	0	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	0	0	0
2008	0	0	0	0	0	0	0	0	0
2009	0	0	0	0	0	0	0	0	0
2010	0	0	0	0	0	0	0	0	0
2011	0	0	0	0	0	0	0	0	0
2012	0	83	0	40	0	196	0	3	0
2013	0	182	0	100	0	71	0	133	0
2014	0	346	0	54	0	15	0	47	0
2015	0	864	0	29	0	9	0	14	0
arith. mean	152	1215	205	1067	179	695	31	257	58

Table 5.2.5.2. Area-4 Sandeel. Standardised effort (fishing days for a 200 GT vessels)

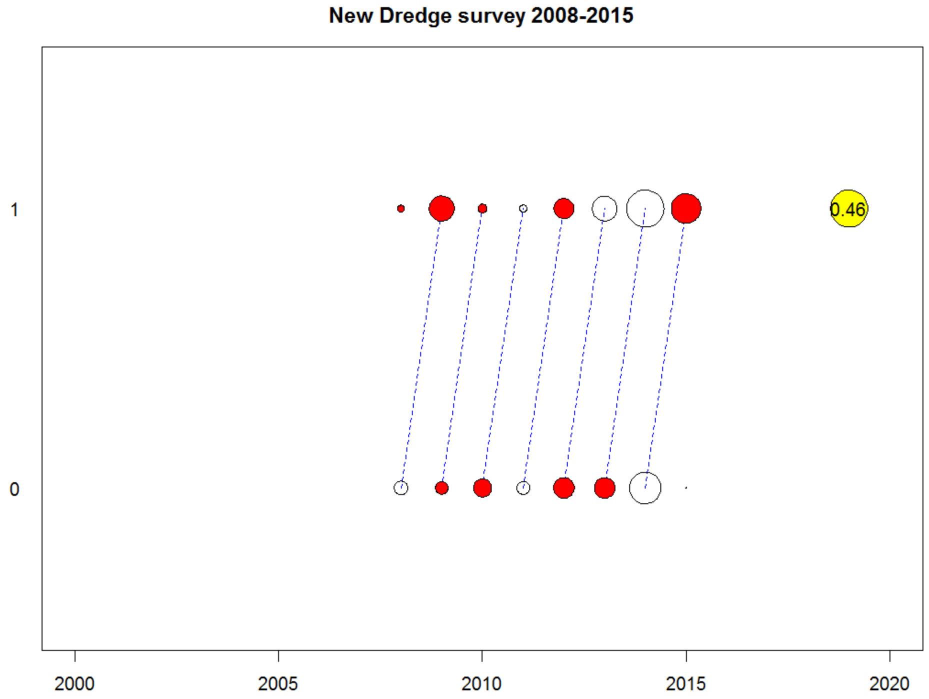
Year/Age	**1st half year**	**2nd half year**	**Sum**
1993	1200	186	1386
1994	1409	178	1587
1995	435	1	437
1996	518	945	1463
1997	490	132	621
1998	574	35	609
1999	852	0	852
2000	422	0	422
2001	657	13	670
2002	140	0	140
2003	1029	72	1101
2004	201	2	203
2005	88	0	88
2006	2	0	2
2007	1	0	1
2008	9	0	9
2009	0	0	0
2010	4	0	4
2011	9	0	9
2012	80	0	80
2013	44	0	44

2014	60	0	60
2015	51	0	51
arith. mean	360	68	428

5.2.6 Assessment model

The diagnostics output from SMS are shown in Table 5.2.6.1. The CV of the dredge survey (“sqrt (Survey variance) ~CV” in the table) is low (0.30) for all ages and periods. The survey residual plot (Figure 5.2.6.1) shows no apparent trends or other patterns.

The model CV of catch at age (“sqrt(catch variance) ~CV”, in Table 5.2.6.1 is high (0.68) for age 1 and age 2 in the first half of the year and higher for the remaining ages and season combinations. The catch at age residuals (Figure 5.2.6.2) show a tendency for year effects but otherwise no alarming patterns.



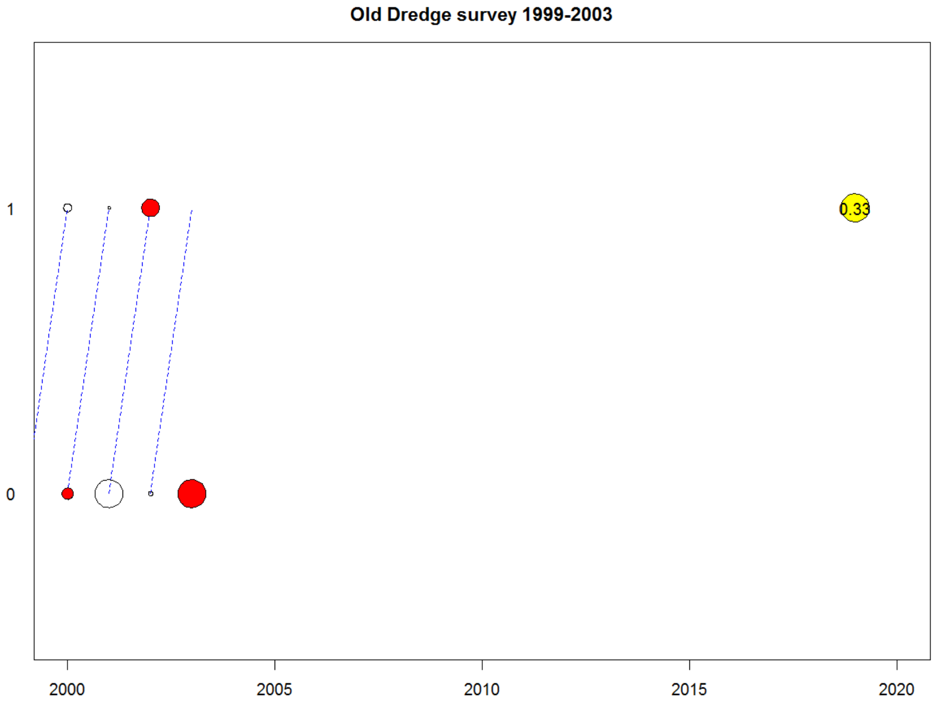


Figure 5.2.6.1 Survey residuals.

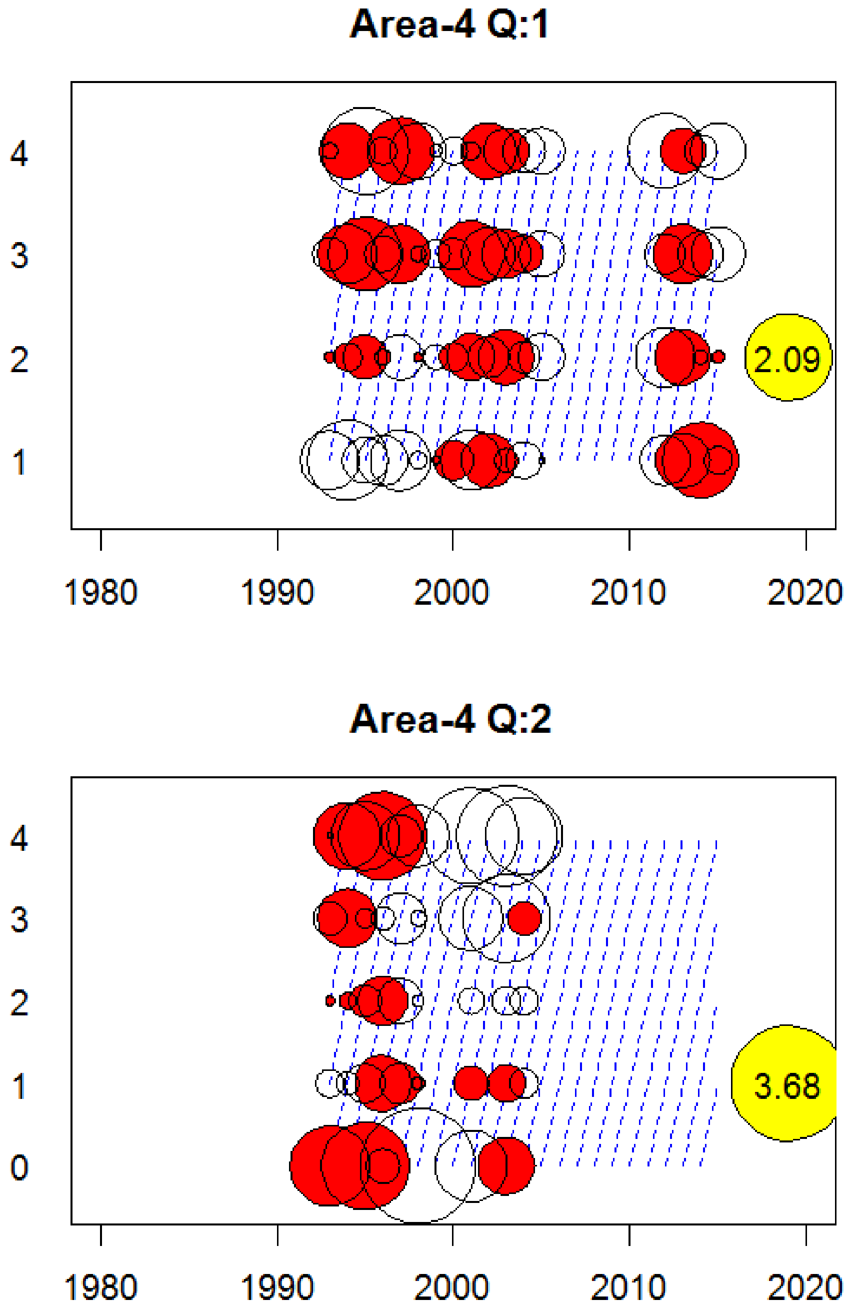


Figure 5.2.6.2 Catch residuals.

The CV of the fitted Stock recruitment relationship (Table 5.2.6.1) is high (1.21), which is also indicated by the stock recruitment plot (Figure 5.2.6.3). The high CV of recruitment is probably due to biological characteristic of the stock and not the quality of the assessment. The *a priori* weight on likelihood contributions from SSR-R observations is therefore set low (0.05 in "objective function weight" in Table 5.2.6.1) such that SSB-R estimates do not contribute much to the overall likelihood and model fit.

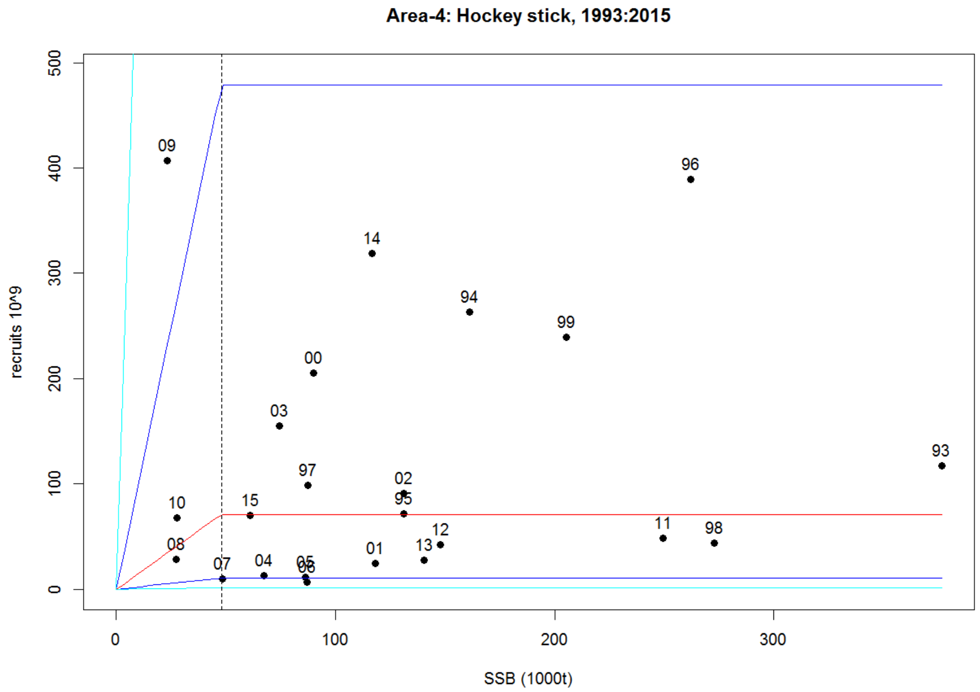


Figure. 5.2.6.3. Stock-recruitment relationship.

The retrospective analysis (Figure 5.2.6.4) shows very consistent assessment results from one year to the next but some retrospective pattern in recruitment and SSB. This high consistency for F is partly due to the assumed robust relationship between effort and F, which is rather insensitive to removal of a few years and the low weight of the dredge survey.

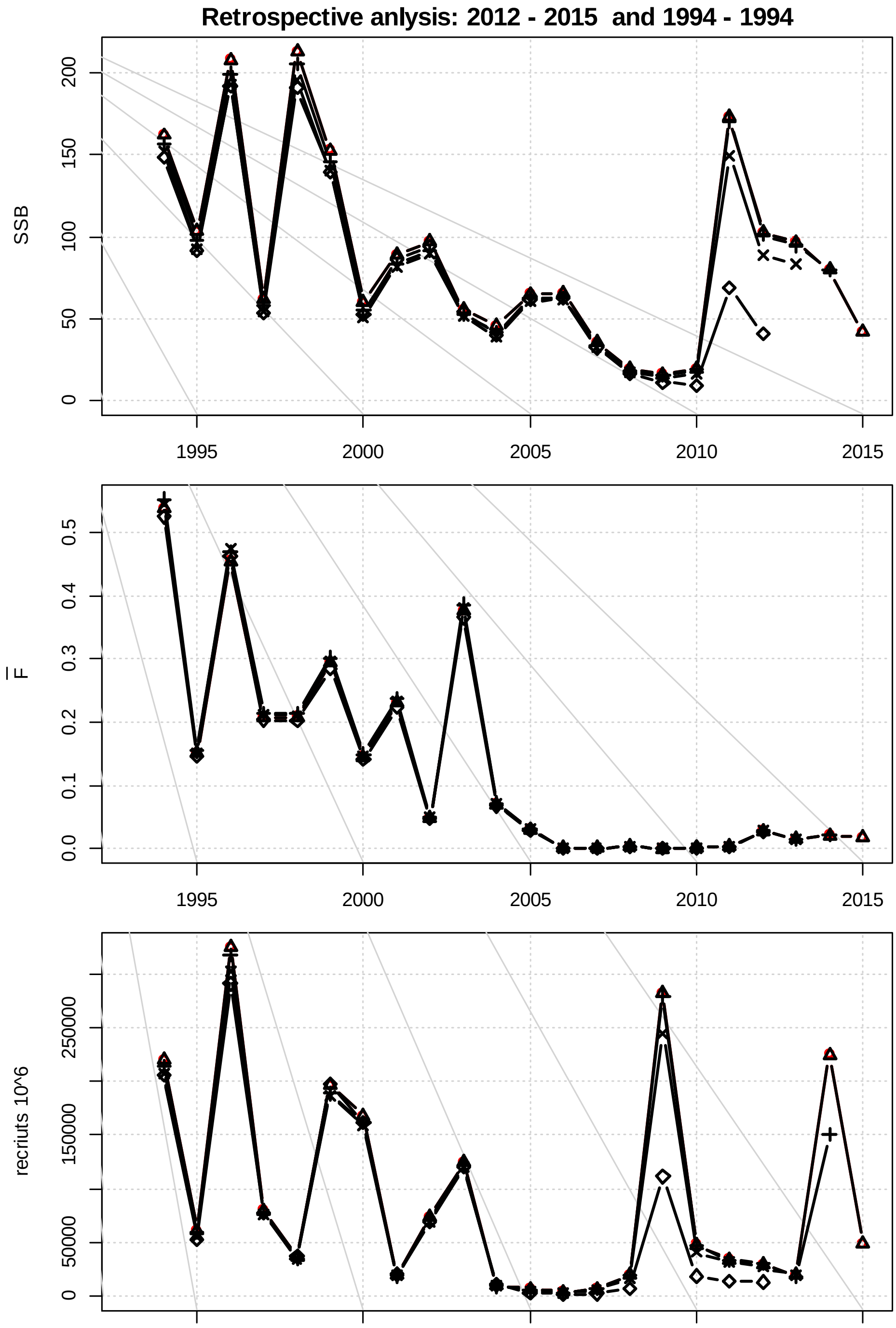


Figure 5.2.6.4. Retrospective analysis.

Uncertainties of the estimated SSB, F and recruitment (Figure 5.2.6.5) are in general small. For F, uncertainties are lowest for the most recent years, which are not normally seen. This is due to the model fit where the most recent effort values estimate F with a small error (Figure 5.2.6.6), while older observations have a larger difference between effort and F (Figure 5.2.6.7).

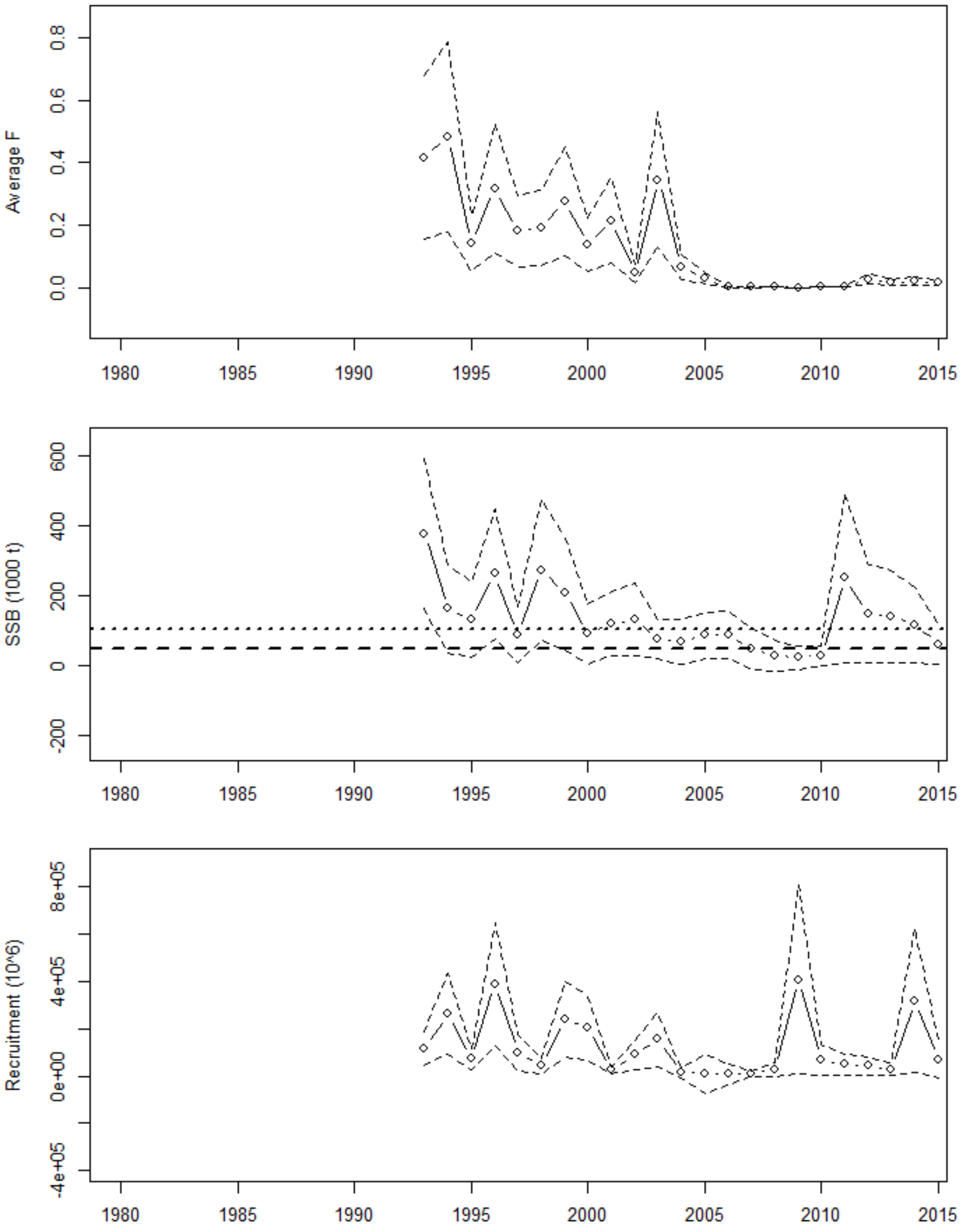


Fig. 5.2.6.5. Predicted stock size, F and recruitment and associated uncertainties.

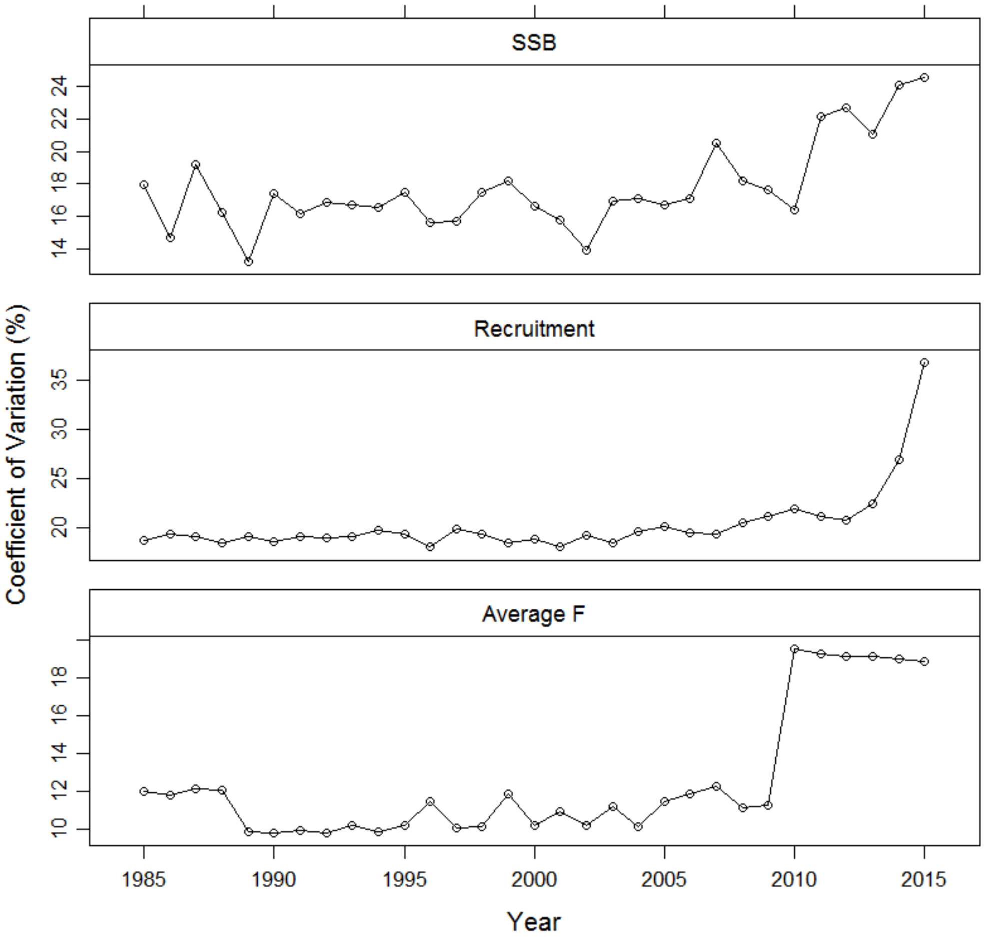


Fig. 5.2.6.6. CV of SSB, recruitment and F.

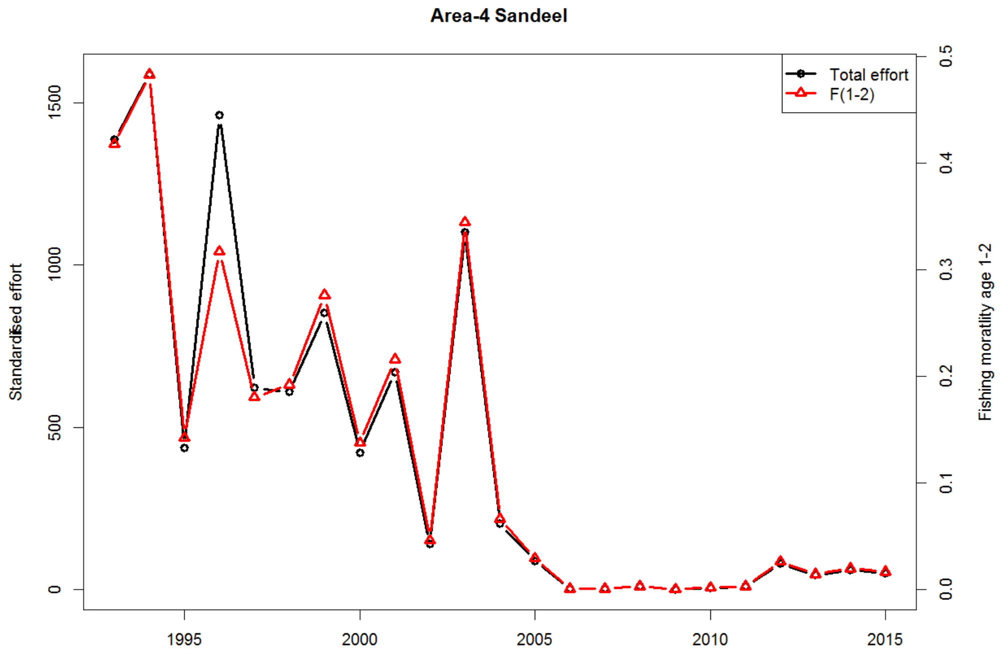


Fig. 5.2.6.7. Effort and estimated F.

Table 5.2.6.1. Assessment fit summary.

```
Date: 11/04/16  Start time:12:17:57 run time:0 seconds


objective function (negative log likelihood):  2.50836

Number of parameters: 42

Maximum gradient: 1.75661e-005

Akaike information criterion (AIC):   89.0167

Number of observations used in the likelihood:

                    Catch   CPUE    S/R Stomach    Sum

                     207     25     23      0    255


objective function weight:

                  Catch  CPUE   S/R

                  1.00  1.00  0.05


unweighted objective function contributions (total):

          Catch    CPUE    S/R   Stom.  Stom N.  Penalty    Sum

          27.3   -25.6    15.9    0.0     0.0     0.00      18



unweighted objective function contributions (per observation):

          Catch   CPUE     S/R   Stomachs

          0.13   -1.02    0.69    0.00



contribution by fleet:

----------------------

Old Dredge survey 1999-2003     total:  -9.458   mean:  -1.051

New Dredge survey 2008-2015     total: -16.112   mean:  -1.007


F, season effect:

-----------------

age: 0

   1993-2015:   0.000 1.000

age: 1 - 4
```

```
   1993-2015:   0.576 0.500


F, age effect:
--------------
             0      1      2      3      4
1993-2015:  0.003  0.107  0.182  0.234  0.234



Exploitation pattern (scaled to mean F=1)
----------------------------------------
                   0      1      2      3      4
1993-2015 season 1:      0  0.652  1.110  1.426  1.426
         season 2:  0.005  0.088  0.150  0.192  0.192



sqrt(catch variance) ~ CV:
--------------------------


            season
----------------------
age       1       2


 0             2.004
 1      0.681   0.374
 2      0.681   0.374
 3      0.808   1.254
 4      0.808   1.254



Survey catchability:
--------------------
                        age 0    age 1
 Old Dredge survey 1999-2003       0.732   16.732
 New Dredge survey 2008-2015       0.525    2.798


sqrt(Survey variance) ~ CV:
```

```
---------------------------
                     age 0   age 1
 Old Dredge survey 1999-2003      0.30    0.30
 New Dredge survey 2008-2015      0.30    0.30


Recruit-SSB                          alfa     beta      recruit s2    recruit s
Area-4     Hockey stick -break.:    2162.649   3.100e+004   1.464         1.210
```

5.2.7 Final assessment

The output from the assessment is presented in Tables 5.2.7.1 (fishing mortality at age by year), 5.2.7.2 (fishing mortality at age by half year), 5.2.7.3 (stock numbers at age) and 5.2.7.4 (stock summary).

Table 5.2.7.1. Sandeel SA 4. Annual fishing mortality (F) at age.

Year/Age	Age 0	Age 1	Age 2	Age 3	Age 4	Avg. 1-2
1993	0.002	0.315	0.522	0.654	0.652	0.419
1994	0.002	0.365	0.603	0.754	0.752	0.484
1995	0.000	0.108	0.177	0.220	0.218	0.142
1996	0.008	0.231	0.405	0.537	0.541	0.318
1997	0.001	0.135	0.226	0.285	0.285	0.181
1998	0.000	0.146	0.240	0.299	0.298	0.193
1999	0.000	0.210	0.344	0.426	0.424	0.277
2000	0.000	0.104	0.171	0.212	0.211	0.138
2001	0.000	0.164	0.269	0.334	0.332	0.216
2002	0.000	0.035	0.057	0.071	0.071	0.046
2003	0.001	0.261	0.430	0.535	0.533	0.345
2004	0.000	0.050	0.082	0.102	0.102	0.066
2005	0.000	0.022	0.036	0.045	0.045	0.029
2006	0.000	0.000	0.001	0.001	0.001	0.001
2007	0.000	0.000	0.001	0.001	0.001	0.000
2008	0.000	0.002	0.004	0.004	0.004	0.003
2009	0.000	0.000	0.000	0.000	0.000	0.000
2010	0.000	0.001	0.002	0.002	0.002	0.001
2011	0.000	0.002	0.004	0.004	0.004	0.003
2012	0.000	0.020	0.033	0.040	0.040	0.026
2013	0.000	0.011	0.018	0.022	0.022	0.014
2014	0.000	0.015	0.024	0.030	0.030	0.020
2015	0.000	0.013	0.021	0.026	0.026	0.017
arith. mean	0.001	0.096	0.159	0.200	0.200	0.128

Table 5.2.7.2. Sandeel SA 4. Seasonal fishing mortality (F) at age.

Year/Age	Age 0, 2nd half	Age 1, 1st half	Age 1, 2nd half	Age 2, 1st half	Age 2, 2nd half	Age 3, 1st half	Age 3, 2nd half	Age 4+, 1st half	Age 4+, 2nd half
1993	0.002	0.233	0.031	0.397	0.054	0.509	0.069	0.509	0.069
1994	0.002	0.274	0.030	0.466	0.051	0.599	0.066	0.599	0.066
1995	0.000	0.085	0.000	0.144	0.000	0.185	0.001	0.185	0.001
1996	0.008	0.101	0.159	0.171	0.271	0.220	0.348	0.220	0.348
1997	0.001	0.095	0.022	0.162	0.038	0.208	0.049	0.208	0.049
1998	0.000	0.112	0.006	0.190	0.010	0.244	0.013	0.244	0.013
1999	0.000	0.166	0.000	0.282	0.000	0.362	0.000	0.362	0.000
2000	0.000	0.082	0.000	0.139	0.000	0.179	0.000	0.179	0.000
2001	0.000	0.128	0.002	0.217	0.004	0.279	0.005	0.279	0.005
2002	0.000	0.027	0.000	0.046	0.000	0.060	0.000	0.060	0.000
2003	0.001	0.200	0.012	0.340	0.021	0.437	0.026	0.437	0.026
2004	0.000	0.039	0.000	0.067	0.001	0.086	0.001	0.086	0.001
2005	0.000	0.017	0.000	0.029	0.000	0.038	0.000	0.038	0.000
2006	0.000	0.000	0.000	0.001	0.000	0.001	0.000	0.001	0.000
2007	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.001	0.000
2008	0.000	0.002	0.000	0.003	0.000	0.004	0.000	0.004	0.000
2009	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2010	0.000	0.001	0.000	0.001	0.000	0.002	0.000	0.002	0.000
2011	0.000	0.002	0.000	0.003	0.000	0.004	0.000	0.004	0.000
2012	0.000	0.016	0.000	0.026	0.000	0.034	0.000	0.034	0.000
2013	0.000	0.008	0.000	0.014	0.000	0.019	0.000	0.019	0.000
2014	0.000	0.012	0.000	0.020	0.000	0.025	0.000	0.025	0.000
2015	0.000	0.010	0.000	0.017	0.000	0.022	0.000	0.022	0.000
arith. mean	0.001	0.070	0.011	0.119	0.020	0.153	0.025	0.153	0.025

Table 5.2.7.3. Sandeel SA 4. Stock numbers (millions). Age 0 at start of 2nd half-year, age 1+ at start of the year.

Year/Age	Age 0	Age 1	Age 2	Age 3	Age 4
1993	116966	21525	24454	7738	1708
1994	262703	37346	4245	5241	2347
1995	71274	83884	7081	851	1740
1996	388334	22794	19799	2061	976
1997	98554	123157	4515	4276	767
1998	43548	31482	28138	1243	1726
1999	238748	13923	7192	7746	1037
2000	204642	76356	3031	1824	2701
2001	24558	65448	18075	887	1709
2002	90414	7853	14766	4871	885
2003	154364	28916	1963	4739	2399
2004	13038	49337	6010	460	2004
2005	11381	4170	12186	1889	1031

2006	6706	3640	1053	3979	1256
2007	9551	2145	935	354	2324
2008	28439	3055	551	314	1224
2009	406169	9095	783	185	699
2010	67842	129901	2337	263	403
2011	48412	21697	33346	785	300
2012	42399	15483	5565	11180	481
2013	27712	13560	3917	1822	4959
2014	317865	8863	3454	1298	3026
2015	69969	101659	2251	1139	1914
2016		22378	25862	744	1351

Table 5.2.7.4. Sandeel SA 4. Estimated recruitment, total stock biomass (TBS), spawning stock biomass (SSB), catch weight (Yield) and average fishing mortality.

Year	**Recruits**	**TSB**	**SSB**	**Yield**	**Mean F**
(million)	(tonnes)	(tonnes)	(tonnes)	ages 1-2	
1993	116966	597534	376039	132599	0.419
1994	262703	578068	160787	158690	0.484
1995	71274	860563	130729	52591	0.142
1996	388334	436449	261333	158490	0.318
1997	98554	919644	87208	58446	0.181
1998	43548	524516	272171	58746	0.193
1999	238748	308088	204748	53334	0.277
2000	204642	390742	89493	37714	0.138
2001	24558	362923	117717	47902	0.216
2002	90414	179376	130558	12736	0.046
2003	154364	210627	74140	63731	0.345
2004	13038	274259	66890	6882	0.066
2005	11381	119579	85934	1557	0.029
2006	6706	110047	86804	0	0.001
2007	9551	60292	48098	0	0.000
2008	28439	42486	26878	0	0.003
2009	406169	77603	22822	0	0.000
2010	67842	697728	27586	0	0.001
2011	48412	416721	248808	0	0.003
2012	42399	221174	147294	2585	0.026
2013	27712	219903	140047	5225	0.014
2014	317865	188618	116239	4314	0.020
2015	69969	508759	60706	4384	0.017
2016			224795		
arith. mean	119286	361117	133659	37388	0.128
geo. mean	65214				

5.2.8 Historic Stock Trends

The stock summary (Figure 5.2.8.1 and Table 5.2.8.1) shows that SSB have been below B_{lim} from 2008 to 2010. SSB has been above B_{lim} but below B_{pa} in 1997, 2000, 2003–2007 and 2015. SSB is estimated just above B_{pa} in 2016. $F_{(1\text{-}2)}$ is estimated to have been below very low since 2005.

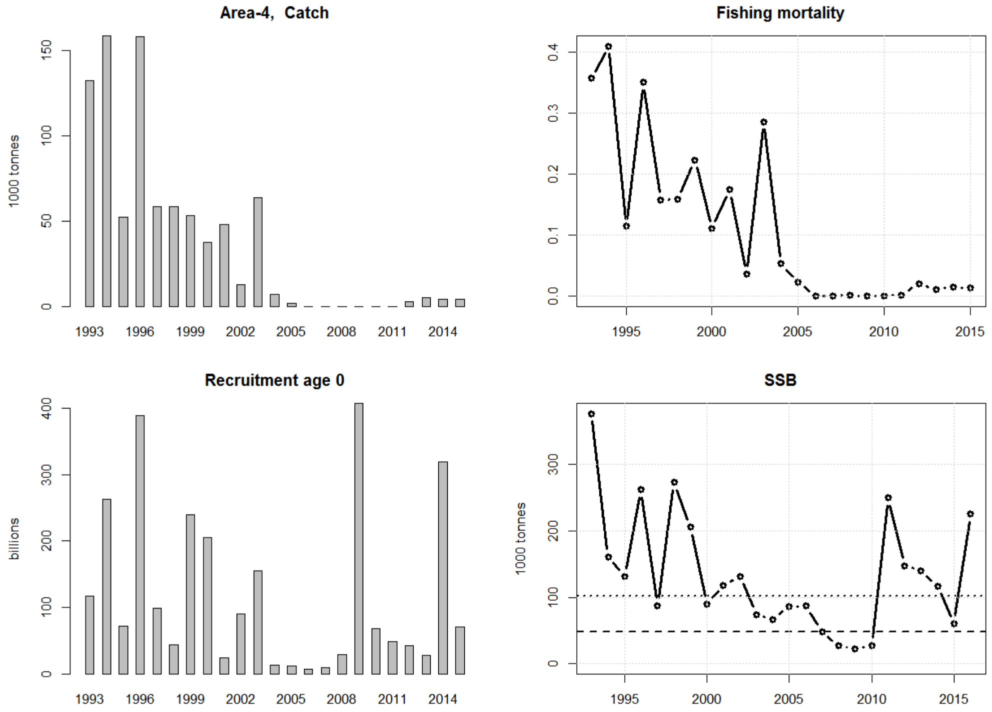


Fig. 5.2.8.1. Stock summary.

5.3 Short term projections

Weight at age shows no recent trends and should be set at 5 years.

Selection pattern is taken as the last year estimated in SMS. Natural mortality and maturity is fixed across the time series and hence retained. Recruitment has shown substantial autocorrelation in the past, and to respond to such changes, a 10-year geometric average should be used.

5.4 Appropriate Reference Points (MSY)

Examining the stock recruitment relationship, there appeared to be a decrease in recruitment at low stock size and no clear breakpoint of the relationship. Above average cohorts in the low end of the SSB range occurred in 2009 and 2003. The 2009 cohort was 256% above average whereas the 2001 cohort was 35% above average. The average SSB of the two years was 48 481t, and accordingly, Blim was set at 48 000t. With a CV of 0.46, this results in a Bpa of 102 000t.

6 Stock (SA5r)

Sandeel (*Ammodytes* spp.) in Division 4.a, Sandeel Area 5r (northern North Sea, Viking and Bergen banks); ICES statistical rectangles 47-52 F1-F5.

6.1 Multispecies and mixed fisheries issues

The sandeel fishery in SA5r has mainly been carried out on the fishing ground "Vikingbanken", however, between 1982 to 1994 only very small landings were reported from the "Vikingbanken". A strong recruitment of the 1994 year-class gave very high catches in 1995 (about 150 000t), and relatively large landings were reported from Vikingbanken in 1996 and 1997. Since then, no significant landing of sandeel has been reported from the area. In contrast to many other sandeel grounds, the fish species diversity and density is large on Vikingbanken compared with other sandeel grounds in the North Eastern part of the North Sea. A sandeel fishery in the area may have higher by-catches than typically reported in other sandeel grounds.

6.2 Ecosystem drivers

There is strong evidence that sandeel stocks are affected by bottom-up processes involving climate and changing plankton stocks. Sandeel are high quality food for many predatory fish, seabirds and marine mammals. Given the semi-sedentary behaviour of sandeel after settling, local depletion of sandeel aggregations at a distance less than 100 km from seabird colonies may affect some species of birds, whereas the more mobile marine mammals and fish are likely to be less vulnerable to local sandeel depletion. Section 1.5 contains a comprehensive description of ecosystem aspects.

6.3 Stock Assessment

6.3.1 Catch – quality, misreporting, discards

General information about the sandeel fishery can be found in Section 1.6 (WKSAND 2016).

Table 6.3.1 Landing by year for SA5r. Note that there has not been any landings in SA5r since 2004.

Year	Landing (tonnes)
1982	7393.48
1983	0.00
1984	5820.67
1985	3003.87
1986	627.61
1987	1713.49
1988	0.00
1989	2902.80
1990	373.90
1991	1168.06

Year	Landing (tonnes)
1992	1098.75
1993	586.07
1994	2757.23
1995	152274.11
1996	27570.39
1997	10771.84
1998	2952.37
1999	145.05
2000	303.43
2001	1678.00
2002	8.34
2003	43.88
2004	0.00
2005	0.00
2006	0.00
2007	4.24
2008	0.00
2009	0.00
2010	0.00
2011	0.00
2012	0.00
2013	0.00
2014	0.00
2015	0.00
2016	0.00

6.3.2 Surveys

The estimated acoustic survey index not separated by age due too poor biological sampling and very few individuals caught. However, the acoustic survey show that the abundance of lesser sandeel is very low on Vikingbanken (SA5) (Table 6.3.2.1, Total annual catches by area) compared to the historical landings in e.g. 1995. The acoustic survey method is described in 1.7.2.

Table 6.3.2.1 Acoustic survey index is estimated as biomass (tons) using acoustic target strength described in 1.7.2.

YEAR	BIOMASS (TONS)
2009	256.5
2010	6320.9
2011	3300.2
2012	732.2
2013	3949.1
2014	1331.8
2015	10477.6
2016	733.2

6.3.3 Weights, maturities, growth

Insufficient number of biological samples to make any estimates.

6.3.4 Assessment model

This is a category 5 stock with no or incidental landings in recent years and there is no analytical stock assessment of sandeel in this area.

7 Stock (SA6)

Sandeel (*Ammodytes* spp.) in Subdivision 21, Sandeel Area 6 (Kattegat); ICES statistical rectangles 41–43 G0–G3; 44 G1. The 2016 benchmark did not alter the definition of this sandeel area.

7.1 Multispecies and mixed fisheries issues

The fishery in sandell area 6 (SA6) is small in terms of catches compared to the fishery taken place in the more central parts of the North Sea. Since 1983 catches have been less than 5000t and since 2008 less than 500t. There is not much area specific knowledge on the importance of sandeel in the ecosystem in area 6. There are speculations that the proportion of *Ammodytes tobianus* and *Hyperoplus lanceolatus* relative to *Ammodytes marinus* increases as you move through the Danish waters towards the Baltic sea, however information on the excact sandeel species compositon for these catches is uncertain.

7.2 Ecosystem drivers

There is strong evidence that sandeel stocks are affected by bottom-up processes involving climate and changing plankton stocks. Sandeel are high quality food for many predatory fish, seabirds and marine mammals. Due to its physical characteristics the Kattegat ecosystem is different from the North Sea ecosystem. Section 1.5 contains a comprehensive description of ecosystem aspects.

7.3 Stock Assessment

7.3.1 Catch – quality, misreporting, discards

This stock is in the stock category 5. Only catch statistics are available for SA6. Until 2004 catches were on average more than 1500t annually, but since 2005 catches have remained low (< 500t annually).

General information about the sandeel fishery can be found in Section 1.6.

Table 7.3.1.1 Landing by year for SA6.

Year	Landing (1000't)
1983	0
1984	0
1985	0
1986	0
1987	0
1988	0
1989	909
1990	499
1991	17
1992	4277
1993	4490
1994	3748

1995	1830
1996	1263
1997	2373
1998	936
1999	134
2000	680
2001	312
2002	2378
2003	869
2004	570
2005	262
2006	161
2007	661
2008	472
2009	260
2010	132
2011	481
2012	211
2013	90
2014	79
2015	229
2016	

7.3.2 Surveys

There is no useful information on sandeel in this area from scientific surveys.

7.3.3 Weights, maturities, growth

Insufficient number of biological samples to make any estimates.

7.3.4 Commercial data series

Biological sampling has on average been at a low level (2.6 samples per year since year 2000). This information is inadequate to evaluate stock status or trends, and the state of the stock is therefore unknown.

7.3.5 Assessment model

Not applicable. This is a category 5 stock.

7.4 Short term projection

Not applicable. This is a category 5 stock.

7.5 Appropriate Reference Points (MSY)

Not applicable. This is a category 5 stock.

7.6 Future Research and data requirements

It is an open question whether an assessment exclusively for this area may be established. However there is a need for an analysis of the stock affiliation to other areas like SA2r. Drift modelling and genetic studies may provide useful information.

8 Stock (SA7r)

Sandeel (*Ammodytes* spp.) in Division 4.a, Sandeel Area 7r (northern North Sea, Shetland); ICES statistical rectangles 47-52 E6-F0.

8.1 Multispecies and mixed fisheries issues

8.2 Ecosystem drivers

Around Shetland, sandeels were fished commercially on a number of small inshore grounds within 10 km of the coast. The fishery at Shetland started in the early 1970s and peaked in 1982 when 52 000t were landed. However, the fishery was closed from 1 July 1989 until 1995 following poor recruitment and the fishery ended in 2006 following a series of poor year-classes.

Shetland is home to some internationally and nationally important concentrations of breeding seabirds. During the 1980s there was a substantial reduction in the breeding success of a number of seabird species beginning with Arctic Tern (Sterna paradisea), from around 1984. It was clear that the poor breeding success of sandeels was largely due to the low availability of sandeels, particularly 0-group sandeels (Monaghan *et al.*, 1989). At the time of the 1980s collapse in recruitment the sandeel aggregations at Shetland were regarded as a unit stock. Assessments of this stock showed a clear decrease in recruitment after 1982 consistent with the poor seabird breeding success over this period. However, as the decline in recruitment preceded a decline in spawning biomass, and fishing effort was decreasing in the fishery, the view of fishery scientists at the time was that the fishery was unlikely to be the cause of the recruitment decline. As a result, no management measures were implemented until 1989 when the fishery was closed from 1 July.

Concern over the continuing breeding failure of Shetland seabird led to meetings in Aberdeen in September 1988 and Lerwick in October 1988 (Heubeck 1989) to discuss the problem and identify research priorities. These resulted in a directed research project on the biology of sandeels in the vicinity of seabird colonies at Shetland, which started in 1990 (Wright and Bailey, 1993). A key result from this project was that the sandeel aggregations around Shetland appeared to be part of a larger, more widely distributed complex of aggregations. This hypothesis of a sandeel metapopulation was supported by further research (Wright, 1996; Proctor *et al.*, 1998). Spawning aggregations around Orkney are much more productive than those at Shetland (Wright & Bailey, 1996) and larvae and juveniles from this area are frequently transported into Shetland waters. As such the Shetland fishing grounds may be a net sink within the larger meta-population. Evidence from observations on 0-group distributions and plankton (Wright, 1996) together with model simulations of larval transport (Proctor *et al.*, 1998) indicated that sea circulation was unfavourable to the transport of young sandeels into Shetland waters during the period of low recruitment in the 1980s. This trend was reversed in 1991. As such recruitment and hence stock abundance in Shetland waters appears largely dependent on oceanographic conditions. Poloczanska *et al.* (2004) used stochastic population models to evaluate the likely effect of varying fishing mortality on kittiwake breeding success in Shetland. The models indicated that even with low exploitation rates, poor years for seabird breeding were inevitable. This may explain why, after a few years of good recruitment, there was a protracted period of low recruitment leading to a second collapse in the 2000s.

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8.3 Stock Assessment

This is a category 5 stock with no or incidental landings in recent years. As such, there is no stock assessment of Sandeel in this area.

8.3.1 Catch – quality, misreporting, discards

Not applicable as this is a stock with zero catch in recent years

8.3.2 Surveys

Not applicable. This is a category 5 stock.

8.3.3 Commercial data series

Not applicable as this is a stock with zero catch in recent years

8.3.4 Assessment model

Not applicable. This is a category 5 stock.

8.4 Short term projection

Not applicable. This is a category 5 stock.

8.5 Appropriate Reference Points (MSY)

Not applicable. This is a category 5 stock.

9 Future Research

9.1 Genetic evidence for population structures

There is currently no genetic basis for the stock delineation used to identify sandeel stocks. Rather, reproductive isolation is inferred from biophysical models of larval transport. It is thus largely unknown to which extent local areas exhibit reproductive cohesiveness at levels consistent with a definition of local populations. Evidence for genetic structuring would therefore improve the basis for stock assessment areas. Genetic marker analysis may also identify undescribed population structure, the knowledge of which is a prerequisite for a robust stock assessment. Genetically unique populations often exhibit different productivities and stock-recruitment relationships (e.g. Heath *et al*. 2014; Bonanomi *et al*. 2015). Previous analyses of genetic markers in lesser sandeel applied marker systems with limited resolution for detecting local populations at within-basin scale (Nævdal and Thorkildsen 2002). Newer methods have been developed that allow for a more detailed assessment of genetic differences among local stocks. Two ongoing studies using such molecular approaches address population structure within and across currently defined *A. marinus* stocks in and around the North Sea. Once a genetic baseline is established for major stock components it will further serve as a traceability tool allowing the determination of spatio-temporal trends in exploitation rates of individual genetic stocks.

9.2 Depletion and hyperstability

The effect of concentrating high levels of fishing effort on single banks is not fully understood. Overall, the spatial extent of the fishery has decreased in recent years with the majority of the catch landed by fewer, larger vessels greater than 500GT (Ohlberger and Hilborn 2016). Fishing over the course of a season also tends to cluster spatially, with vessels moving co-operatively at times synchronously as the season progresses and sandeels become available to the fishery. At the level of the individual vessel, continuation of fishing over individual banks is predicated on CPUE, with fishing ceasing when levels indicate that tows are no longer economically viable. The co-ordinated nature of this fishing pattern inevitably causes the concentration of fishing effort over banks. However, if the fishery exhibits hyperstability due to the aggregating behaviour of fish, CPUE will remain elevated as stock abundances decline, risking localised depletion. While only few studies have investigated the post-settlement movements/migrations of the sandeel, post-settlement movement of sandeel has been documented over local scales (Gauld, 1990; Wright *et al*. 1998; Jensen *et al*. 2011) and this, combined with site preferences, may underpin hyperstability. Further work identifying how widespread localised depletion is within the fishery or the conditions that precede such events is required.

9.3 Maturity and fecundity at age and drivers of annual variation

Maturity at age is used in the SMS stock assessment. With regard to maturity, assessments prior to 2010 used a knife-edge maturity relationship, with all fish > 2 y old being assumed to be mature on 1 January. However, Boulcott *et al*. (2007) demonstrated that there were regional differences in maturity at age and the proportion at age-2 could be < 100%. Current assessments up to 2016 use maturity proportions calculated from the dredge survey that vary with age and region, although SA2 (old nomenclature) took its values from SA1. However, in the benchmark assessment an average maturity at age from the dredge survey was used. Boulcott and Wright (2011) demonstrated that the fecundity length exponent is relatively high, ranging from 3.3 to 4.8, and hence large individuals may have a much larger eggs per size. Therefore, it would be useful to consider how egg production per SSB varies relative to length composition. Data from the dredge surveys indicates substantial inter-annual variation in maturity at age and it would be potentially useful to forecast if the environmental driver such variability could be better understood.

9.4 Recruitment / Density dependence / Ecological drivers/ Regime change

The underpinning mechanism driving recruitment in sandeel is not fully understood. Spawning stock biomass is not the main driver of recruitment variability in sandeels, as indicated by spasmodic recruitment relationship. There is both empirical and modelling evidence that the match with plankton prey is a key driver of recruitment (Wright and Bailey, 1996; Gurkan *et al*. 2012, 2013). Van Deurs *et al*. (2009) found a negative relationship between recruitment and sea-surface temperature and a positive relationship with *Calanus finmarchicus* abundance. Negative density dependent effects of the preceding year class on recruitment have also been reported (Arnott and Ruxton, 2002; van Deurs *et al*., 2009). Further work relating to the relative strength and nature of density dependence would be beneficial. Moreover, since 2002 the frequency of strong recruitment years has declined across all assessed areas. This change has been accompanied by a change in fleet structure. Additional work to define the drivers behind the change and the extent to which their effects are widespread within the ecosystem is required. Whether the persistence in this trend can be regarded as a long term change in environmental state or regime, with consequences as to how the stock might be managed, is not clear. The implications of the weak recruitment relationship observed within stocks and the possibility of a regime change in recruitment should also be examined with regard to the setting of reference points.

9.5 Spatial management measures

A full evaluation of the Norway closed management regime is recommended to evaluate the efficacy of this approach. This would act as a case study into how well the spatial system of management works for the sandeel fishery in contrast to currently established escapement strategies in EU waters. Comparisons of bank level demographic composition could be made with permanently closed areas in the north-west of the North Sea and fully open areas in the north-west and in southern and central areas. This would provide an indication in differences in local mortality regime, which could be related to local fishing effort. The design of the closed area network and how it contributes to management objectives should be examined, focusing on the size, number and contribution to the stock of closed areas operating across the fishery. Examination of criteria for the selection of closures and reopening of closed areas should also be investigated.

9.6 Patchiness at a local scale

Further work to investigate the causes of local scale differences in recruitment variability between adjacent banks would be beneficial. Adjacent banks in the Norwegian sector of SA3 have displayed considerable variation in sandeel abundance and age composition. This distribution pattern can occur at spatial scales that are expected to be served by the same system of larval transport. A finer scale prediction of larval transport and a better understanding of juvenile settlement / habitat selection would help to inform the management of such areas.

9.7 The effect of species composition in SA2

The stock in SA2 is likely to be comprised of various sandeel species: *Ammodytes marinus* and *A. tobianus, Gymnammodytes semisquamatus,* and *Hyperoplus immaculatus* and *H. lanceolatus.* However, the visual difference between certain sandeel species can be difficult to discern, making reliable classification during the survey very difficult. Due to a lack of reliable species data, the assessment treats these species as a single unit. However, the different species may exhibit different productivities and stock-recruitment relationships. The consequences of treating different species as a single unit on the assessment is not fully understood and should be further investigated.

9.8 Data Requirements:

Genetic results should be taken into consideration in the delineation of stocks in next benchmark. DTU-Aqua requested further tissue samples for their genetic analysis using … DDRAD. In order to assess the genetic connectivity among reproductive units it is important to analyse samples collected from all sandeel areas at or as close as possible to the spawning season to minimize potential transients contributing to the reproductive sample.

Currently, data collected from DTU and MSS dredge surveys are not collated into the same format. It is recommended that future data submissions match index analysis requirements

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Annex 1: List of participants

Name	Address	Phone/Fax	Email
Amy Schueller *External Reviewer*	National Marine Fisheries Service, Southeast Fisheries Science Center, Beaufort Laboratory, 101 Pivers Island Road, Beaufort, NC 28516 USA	1-252-838-0815	Amy.Schueller@noaa.gov
Anna Rindorf	DTU Aqua Jægersborg Alle 1 2920 Charlottenlund Denmark	+45 35883333	ar@aqua.dtu.dk
Anne Cooper *ICES Secretariat*	International Council for the Exploration of the Sea (ICES) H. C. Andersens Boulevard 44-46 1553 Copenhagen V Denmark Tel: +45 3338 6700 Fax: +45 3393 4215	+45 33386767	Anne.Cooper@ices.dk
Bob Furness *External Chair*	University of Glasgow, Glasgow G12 8QQ and MacArthur Green, 95 South Woodside Road, Glasgow G20 6NT	+44 1301702603	bob.furness@glasgow.ac.uk
Casper Berg	DTU Aqua Jægersborg Alle 1 2920 Charlottenlund Denmark	+45 35883433	cbe@aqua.dtu.dk
Cecilie Kvamme	Institute of Marine Research PO Box 1870 Nordnes 5817 Bergen Norway	+47 45449350	Cecilie.Kvamme@imr.no
Claus Reedtz Sparrevohn	Danish Pelagic Prodcuers' Orgnaisation Willemoesvej 2 9850 Hirtshals Denmark		crs@pelagisk.dk
Dorte Bekkevold	DTU Aqua Jægersborg Alle 1 2920 Charlottenlund Denmark		db@aqua.dtu.dk
Emma Hatfield	DG MARE. European Commission, Rue Joseph II, 99. 1000 Brussels, Belgium	+32 2 29 80156	Emma.Hatfield@ec.europa.eu

Espen Johnsen	Institute of Marine Research PO Box 1870 Nordnes 5817 Bergen Norway	+47 90606304	Espen.Johnsen@imr.no
Harald Gjøsæter *ICES Chair*	Institute of Marine Research PO Box 1870 Nordnes 5817 Bergen Norway	+47 41479177	Harald.Gjoesaeter@imr.no
Helge Viksaaland	Norwegian Fisheries Industry		helgeviks@gmail.com
Henrik Mosegaard	DTU Aqua Jægersborg Alle 1 2920 Charlottenlund Denmark	+45 35883461	hm@aqua.dtu.dk
Henrik S. Lund	Danish Fishermen's Association Nordensvej 3 Tauov Denmark	+45 76109652	hl@dkfisk.dk
Jan Ohlberger			Jan.ohlberger@bio.uio.no
Jens Borup	FF Skagen Havnevagtvej 5 9990 Skagen Denmark		jb@ffskagen.dk
Jesper Juul Larsen	Danish Fishermen's Association Nordensvej 3 Tauov Denmark		jjl@svjfisk.dk
Jon Albretsen	Institute of Marine Research PO Box 1870 Nordnes 5817 Bergen Norway		Jon.Albretsen@imr.no
Lars O. Mortensen	DTU Aqua Jægersborg Alle 1 2920 Charlottenlund Denmark		laomo@aqua.dtu.dk
Lotte Worsøe Clausen	DTU Aqua Jægersborg Alle 1 2920 Charlottenlund Denmark		law@aqua.dtu.dk
Mikael van Deurs	DTU Aqua Jægersborg Alle 1 2920 Charlottenlund Denmark		mvd@aqua.dtu.dk
Morten Vinther	DTU Aqua Jægersborg Alle 1 2920 Charlottenlund Denmark		mv@aqua.dtu.dk
Nina Rasmussen	Fiskebåt Røysegata 15 6001 Ålesund Denmark		nina@fiskebat.no
Peter Wright	Marine Scotland		P.J.Wright@marlab.ac.uk

	Science Marine Laboratory 375 Victoria Road Aberdeen AB11 9DB		
Philip Boulcott	Marine Scotland Science Marine Laboratory 375 Victoria Road Aberdeen AB11 9DB		p.boulcott@marlab.ac.uk
Richard D.M Nash	Institute of Marine Research PO Box 1870 Nordnes 5817 Bergen Norway	+47 480 36416 +47 552 38584	Richard.Nash@imr.no
Søren Anker Pedersen	EUfishmeal H. C. Andersens Boulevard 37,1 1553 København V Denmark	+45 33145800	sap@marine.org

Annex 3 Working Documents

WD 01 Larvae surveys in the North Sea which can be relevant for insights in to the spatial distribution and dynamics of sandeel (*Ammodytes spp.*). *By Richard D. M. Nash.*

WD 02 The scale of larval transport in sandeel inferred from otolith microchemistry. *By Peter Wright, Thomas Regnier, Fiona M. Gibb, Dandhya Devalla and Julian Augley.*

WD 03 External consistency between CPUE at age. *By Anna Rindorf.*

WD 04 Analysis of ecosystem drivers of sandeel recruitment in subdivision SA1 (Dogger area). *By Martin Lindegren, Brian McKenzie, Asbjorn Christiensen, Lotte Worsøe Clausen, Anna Rindorf, and Mikael van Deurs.*

WD 05 A time series of abundance of sandeel in the north-eastern North Sea estimated by acoustic surveys. *By Espen Johnsen.*

WD 06 SMS, a stochastic age-length-structured multispecies model applied to North Sea and Baltic Sea Stocks. *WD to ICES WKMULTBAL, March 2012. By Morten Vinther and Peter Lewy.*

WD 07 Real Time Monitoring of Area-1 sandeel. *By Anna Rindorff and Morten Vinther.*

WD 08 Ageing Small Sandeel individuals caught during the 2016 Acoustic Sandeel Survey. *By Åse Husebø and Espen Johnsen*

WD 09 Fcap for sandeel area 1-4. *By Mikael van Deurs*

WD 01 Larvae surveys in the North Sea which can be relevant for insights in to the spatial distribution and dynamics of sandeel (*Ammodytes spp.*).

By Richard Nash

Institute of Marine Research, PB 1870 Nordnes, 5817 Bergen, Norway

Introduction

Larvae surveys can provide evidence of reproduction and survival of early life history stages of fishes. If the surveys capture early stage eggs (pelagic spawning) or recently hatched larvae (demersal or benthic spawned eggs) then the surveys can provide an indication of the reproductive effort or spawning stock. In the case of e.g. herring or sandeel larvae surveys which capture very young larvae can also provide an indication of the spatial distribution of spawning grounds and/or habitat for the reproductively active portion of a population.

The larvae survey data along with the use of particle tracking modelling e.g. Proctor *et al.* (1998) and Christensen *et al.* (2008) for sandeel in the North Sea and otolith microchemistry e.g. Wright *et al.* (2016) and Gibb *et al.* (2017) give insights in to connectivity between spawning locations and settlement areas (recruitment) in sandeels. The larvae data on their own provide insights in to the ecology of these sandeel populations.

Survey descriptions

Continuous Plankton Recorder (CPR)

The Sir Alister Hardy Foundation for Ocean Science (SAHFOS) has been undertaking CPR sampling for many decades in the North Sea. The coverage is very good and regularly sampled routes are documented in Edwards *et al.* (2011) or can be viewed at https://www.sahfos.ac.uk/about-us/our-network-of-ships/ . The continuous plankton recorder instrument is towed at between 5 and 10m below the surface and provides spatial explicit samples of plankton (https://www.sahfos.ac.uk/services/the-continuous-plankton-recorder/). The zooplankton and a proxy for phytoplankton (colour) is routinely analysed and species identified. In recent years SAHFOS undertook to identify the fish larvae in the archived material and combine this with previous records to give a fish larvae database covering the period 1948 to 2005 (see Edwards *et al.* 2011). A more detailed analysis of the sandeel data was undertaken by Lynam *et al.* (2013) using the data from 1950 to 2005.

ICES coordinated 1st Quarter International Bottom Trawl Survey (1QIBTS) of the North Sea.

Sampling for fish larvae during the 1st Quarter IBTS (annually between January and March) started in 1977. The current 2m Midwater Ring Trawl was adopted in 1992. The survey is targeted at overwintering North Sea autumn spawning herring larvae. Sampling is only undertaken between dusk and dawn, using a double oblique tow profile either to a maxim depth of 100m or 5m above the bottom. The standard sampling grid currently takes a maxim of four hauls per ICES statistical rectangle i.e. 1° longitude x 0.5° latitude.

In 2012 the inclusion of 20cm diameter rings, attached to the outside of the standard MIK ring, with 335µm mesh nets was implemented (MIKeyM sampler, see ICES WGEGGS2 2013). These devices were specifically designed to simultaneously sample fish eggs and small fish larvae during the MIK deployments. The tow profiles are identical to the MIK and their own internal flow meters are used to estimate the volume of water filtered by the MIKeyM nets.

In 2012 and 2013 Norway, The Netherlands and France undertook MIKey-M sampling, giving a reasonable coverage of the North Sea. The coverage increased in 2014 with Germany and Denmark also participating. With the inclusion of Scotland in 2015, full coverage was achieved (see Fig. 1) and maintained for the subsequent year. As of 2016 MIKeyM sampling is a requirement for all countries participating in the MIK sampling during the 1QIBTS. The initial intention is for all samples to be worked up at 2 to three year intervals for providing information of winter spawning locations of fishes in the North Sea.

To date the most complete set of samples fully worked up are the 2012 series. Both the Norwegian and French sectors have been analysed to varying degrees. The sampling and data archiving is within the responsibility of the ICES WGEGGS2.

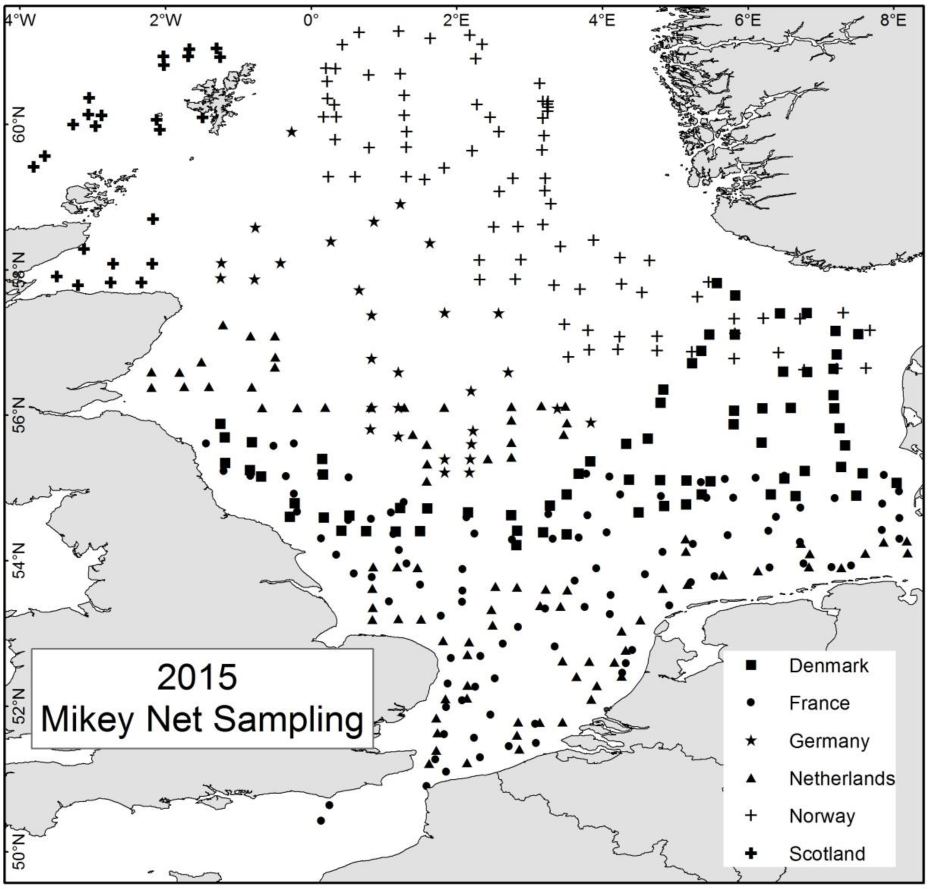


Fig. 1. Distribution of MIKeyM samples taken during the 2015 ICES 1QIBTS (MIK sampling).

Institute of Marine Research North Sea Ecosytem Survey (IMRNSES)

IMR has combined a series of standard hydrographic and plankton transects traversing the northern North Sea in to one cruise in the second half of April to mid May. These surveys occur annually starting in 2012. The surveys collect physical data, phytoplankton, zooplankton and fish eggs and larvae. In the most recent years (2015 and 2016) stations in the Skagerrak and Kattegat have also been included giving a comprehensive coverage of the northern North Sea and Skagerrak (see Fig. 2). The standard transect sampling includes CTD casts with rosettes for temperature, salinity, density, Chlorophyll a fluorescence, chlorophyll a and nutrients. Vertical hauls with WPII nets give zooplankton composition and size fractionated dry weights of zooplankton. Algae hauls provide phytoplankton samples. A Gulf VII high speed sampler provides samples of fish eggs and larvae and its PUP sampler provides samples of microzooplankton. Vertically stratified samples of zooplankton are taken at selected stations with a MOCNESS.

In addition to the standard transects two 'process stations' are occupied for a maximum of 48h each where short term temporal variability in the vertical distribution of fish egg and larvae are determined.

The fish egg and larvae samples are currently being worked up through external contracts.

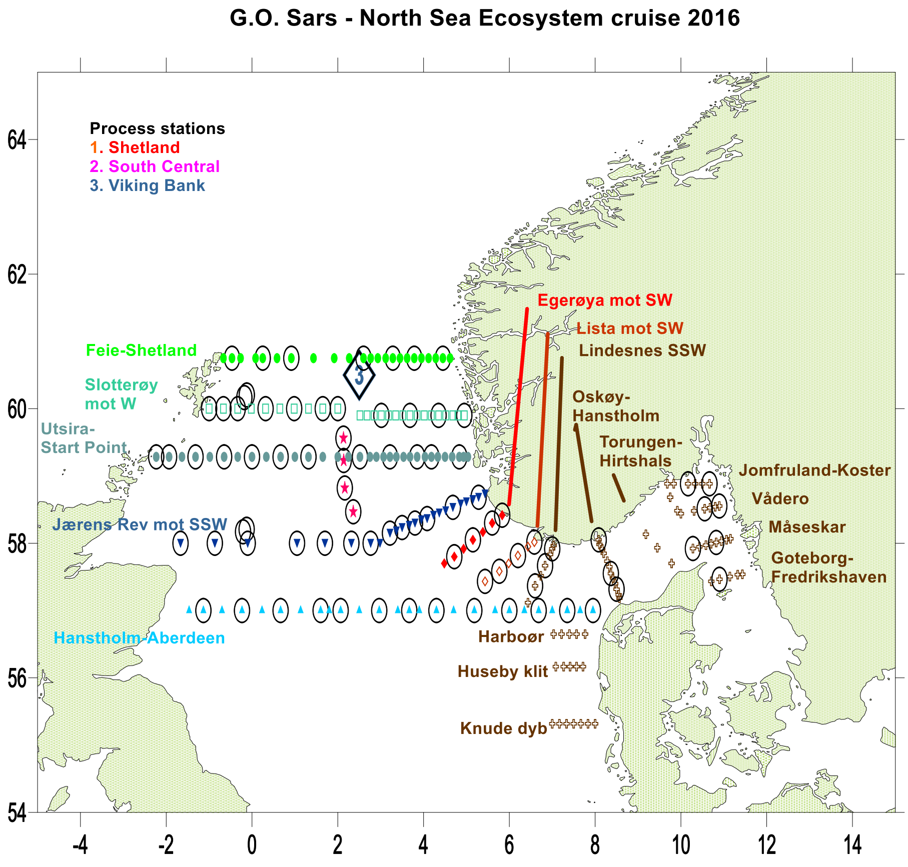


Fig. 2. Sampling stations for the 2016 IMRNSES. Circles indicate Gulf VII stations. Small symbols indicate CTD, WPII and Algae haul stations.

Available data and preliminary results

The data that are available from the CPR data collections are documented in Edwards et al. (2011) and Lynam et al (2013) and are not reproduced here.

Sandeels are caught in the MIK sampling but there is currently no requirement for these data to be uploaded in to the ICES Egg and Larvae Database. As such these data currently reside in national archives. Much of the MIK data will relate to 1 year old sandeels, however, there is a possibility that there are some data related to the O groups. This is primarily due to mesh selectivity because the MIK uses a 1.6mm mesh size which will not retain the very small larvae.

Sandeel larvae are caught in the MIKeyM nets. Currently the only compiled data are from the 2012 sampling and from the Norwegian samples (see Fig 3). The sampling was not undertaken in the northern part of the survey area as this was the trial year for this sampling. The larvae occur in the vicinity of the principal sandeel habitats.

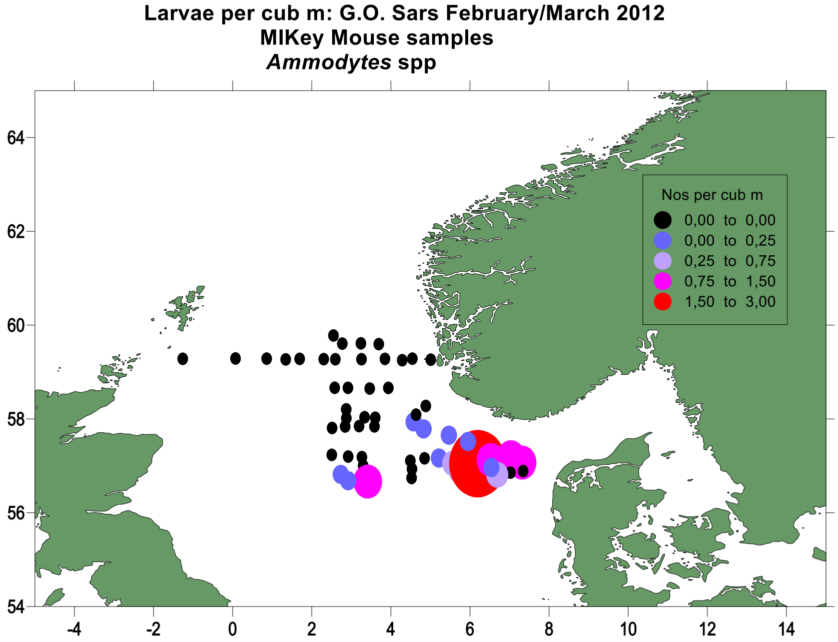
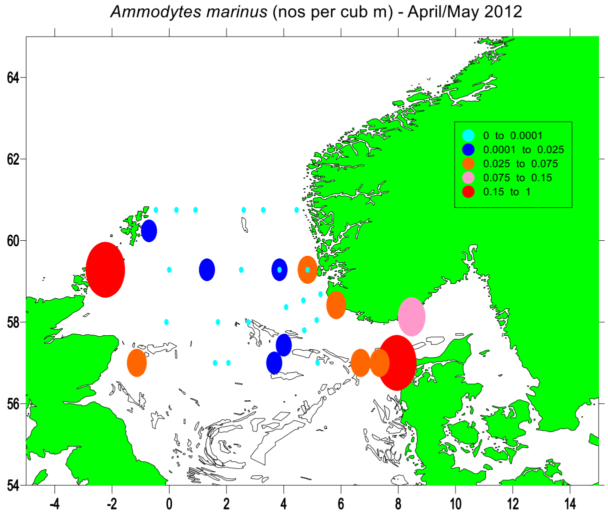


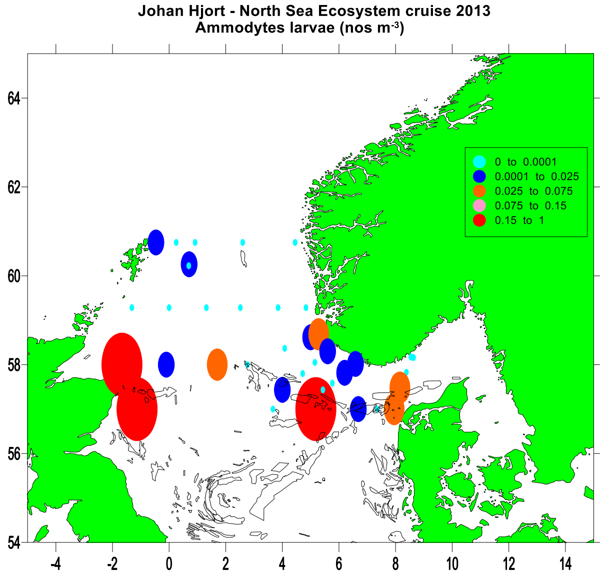
Fig. 3. Distribution of sandeel larvae caught in the MIKeyM sampling in February to March 2012 in the Norwegian section of the 1QIBTS.

Very few larvae have been noted in many of the subsequent Norwegian sector samplings (eggs and larvae are sorted and enumerated at sea). This is probably due to the survey starting in early to mid January with the southern portion sampled before the end of January (unlike in 2012). In future years (2017 onward) the Norwegian section will be sampled ack in its February/March time slot. Other nations sampling in the northern North Sea are generally sampling later. However, the French sampling in the southern North Sea in January have noted sandeel larvae in that area. Those data are not immediately available at present.

The IMRNSES also samples *Ammodytes* larvae in April/May, again giving a spatial coverage of their abundance. At this time of the year there may be more than one species caught so the larvae abundances are generally recorded as *Ammodytes* spp. Similar patterns are seen in the 2012 and 2013 distributions of larvae (see Fig. 4). Larvae occur close to the northwest Danish coast and along the southwestern Norwegian coast in the vicinity of the Norwegian trench. Larvae also occur off the Scottish east coast and in the vicinity of the Orkney/Shetland islands. Part of the differences in distribution and abundance are probably caused by differences in the timing of the surveys relative to the hatching times of the larvae in any particular year.



Ammodytes marinus (nos per cub m) - April/May 2012



Johan Hjort - North Sea Ecosystem cruise 2013
Ammodytes larvae (nos m^{-3})

Fig. 4. Distribution of *Ammodytes* spp larvae caught in a Gulf VII high-speed plankton sampler during the IMRNSES in 2012 and 2013. The surveys were conducted in April/May of each year. The suitable sandeel habitats are also indicated.

In 2016 there was a similar pattern to previous years in the distribution of larvae (Fig. 5). However, the densities were generally lower. There was a lack of sandeel larvae in the northern area, specifically in the vicinity of Viking Bank.

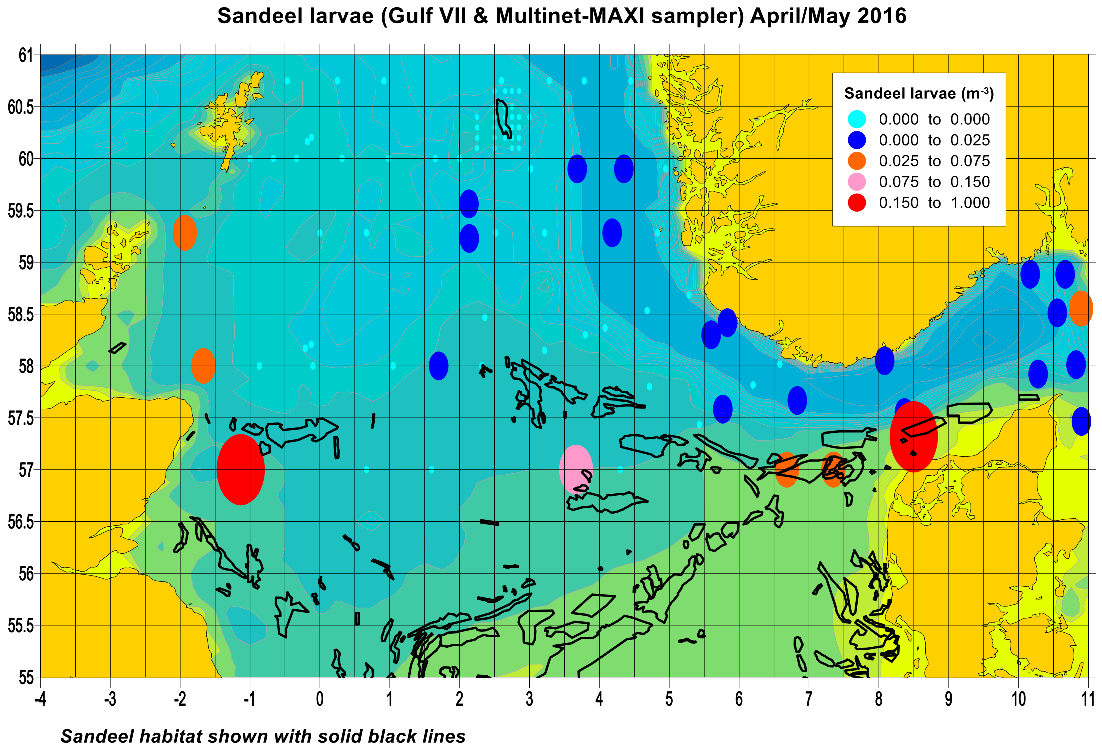


Fig 5. Distribution of *Ammodytes* spp larvae (April/May) caught with a Gulf VII during the IM-RNSES in 2016. A fine scale survey using a Multinet MAXI was undertaken over Viking Bank in the north.

Potential input to North Sea sandeel ecosystem level assessments

1. *Historical seasonal distributions and abundance from the CPR data.* There is a need to fund the identification of larvae from surveys conducted after 2005 and for this to be ongoing. The data will not be available for 'in-year' decisions.
2. *Distributions and abundance of larvae in February/March from MIKeyM 1QIBTS*. A request to ICES WGEGGS2 and WGALES will ensure that this sampling is continued due to its potential value to a specific assessment working group. Support for working up the samples will need to be sought from the national laboratories.
3. *Distributions of large larvae in February/March from the MIK 1QIBTS*. A request to ICES IBTSWG for sandeel larvae data to be made available from the 1QIBTS and these data to be uploaded in to the ICES Egg and Larvae Database.
4. *Distributions and abundance of larvae in April/May in the northern North Sea*. Data from this survey is dependent on IMR being able to undertake and obtain sandeel larvae identifications.

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WD 02 The scale of larval transport in sandeel inferred from otolith microchemistry.

By Peter J. Wright, Thomas Régnier, Fiona M. Gibb, Sandhya Devalla and Julian Augley

Marine Scotland Science, 375 Victoria Road, Aberdeen, AB11 9DB, UK

Introduction

The scale of population structuring in the lesser sandeel, *Ammodytes marinus* (Raitt) is driven by dispersal of the planktonic phase because the distribution of settled phases are limited by the need to bury in sandy areas with a low silt content (Holland et al., 2005; Wright et al., 2000). Following settlement, sandeels are rarely found further than 15 km away from known habitat (Engelhard et al., 2008; van der Kooij et al., 2008; Wright, 1996) and the maximum distance travelled by tagged individuals displaced from grounds was only 64 km over 1 – 3 years (Gauld, 1990). As a consequence of their habitat requirement the distribution is fragmented (Jensen et al., 2011). *A. marinus* spawn eggs into sand between December and January (Gauld and Hutcheon, 1990; Winslade, 1971) and the larvae hatch between February and May (Langham, 1971; Macer, 1966; Wright and Bailey, 1996). The duration of this pelagic stage lasts between 32 and 90 days (Jensen, 2001; Wright and Bailey, 1996; Wright, 1993) and later stages begin schooling before settlement in late May to June (Wright and Bailey, 1996; Wright et al., 2000).

The current sub-division of sandeels in the North Sea was derived from information on the location of grounds and suitable habitat and biophysical models of larval transport (ICES 2010). A number of biophysical models of sandeel larval transport have been produced, differing in horizontal and vertical resolution of the underlying hydrodynamic models and the accuracy of biological parameters for particle tracking (Berntsen et al., 1994; Christensen et al., 2008; Proctor et al., 1998). However, models that used estimates of pelagic larval duration from age estimates (Wright and Bailey, 1996; Jensen, 2001) produced broadly comparable results, and suggested that the smaller grounds in the north west North Sea were relatively hydrographically isolated from the extensive grounds in the central North Sea and similarly that larvae from these grounds were unlikely to be transported to north east North Sea grounds (Christensen et al., 2008; Proctor et al., 1998). The distributions of pre-settled juveniles in the north west North Sea were also consistent with these predictions (Proctor et al., 1998; Wright, 1996). Nevertheless, there is always uncertainty in the accuracy of bio-physical model predictions due to the resolution of the underpinning hydrodynamic models and the behaviour of larvae and pre-settled juveniles. Therefore, there is a need to verify biophysical model predictions.

Otolith microchemistry can provide a useful tool for examining life stage dispersal and connectivity in regions where significant spatial differences can be detected (Campana et al., 2000; Gillanders and Kingsford, 1996). Although otolith microchemistry can reflect a combination of local environmental chemistry and individual physiology, the resulting elemental composition can create a unique chronological 'signature' that can be used as a natural tag (Campana and Thorrold, 2001; Elsdon et al., 2008) to distinguish location and infer ontogenic change. Otolith microchemistry has previously been used to discriminate between capture location and detect the habitat shift from pelagic to bentho-pelagic behaviour in the sandeel *Ammodytes tobianus* (Laugier et al., 2015) and has been applied to *A. marinus* in the north west North Sea and West of Scotland to evaluate biophysical model predictions of larval separation (Gibb et al., 2017). Seasonal temperature induced changes in some elements together with ontogenetic sources of variation mean that changes in chemistry are not only related to geographic location. Therefore, it is important to consider comparable stages of the life-cycle and time of year, when investigating geographic variation.

Using approaches applied in Gibb et al. (2017) this study examines 1) the scale of geographical variation in otolith microchemistry among capture locations from an analysis of the elemental signature in the settled region of the juvenile otolith, (2) the number of possible chemically distinct natal sources settling to grounds in Scottish waters using an unsupervised cluster analysis of near-core chemistry and, (3) the ground related variation in chemistry of larval and settled juvenile phases. From this we evaluate whether there is a detectable geographic variation in otolith chemistry, evidence for separate natal sources identified from biophysical models and a consistency between natal source and settled juvenile chemistry at grounds, suggestive of local recruitment.

Methods

Otolith preparation and analysis

Trace element analysis was conducted on 194 prepared sagittal sandeel otoliths from 8 sites in 2011 (Figure 1) using LA-ICP-MS according to the methods of Gibb et al. (2017). Otoliths were analysed for the presence of 8 elements (^{24}Mg, ^{55}Mn, ^{65}Cu, ^{44}Ca, ^{88}Sr, ^{66}Zn, ^{85}Rb, ^{138}Ba) using a NewWave Research UP-213 laser ablation instrument and an Agilent 7700x inductively coupled plasma - mass spectrometer (Agilent Technologies Ltd, UK), using helium gas as the carrier. External calibration was performed with a glass standard reference material (NIST 612; National Institute of Standards and Technology), with concentrations of each element being determined relative to this standard. A microanalytical carbonate standard (MACS 3; United States Geological Survey) was used to monitor the efficiency of analyte recovery.

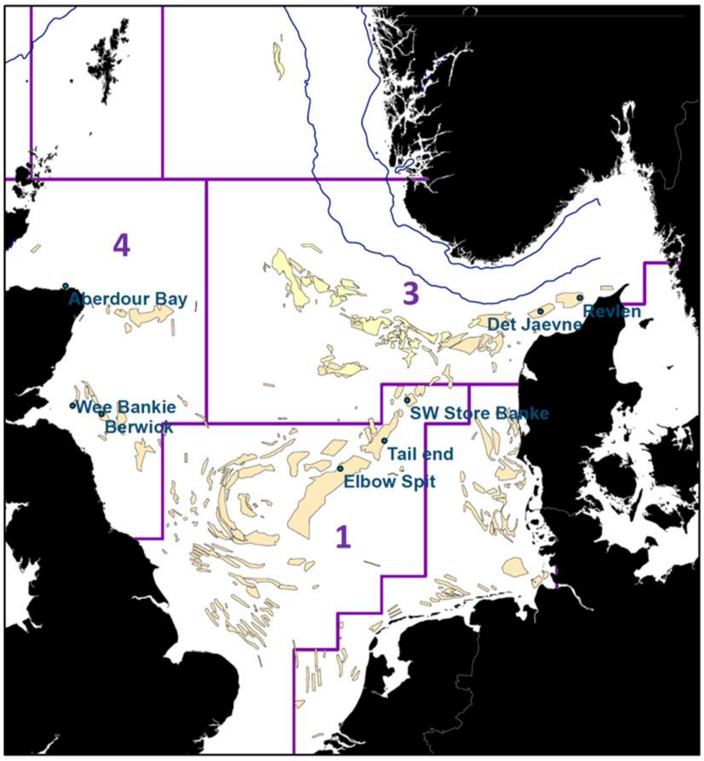

Figure 1. Chart showing location of samples in the 8 grounds (named yellow polygons) and 3 sandeel assessment areas (purple lines denote boundaries, ICES 2010).

All elements were expressed as ratios relative to ^{44}Ca, compensating for any variation in ablation yield between samples and standards, and are hereafter referred to as Mg, Mn, Cu, Sr, Zn, Rb, Ba and Zn. Pre-ablation runs were undertaken on both standards and each otolith to remove any extraneous impurities. For each otolith, 4 pits of 55 µm diameter were ablated corresponding to the near core (hatch), settled juvenile, summer and over-wintering phases. These areas were identified based on the appearance of hatch checks, accessory primordia formed at metamorphosis (Wright, 1993) as well as opaque and translucent zones corresponding to summer and winter (Worsøe, 1999; Figure 2). After every 10 otolith surface ablations, a helium blank, NIST and MACS ablation were also taken for calibration and instrument drift correction. Blank subtracted count data were gathered for each sample ablation in Masshunter software and converted to element concentrations ($\mu g.g^{-1}$) in the otoliths by manual calculations using the internal standardisation equation described by Longerich et al. (1996).

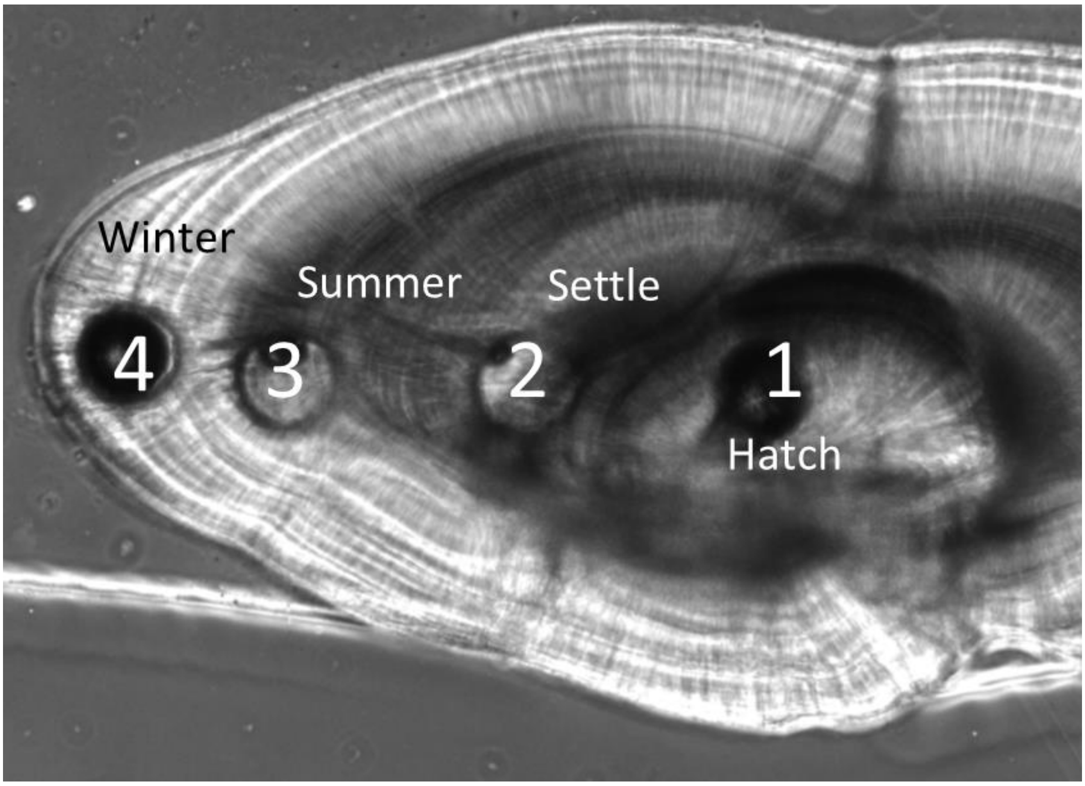

Figure 2. Polished section of sandeel sagitta of 0-group sandeel showing ablation pits in relation to components of the microstructure linked to life-stage and time of year.

Statistical analyses

Spatial differences in elemental ratio were tested for in the four ablated regions of the otolith using ANOVA or Kruskal-Wallis tests, depending on whether data could be transformed to satisfy normality and homoscedasticity assumptions. Post-hoc tests were used to identify pair-wise differences in element ratios between grounds.

The ability of the otolith chemical signature of juveniles to discriminate among grounds and sandeel assessment areas was assessed using Random forest (RF) classification (see Gibb et al., 2017) as this method makes no assumptions on variable distributions. As burying over-winter may affect otolith chemistry (Laugier et al., 2015) the summer ablation pit (spot 3) was used. The RF classification error was calculated as an aggregate error from all trees considered for both grounds and sandeel assessment areas. The RF approach was also used to distinguish larval (natal) chemical clusters based on the larval chemistry. Larval clusters were defined by the dissimilarity between samples generated by an unsupervised RF without considering sample origin

A linear mixed model was used to test whether the larval and recently settled chemistry (spot 2) differed among sampling locations and between life stages, with individual as a random effect to account for non-independence of data sampled within each otolith. As the variance in element data increased with the mean the data were log transformed.

Results

Regional variation in edge chemistry

The edge region of the otolith formed in winter showed significant geographical variation for Mg ($H = 42.38$, 7 d.f, $p < 0.001$), Rb ($H = 35.47$, 7 d.f, $p < 0.001$), Ba ($H = 86.79$, 7 d.f, $p < 0.0001$), Mn ($H = 61.23$, 7 d.f, $p < 0.0001$) and Zn ($H = 37.26$, 7 d.f, $p < 0.0001$). Post-hoc comparisons indicated significant differences between grounds, especially comparing grounds between different sandeel assessment areas (Table 1).

Ground X	Ground Y	SA X	SA Y	Mg	Rb	Ba	Mn	Zn
Elbow	Store	1	1	***0.002***	***0.006***	***<0.001***	0.55	0.82
Elbow	Tail End	1	1	***0.05***	0.28	***0.02***	***0.007***	0.96
Elbow	Det Javne	1	3	***0.03***	0.87	***<0.001***	***<0.001***	0.47
Elbow	Revlen	1	3	***0.002***	0.46	0.09	***<0.001***	0.08
Elbow	Aberdour	1	4	0.11	0.07	***<0.001***	0.9	***0.018***
Elbow	Berwick	1	4	0.83	***0.001***	***<0.001***	0.27	***0.002***
Elbow	Wee	1	4	0.11	***0.003***	***0.07***	***0.01***	***0.005***
Store	Tail End	1	1	0.2	0.09	0.2	0.35	0.35
Store	Det Javne	1	3	***0.02***	***0.02***	***<0.001***	***0.005***	***0.005***
Store	Revlen	1	3	***<0.001***	0.27	***<0.001***	***0.04***	***0.04***
Store	Aberdour	1	4	***0.005***	0.48	0.27	0.34	0.34
Store	Berwick	1	4	***0.02***	0.06	0.84	***0.01***	***0.01***
Store	Wee	1	4	***0.003***	***0.01***	0.34	***0.02***	***0.02***
Tail End	Det Javne	1	3	0.78	0.67	***<0.001***	***0.02***	***0.02***
Tail End	Revlen	1	3	***<0.001***	0.19	***<0.001***	0.06	0.06
Tail End	Aberdour	1	4	***0.02***	0.13	0.12	***0.02***	***0.02***
Tail End	Berwick	1	4	0.17	***0.001***	0.14	***<0.001***	***<0.001***
Tail End	Wee	1	4	***0.02***	***0.0005***	0.53	0.32	0.32
Det Jaevne	Revlen	3	3	***<0.001***	0.24	***0.002***	0.07	0.14
Det Jaevne	Aberdour	3	4	***0.04***	***0.05***	***<0.001***	***<0.001***	***0.004***
Det Jaevne	Berwick	3	4	0.13	***0.001***	***<0.001***	***<0.001***	***<0.001***
Det Jaevne	Wee	3	4	***0.01***	***0.002***	***<0.001***	***0.008***	***0.004***
Revlen	Aberdour	3	4	0.47	0.75	***<0.001***	***<0.001***	***0.04***
Revlen	Berwick	3	4	***0.01***	0.15	***<0.001***	***<0.001***	***0.002***
Ground X	Ground Y	SA X	SA Y	Mg	Rb	Ba	Mn	Zn
Revlen	Wee	3	4	0.67	***0.04***	***0.002***	0.61	***0.06***
Aberdour	Berwick	4	4	0.54	0.16	0.65	0.27	0.78
Aberdour	Wee	4	4	0.95	***0.04***	0.12	***0.01***	0.35
Wee	Berwick	4	4	0.12	0.89	0.32	***<0.001***	0.15

Table 1: Post-hoc (Tukey's Honest Significant Difference method and pairwise Wilcoxon tests) comparisons performed on the settled juvenile region of the otolith by ground and 3 sandeel assessment areas. Statistically significant values indicated in bold.

Differences in juvenile otolith chemistry among areas were reflected in the assignment to individual grounds and sandeel areas. Classification error from the RF clustering approach for individual grounds ranged from 0.26 – 0.87, but the settled individuals were classified to assessment area with a high accuracy and most mis-assignments were to nearby grounds (Table 2).

	origin/assigned	1	1	1	3	3	4	4	4	Ground	

Area origin		Elbow	Tail End	Store	Det Jaevne	Revlen	Aberdour	Berwick	Wee	class.error	Area class.error
1	Elbow	11	6	6	1	1	0	0	0	0.54	0.19
	Tail End	8	3	5	1	2	1	0	3	0.87	
	Store	3	3	11	3	0	3	0	1	0.54	
3	Det Jaevne	0	0	5	16	2	1	0	0	0.33	0.18
	Revlen	3	1	0	2	17	0	0	0	0.26	
4	Aberdour	0	1	1	0	0	9	12	2	0.64	0.06
	Berwick	0	0	0	0	0	6	14	5	0.44	
	Wee	0	1	1	0	0	4	7	11	0.54	

Table 2. Numbers of individuals assigned to sandeel areas 1-3 and grounds based on a supervised RF clustering of summer (spot 3) chemistry. Numbers in bold refer to individual assignment to capture location.

The near core (natal) chemistry of the otolith showed significant variation for Mg ($F_{7,186} = 55.92$, $p < 0.0001$), Rb ($F_{7,184} = 33.11$, $p < 0.0001$), Ba ($F_{7,181} = 17.02$, $p < 0.0001$), Mn ($F_{7,184} = 10.65$, $p < 0.0001$) and Zn ($F_{7,183} = 34.42$, $p < 0.0001$). Post-hoc comparisons also indicated significant differences between sandeel assessment areas and within SA3 (Table 3). For both edge and core, Mg in SA4 differed from the other two areas, Mn differed between SA3 and other areas while Ba differed among all three areas and within SA3.

Ground A	**Ground B**	**SA X**	**SA Y**	**Mg**	**Rb**	**Ba**	**Mn**	**Zn**
Elbow	Store	1	1	***0.002***	***0.006***	***<0.001***	0.555	0.82
Elbow	Tail End	1	1	***0.04***	0.28	***0.02***	***0.007***	0.96
Elbow	Det Javne	1	3	***0.03***	0.87	***<0.001***	***<0.001***	0.47
Elbow	Revlen	1	3	***0.002***	0.46	***0.09***	***<0.001***	0.08
Elbow	Aberdour	1	4	0.11	0.07	***<0.001***	0.9	***0.02***
Elbow	Berwick	1	4	0.83	***0.001***	***<0.001***	0.26	***0.002***
Elbow	Wee	1	4	0.11	0.003	0.07	***0.01***	***0.005***
Store	Tail End	1	1	0.2	0.09	0.2	0.35	0.35
Store	Det Javne	1	3	***0.02***	***0.015***	***<0.001***	***0.005***	***0.005***
Store	Revlen	1	3	***<0.001***	0.27	***<0.001***	***0.04***	***0.04***
Store	Aberdour	1	4	***<0.001***	0.48	0.27	0.34	0.34
Store	Berwick	1	4	***0.02***	0.06	0.84	***0.01***	***0.01***
Store	Wee	1	4	***0.002***	***0.01***	0.34	***0.02***	***0.02***
Tail End	Det Javne	1	3	***<0.001***	0.68	***<0.001***	***0.03***	***0.03***
Tail End	Revlen	1	3	***<0.001***	0.19	***<0.001***	0.06	0.06
Tail End	Aberdour	1	4	***0.015***	0.13	0.12	***<0.001***	***<0.001***
Tail End	Berwick	1	4	0.17	***0.001***	0.14	***<0.001***	***<0.001***
Tail End	Wee	1	4	***0.02***	***0.001***	0.53	0.32	0.32
Det Jaevne	Revlen	3	3	***<0.001***	0.24	***0.002***	0.07	0.15
Det Jaevne	Aberdour	3	4	***0.04***	***0.05***	***<0.001***	***<0.001***	***<0.001***
Det Jaevne	Berwick	3	4	0.13	***0.001***	***<0.001***	***<0.001***	***<0.001***
Ground A	Ground B	SA X	SA Y	Mg	Rb	Ba	Mn	Zn
Det Jaevne	Wee	3	4	***0.01***	***0.002***	***<0.001***	***0.008***	***0.004***
Revlen	Aberdour	3	4	0.47	0.75	***<0.001***	***<0.001***	***0.04***

Revlen	Berwick	3	4	***0.01***	0.15	***<0.001***	***<0.001***	***0.002***
Revlen	Wee	3	4	0.67	***0.04***	***0.002***	0.61	0.06
Aberdour	Berwick	4	4	0.54	0.16	0.65	0.27	0.78
Aberdour	Wee	4	4	0.95	***0.04***	0.12	0.01	0.35
Wee	Berwick	4	4	0.12	0.89	0.32	***<0.001***	0.15

Table 3. Post-hoc (Tukey's Honest Significant Difference method and pairwise Wilcoxon tests) comparisons performed on the larval region of the otolith by ground and 3 sandeel assessment areas (SA). Statistically significant values indicated in bold.

Using all elements, RF clustering identified 3 clusters of chemically distinct early larval elemental signatures. Although, all 3 clusters were found in the 3 sandeel areas (Figure 3), each area had a dominant cluster. Cluster 1 was the main contributor to SA1 grounds *and* was characterised by low Ba and Mg (Table 4). Cluster 2 was the main contributor to SA3 grounds and was characterised by high Mn, Mg and Rb. Cluster 3 that was the main contributor to SA4 grounds and was characterised by high Zn and Ba.

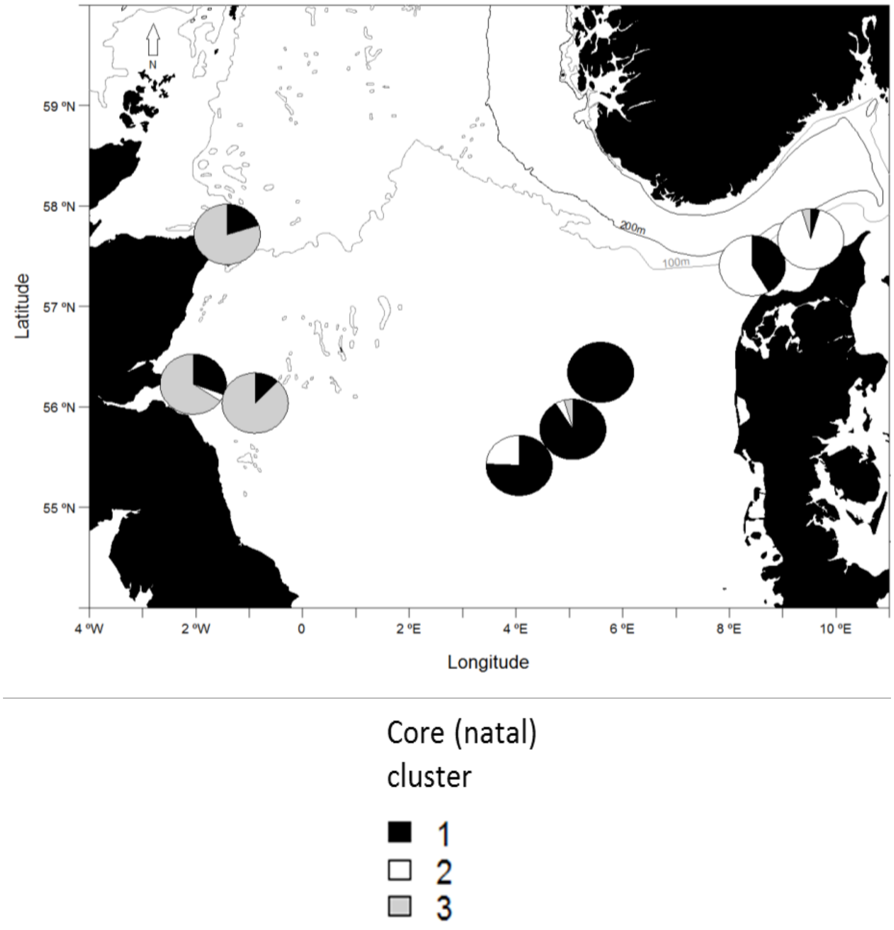

Figure 3. Chart of study area with pie charts representing the contribution of the three larval clusters identified through RF clustering.

cluster	Mg	Mn	Rb	Zn	Ba	Sr
1	72.04 (47.86)	4.39 (2.06)	0.042 (0.013)	0.65 (0.46)	2.92 (1.33)	1502.57 (278.75)

2	244.27 (226.99)	12.27 (6.55)	0.054 (0.022)	0.74 (0.6)	5.12 (2.39)	1463.58 (177.11)
3	118.32 (58.98)	4.44 (1.72)	0.023 (0.009)	2.29 (1.47)	9.89 (9.12)	1519.2 (319.48)

Table 4. Mean elemental signature of the 3 larval clusters identified by RF clustering, standard deviation is indicated between brackets.

The linear mixed model analysis found a significant difference in elemental chemistry of larval and settled juveniles among grounds (Table 5). However, with the exception of ^{66}Zn, there was no significant difference in the intercept between larval and recently settled juvenile chemistry (F) and no significant interaction between life stage and fishing ground (Table 5). Figure 4 shows the differences in predicted mean elemental ratio for the larval and settled juvenile stage chemistry. The pattern broadly corresponds to the larval clusters but also highlights that Ba and Mg vary within SA areas which might explain the high proportion of cluster 1 in Wee bankie and distinction of Revlen in SA3 due to high Mg.

Table 5. Linear mixed model results comparing two life stages: early larvae (near core) and recently settled elemental profiles across otoliths collected at 7 North Sea sandeel grounds. Values are shown for F, degrees of freedom (in brackets) and P values.

Element	Ground	Life stage	Ground* Life stage
Mg/Ca	111.13(7) <0.0001	5.75(1) 0.02	0.11(7) 0.99
Mn/Ca	24.66(7) <0.0001	1.00(1) 0.32	0.48(7) 0.85
Zn/Ca	87.90(7) <0.0001	29.09(1) <0.0001	0.74(7) 0.64
Rb/Ca	60.62(7) <0.0001	0.0(1) 0.96	0.66(7) 0.70
Ba/Ca	28.6(7) <0.0001	1.69(1) 0.19	1.16(7) 0.33

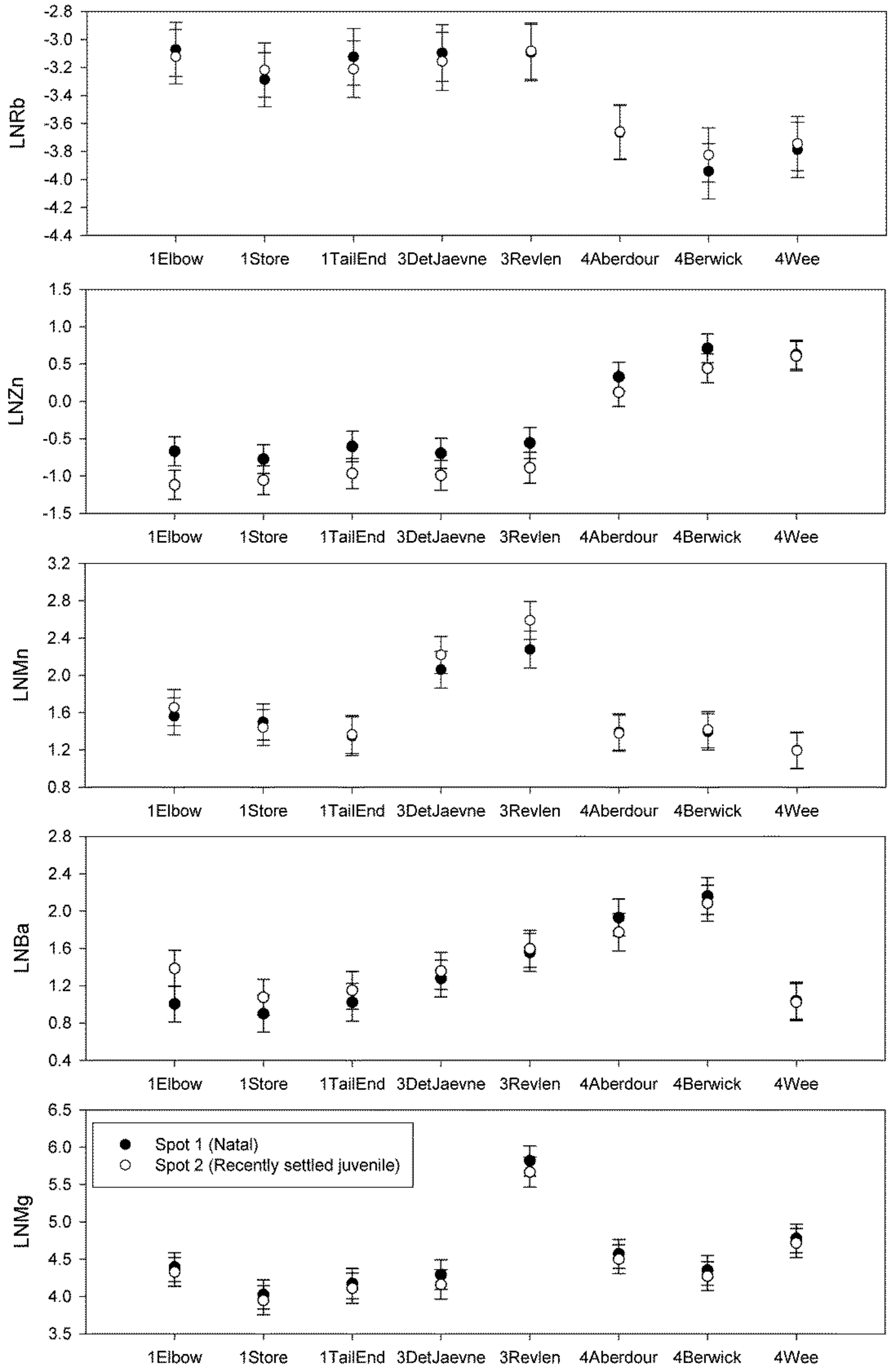

Figure 4. Fitted mean (± standard error) element ratio for larval (spot 1) and juvenile (spot 2) based on linear mixed model in Table 5.

Discussion

The elements manganese, rubidium and zinc varied at the scale of sandeel assessment areas throughout the juvenile otolith. Spatial differences in barium and magnesium also contributed to elemental signatures of specific grounds. These significant differences among sandeel assessment areas and conversely the similarity of some elements between grounds within these areas indicates that there are regional differences in otolith chemistry relevant to the scale of proposed population structuring (Proctor et al., 1998; Christensen et al., 2008; ICES, 2010). The geographic scale of element variation found in this study is consistent with differences detected between the Northern Isles and off the Scottish mainland coast in *A. marinus* (Gibb et al., 2017). Although we cannot explain the observed differences in elemental signatures, variation in water elemental concentrations have been reported over the spatial scales we found (e.g. Balls et al., 1993).

The extent to which larval clusters reflect distinct natal sources or indeed whether low contributing clusters have any biological significance is not known as we did not sample larvae directly. Nevertheless, the virtual absence of any overlap in the larval clusters of area 4 in the west and 3 in the east suggests separate natal sources which are consistent with observations on the distribution of sandeel larvae (Proctor et al., 1998; Munk et al., 2002). The cluster analysis and pair wise comparisons could be interpreted as evidence for some limited exchange between grounds in area 1 and 3 as well as area 1 and 4. However, the comparison of larval and recently settled juvenile elemental signatures were broadly similar and suggest that differences in manganese contribution were maintained between SA1 and 3 and similarly the difference in rubidium and zinc contribution between SA1 and SA4.

Since 2010, management of sandeel in the North Sea has moved from a single stock assessment to seven separate sub-components (ICES, 2010), based on evidence from distribution, predicted larval transport, demographic variation and differences in regional dynamics (Jensen et al., 2011; Boulcott et al., 2007; Christensen et al., 2008; Pedersen et al., 1999; Proctor et al., 1998). Although we are only able to infer probable scales of mixing from our study, the results do appear consistent with previous evidence for limited connectivity between the Scottish east coast (SA4) and the central North Sea (SA1) and the north east North Sea and Skagerrak derived from biophysical models (Proctor et al., 1998; Christenssen et al., 2008).

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WD03 External consistency between CPUE at age in different areas

By Anna Rindorf

Figures 1 and 2 present the external consistency between CPUE (catch in numbers by age per standard fishing day) in different assessment areas using the full time series (Fig. 1 and 2) or only the time series from 1994 onwards (Fig. 3 and 4). Two of the assessment areas are divided in two: Area 4 is divided into Turbot bank (northern area 4, now called area 4) and the Firth of Forth area (southern area 4, now called area 9) and area 3 is divided into Norwegian Zone (western and norther area 3, now called area 3) and EU Zone (eastern area 3, now called area 8).

The figures with shorter time series are plotted as the age compositions before 1993 are based on data from working group reports and hence considered potentially correlated between areas due to the estimation process and there furthermore appears to have been a regime shift in the North Sea pelagic community around this time (See WD by Clausen et al.). Combinations of year and area where less than 10 biological samples are taken are excluded and only data from the first half year is used. Ages 1 and 2 are included in the figures. The correlation between CPUE of age 1 in different areas reveals whether common recruitment patterns are found in the different areas. If this is the case, the correlation between CPUE of age 2 reveals whether the total mortality experienced is similar in the different areas.

High correlations ($r^2>0.5$) are found between recruitment in areas 1 and 2 and between recruitment in areas 3 and 8. Moderate correlations ($r^2>0.25$) are found between recruitment in areas 1 on the one side and 3 and 8 on the other. The same conclusions apply to the correlations between CPUE at age 2. When using only the reduced time series, high correlations are found between recruitment in areas 1, 3 and 8 while the correlation between area 1 and 2 is reduced to moderate. Only the correlation between areas 3 and 8 remains high at age 2.

Table 1. R^2 of the linear relationship between CPUE at age in different areas.

	Area 2	**Area 3**	**Area 8**	**Area 9**
Age 1 1982-2015				
Area 1	0.51	0.33	0.43	0.13
Area 2		0.23	0.22	0.01
Area 3			0.69	0.22
Area 8				0.19
Age 1 1994-2015				
Area 1	0.39	0.56	0.50	0.13
Area 2		0.22	0.31	0.01
Area 3			0.74	0.22
Area 8				0.19
Age 2 1982-2015				
Area 1	0.54	0.33	0.11	0.09
Area 2		0.18	0.11	0.16
Area 3			0.71	0.01
Area 8				0.01

Age 2 1994-2015				
Area 1	0.36	0.48	0.20	0.09
Area 2		0.19	0.17	0.16
Area 3			0.66	0.01
Area 8				0.01

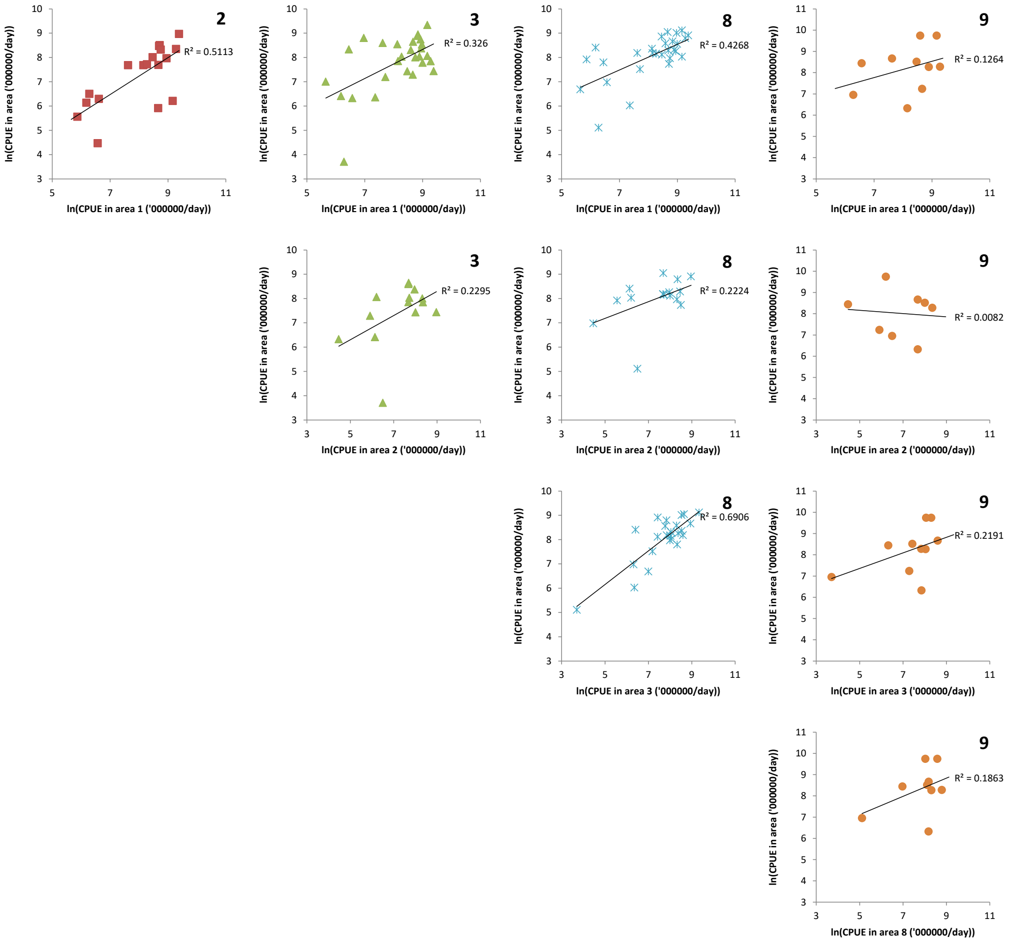

Fig. 1. External consistency between CPUE at age 1 in different areas (years with less than 10 age samples excluded) for the period 1982-2015. Two of the current assessment areas are divided in two: Area 4 is divided into Turbot bank (northern area 4, now called area 4) and the Firth of Forth area (southern area 4, now called area 9) and area 3 is divided into Norwegian Zone (western and norther area 3, now called area 3) and EU Zone (eastern area 3, now called area 8).

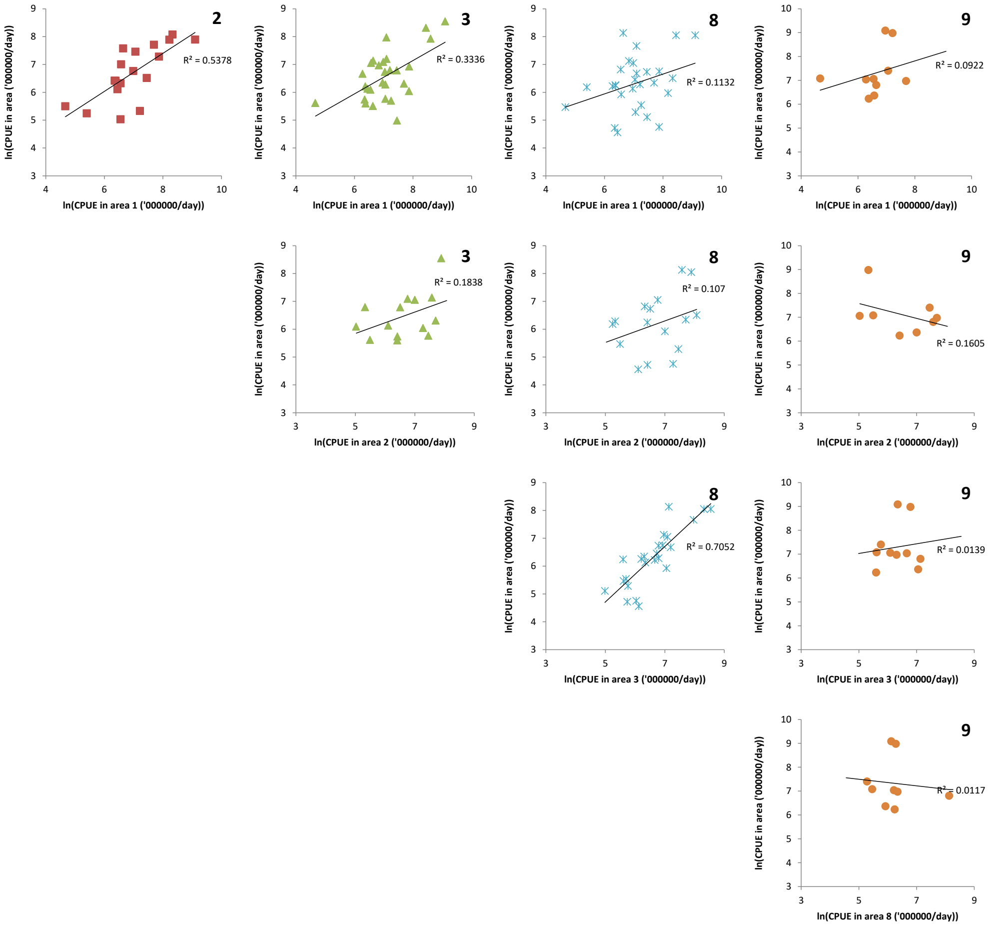

Fig. 2. External consistency between CPUE at age 2 in different areas (years with less than 10 age samples excluded) for the period 1982-2015. Two of the current assessment areas are divided in two: Area 4 is divided into Turbot bank (northern area 4, now called area 4) and the Firth of Forth area (southern area 4, now called area 9) and area 3 is divided into Norwegian Zone (western and norther area 3, now called area 3) and EU Zone (eastern area 3, now called area 8).

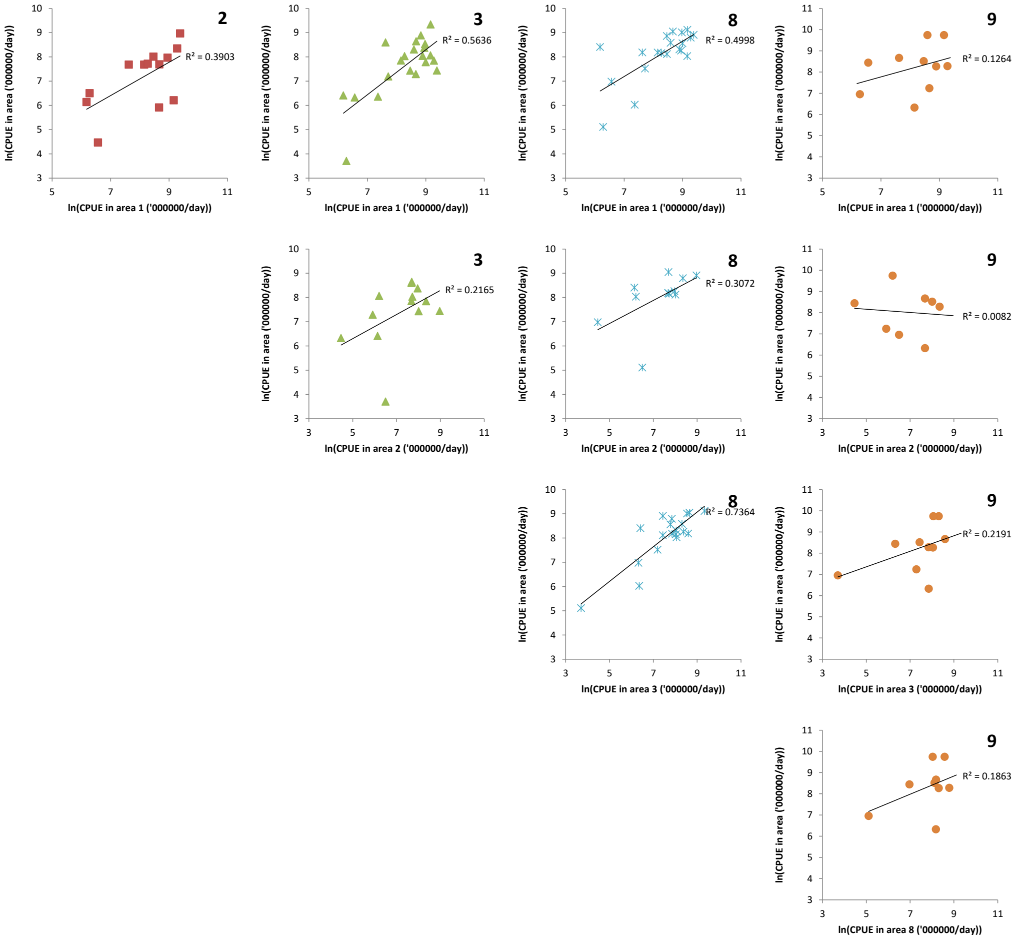

Fig. 3. External consistency between CPUE at age 1 in different areas (years with less than 10 age samples excluded) for the period 1994-2015. Two of the current assessment areas are divided in two: Area 4 is divided into Turbot bank (northern area 4, now called area 4) and the Firth of Forth area (southern area 4, now called area 9) and area 3 is divided into Norwegian Zone (western and norther area 3, now called area 3) and EU Zone (eastern area 3, now called area 8).

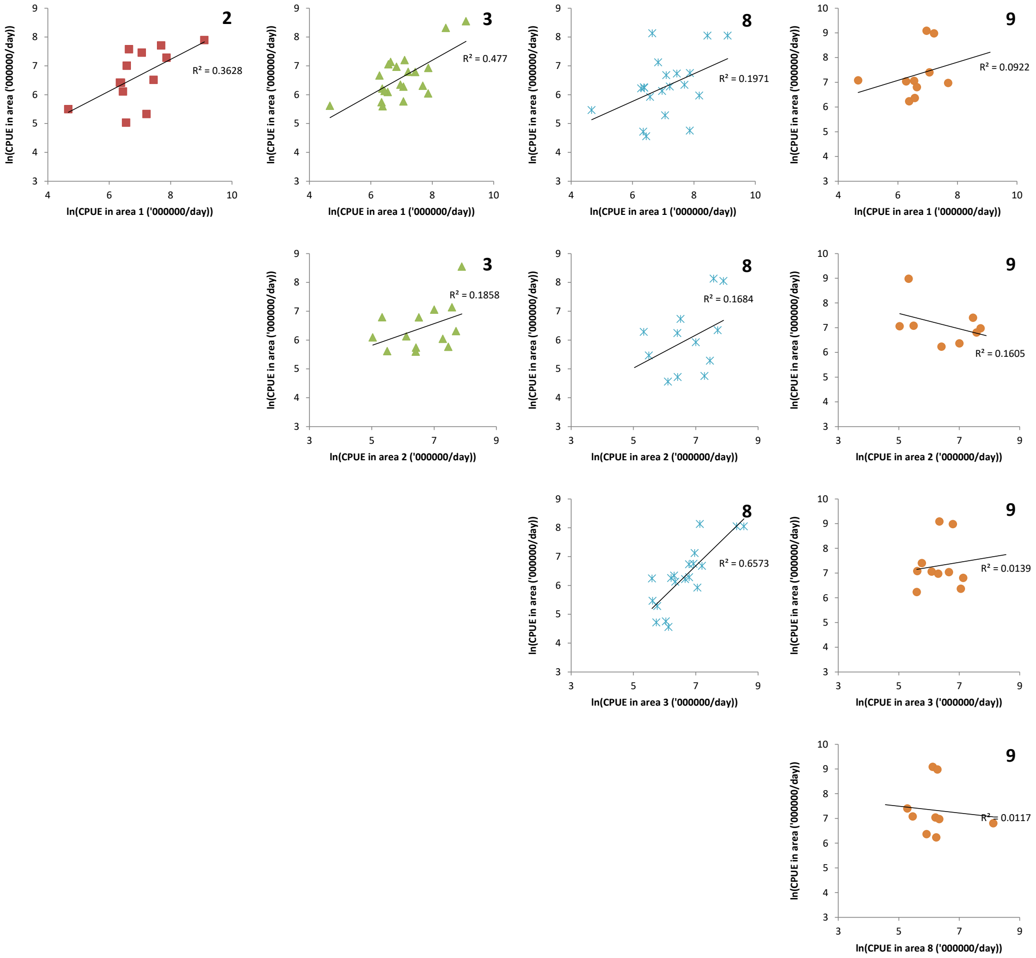

Fig. 4. External consistency between CPUE at age 2 in different areas (years with less than 10 age samples excluded) for the period 1994-2015. Two of the current assessment areas are divided in two: Area 4 is divided into Turbot bank (northern area 4, now called area 4) and the Firth of Forth area (southern area 4, now called area 9) and area 3 is divided into Norwegian Zone (western and norther area 3, now called area 3) and EU Zone (eastern area 3, now called area 8).

WD04 Analysis of ecosystem drivers of sandeel recruitment in subdivision SA1 (Dogger area)

Martin Lindegren, Brian McKenzie, Asbjørn Christensen, Lotte Worsøe Clausen, Anna Rindorf, and Mikael van Deurs

We have investigated the underlying factors regulating recruitment and productivity of North Sea sandeel and assess the productivity and recovery potential of the stock under different climate and fishing scenarios using a coupled model approach. Understanding the combination and potential synergy of these internal and external factors is a prerequisite for development of ecosystem-based management practices necessary to promote sustainable exploitation of pelagic fish stocks.

Material and Methods

Data availability

In order to investigate potential climate effects on sandeel recruitment, a number of variables characterising the local physical conditions, as well as regional ocean-atmospheric forcing, were collected (Table 1). The local climate conditions were represented by average sea surface temperatures (SST) anomalies in the Dogger Bank in each year and quarter, based on the Hadley centre observational data set available on a one-degree grid cell resolution, as well as mean annual sea bottom temperatures available from ICES (http://ecosystemdata.ices.dk/). In order to represent regional ocean-atmospheric forcing, we included winter averages (Dec-Feb) of the North Atlantic Oscillation Index (NAO), representing the leading Empirical Orthogonal Function (EOF) of sea level pressure over the Atlantic sector (20°-80°N, 90°W-40°E), as well as the Atlantic Multi-decadal Oscillation index, an index of de-trended temperature variations across the North Atlantic. The number of recruits at year zero (R) and spawning stock biomass (SSB) estimates were collected from recent stock assessments of sandeel in the Dogger Bank, i.e., representing assessment area 1 (ICES 2015). To account for density-dependent effects on sandeel recruitment (Arnott & Ruxton 2002), the number of one-year old individuals was included. Finally, the abundance of the key prey species Calanus fincmarchicus in the Dogger Bank during the first quarter was made available from the long-term monitoring of the Continuous Plankton Recorder (Zooplankton data from the continuous plankton recorder (CPR) survey was provided by the Sir Alister Hardy Foundation for Ocean Science, SAHFOS (Stevens D. (2015) Monthly averaged data for Calanus species in five sandeel management areas 1958-2014 as recorded by the Continuous Plankton recorder, Sir Alister Hardy Foundation for Ocean Science. Plymouth. [16/04/2015] DOI: 10.7487/2015.106.1.901

Statistical analysis and recruitment modelling

Generalized Additive Models (GAMs; Hastie and Tibshirani, 1990; Wood 2006) were used to examine the relationship between sandeel recruitment success (R/SSB) and the set of biotic and abiotic variables chosen as possible predictors during model fitting and selection. The following linearized Ricker formulations with log-transformed recruitment success estimates as responses were used:

(1)

where a is the intercept, s the thin plate smoothing function (Wood, 2003), SSB the spawning stock biomass, N1 the number of one-year olds, V a number of selected climate predictors potentially affecting sandeel recruitment success (Table 1) and ε the error term. Although the number of regression splines is optimized (and penalized) by the generalized cross validation criterion (GCV; Wood, 2004), the degrees of freedom of the spline smoother function (s) was further constrained to three knots (k=3) to allow for potential nonlinearities, but restrict flexibility during model fitting. Finally, we applied a model reduction routine based on the GCV and partial F-tests to find the best possible set of predictors. In addition, we performed a cross validation analysis by fitting the set of final models to a randomly selected subset of the data (Picard and Cook 1984), i.e., amounting to 75% of the observations, and assessed the predictive accuracy of the models by comparing the observed values with the predicted recruitment estimates for the remaining subset. The cross-validation analysis was repeated 1000 times (i.e., with a new set of random draws each time) in order to assess the range of uncertainty associated with the predictions.

Age-structured model setup

In order to simulate stock dynamics under different climate and fishing scenarios we applied a standard age-structured cohort model based on available information and parameters derived from recent stock assessments (ICES 2015). The simulated population dynamics are represented by numbers-at-age (N) distributed among 5 age classes (from 0 to 4+), where the so-called plus group includes all fish 4 years and older. The following formulation was used:

(2)

where Na,t are number-at-age a in year t, Fa,t and Ma,t the fishing mortality and the natural mortality at age a in year t, respectively. The simulations were performed by estimating R/SSB based on the final S-R model (Eg. 1; Table 3) and the observed values of each covariates in a given year, where SSB was estimated as the sum of the adult population given by the proportion of mature fish in each age and year and their corresponding mean weight-at-age (ICES 2015). In addition, a stochastic element was included by adding Gaussian noise (e; resampled randomly from the residuals of the S-R models) to account for unexplained sources of recruitment variability. After having accounted for intrinsic processes (i.e., growth, maturation, and natural mortality), as well as external factors (i.e., fishing mortality) in the age-structured cohort models, the forward simulation loop is reiterated by estimating R/SSB in the following year. Similar to the available stock assessment model the simulation model applies half-year time steps, where recruitment occurs from the 1st to the 2nd part of the year.

Model simulations and scenario testing

To evaluate the relative importance of the various factors affecting sandeel recruitment and survival we used the model to hindcast the population dynamics over a period from 1997 to 2005 during which the SSB showed an abrupt decline and consecutively low levels (Fig. 1a). The hindcast simulations comprise a control scenario where all input variables (i.e., SST, Calanus finmarchicus and fishing mortalities at age) were kept at observed levels, as well as a set of “treatments” (Fig. S2) represented by: (i) reduced Fs by 50%, (ii) reduced SST (by removing the increasing trend from late 1990s onwards); (iii) introduced peaks in C. finmarchicus in 2000 and 2004 (corresponding to observed peaks prior to 1992); (iv) and all treatments (i-iii) together. Furthermore, we performed multiple stochastic simulations and estimated the probability of collapse as the percentage of simulations in which SSB falls below the limiting stock size (Blim=160 000 tonnes) for each combination of SST (i.e., ±1 °C of observed SST) and fishing mortalities (ranging from 0 to 1.5). Due to the pronounced natural variability of the sandeel population dynamics and the risk of interpreting single year values below Blim as belonging to a "collapsed" state, probabilities were based on consecutive SSB values residing below Blim for a period longer than one generation (i.e., amounting to 4 years). The simulations were initialized at mean number at age (1982-2015) run for 20 years, and replicated 1000 times for each combination of SST and Fs. While observed SST values were used for model fitting and validation, surrogate time series of SST were used as input during simulations. Since marine climate is generally positively autocorrelated (Steele and Henderson 1984), we generated "red-shifted" noise accurately resembling the natural variability of the observed SST time series by allowing the simulated SST time series to fluctuate with the same mean, variance and degree of first-year autocorrelation as the observations (Lindegren et al. 2010). The abundance of Calanus finmarchicus was introduced in the S-R model by stochastic resampling of observed values in each year due to the lack of a clear auto-correlated signal. All statistical analyses were conducted using the R software, version 2.15.1 (www.r-project.org).

Results

Model fitting and validation

After model fitting, spring SST (2nd quarter) was found the most significant explanatory climate variable for recruitment success (Table 2). Although other variables were statistically significant, SST q2 demonstrated the lowest GCV and the highest degree of explained deviance overall (73.3%). Note that the explained variance was considerably higher than SST values averaged over other seasons. In addition to SST, SSB, N1 and the abundance of Calanus finmarchicus were found significant and were therefore retained within the final model (Table 3). The final relationship between recruitment success, SSB and N1 were represented by non-linear decreasing functions (Fig. 2A-B), 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 (Fig. 2C), while the effect of Calanus finmarchicus was linear and positive (Fig. 2D). 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 (Fig. 3E, F). In addition, the explained deviance and significance (p-values) of the model terms remained high when successively fitted and annually updated on data from 1997 to 2012 (Fig. 3A). Furthermore, the cross-validation routine demonstrated a high degree of explained variance for models fitted to a random subset of the data, as well as accuracy in predicting the remaining data (Fig. 3B). Model residuals were normally distributed and temporally uncorrelated for recruitment and recruitment success (Fig. S1).

Model simulations and scenario testing

The hindcast model scenario based on reduced Fs (by 50% relative to observed values) shows a pronounced improvement in stock status and SSB values, well above the control simulation and Blim throughout the entire period (Fig. 4A). The scenario of reduced SST demonstrates a minor improvement in SSB compared to the control during the early 2000s followed by a more substantial improvement until 2008 onwards. However, SSB values remain below Blim and increase above only after 2004. Likewise, the scenario introducing two peaks in C. finmarchicus (in 2000 and 2004) shows only a minor response in SSB in 2002 but a more marked increase following the second peak in 2006. (Note that the lag of two years corresponds to the period until reaching 100% maturity). Interestingly, the combined scenario introducing all “treatments” show SSB values well above also the precautionary stock level Bpa and very pronounced peaks in SSB following the introduced peaks in prey availability. Finally, the model simulations of sandeel dynamics under different combinations of SST and exploitation illustrate a strong dependence on both factors with a high probability of collapse at high levels of Fs and SST (Fig. 4B). Note that mean Fs between 1999 to 2004 amounts to ~1.2 (Fig. 1B) which given the high SST and low food abundance occurring during this period (Fig. 1C-D) proved unsustainable.

Acknowledgement: The study was carried out as part of the GOFORIT project (Intelligent Oceanographically-Based Short-Term Fishery Forecasting Applications), funded by COFASP ERA-net and Innovationsfonden, and the EMFF project ‘Future management of the North Sea Sandeel’ (33113-B-15-002) funded by the European Maritime Fisheries Fond.

Table 1. Abiotic and biotic covariates used during model fitting.

Variable	Month	Area	Source
SST_q1	Jan-March	Dogger Bank	http://www.metoffice.gov.uk/hadobs/hadsst2/data/download.html
SST_q2	April-June	Dogger Bank	http://www.metoffice.gov.uk/hadobs/hadsst2/data/download.html
SST_q3	July-Sept	Dogger Bank	http://www.metoffice.gov.uk/hadobs/hadsst2/data/download.html
SST_q4	Oct-Dec	Dogger Bank	http://www.metoffice.gov.uk/hadobs/hadsst2/data/download.html
SST_ann	Jan-Dec	Dogger Bank	http://www.metoffice.gov.uk/hadobs/hadsst2/data/download.html
SBT_ann	Jan-Dec	North Sea	http://ecosystemdata.ices.dk/
NAO_win	Dec-Feb	North Atlantic	https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-index-pc-based
AMO_win	Dec-Feb	North Atlantic	http://www.esrl.noaa.gov/psd/gcos_wgsp/Timeseries/AMO/

Zooplankton Cal_fin	SAHFOS; Continuous plankton recorder – average of monthly indices calculated specifically for sub division SA1

Table 2. The generalized cross validation scores (GCV) and deviance explained (DEV) after fitting the full S-R model to each abiotic covariate separately. The best covariate is highlighted in bold.

Variable	GCV	DEV
SST_q1	0.571	0.613
SST_q2	0.398	0.733
SST_q3	0.506	0.647
SST_q4	0.628	0.544
SST_ann	0.461	0.689
SBT_mean	0.555	0.624
NAO_win	0.634	0.508
AMO_win	0.459	0.684

Table 3. 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 r2 (%)
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 r2 refer to the percentage of the total deviance explained by each covariate separately.**

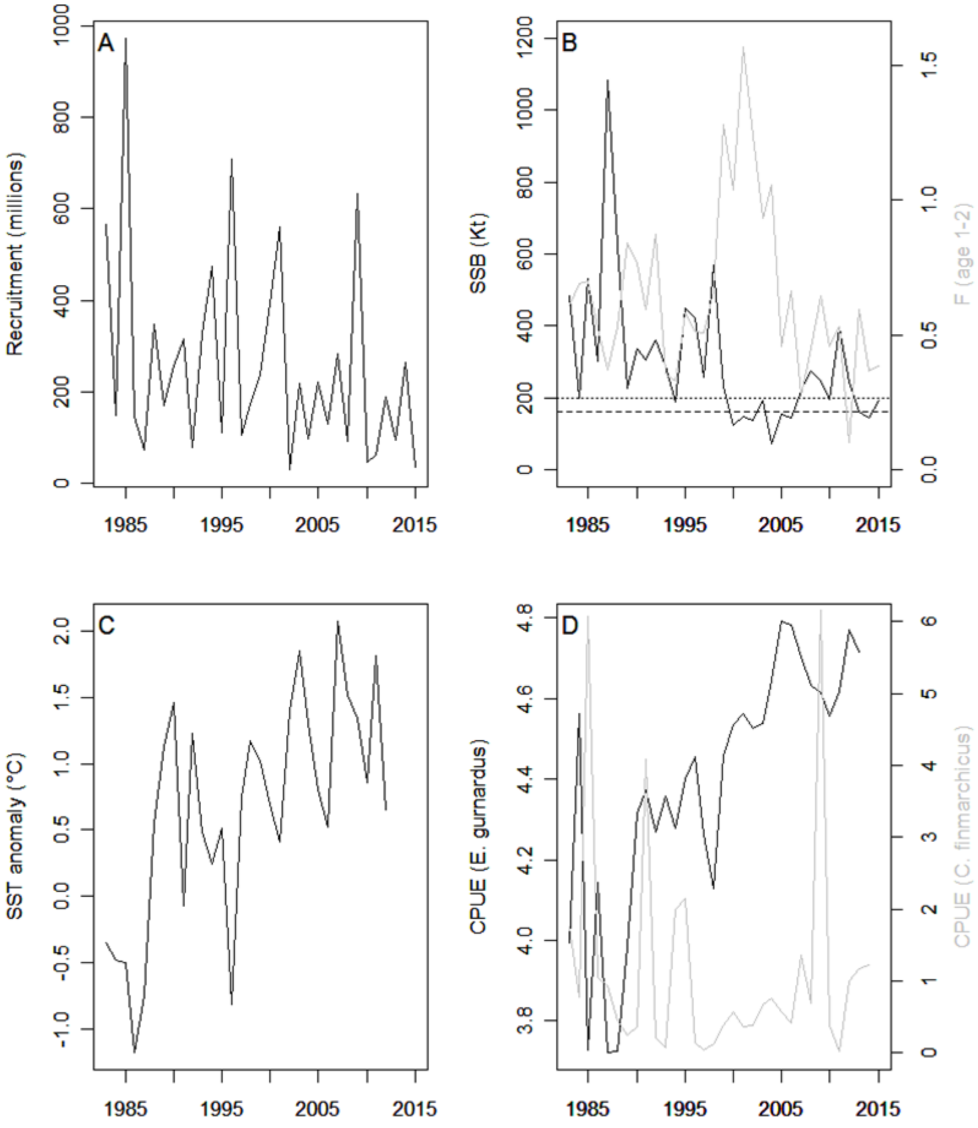

Fig. 1. Long-term trends in (A) sandeel recruitment, (B) spawning stock biomass (SSB; black) and mean fishing mortalities (F at ages 1-2; grey). Horizontal dotted lines represent the precautionary and limiting stock sizes (Bpa and Blim). Abiotic and biotic conditions affecting are recruitment success and juvenile survival are represented by (C) mean temperature anomalies (April-June) and the abundance of E. gurnardus and C. finmarhicus at the Dogger Bank.

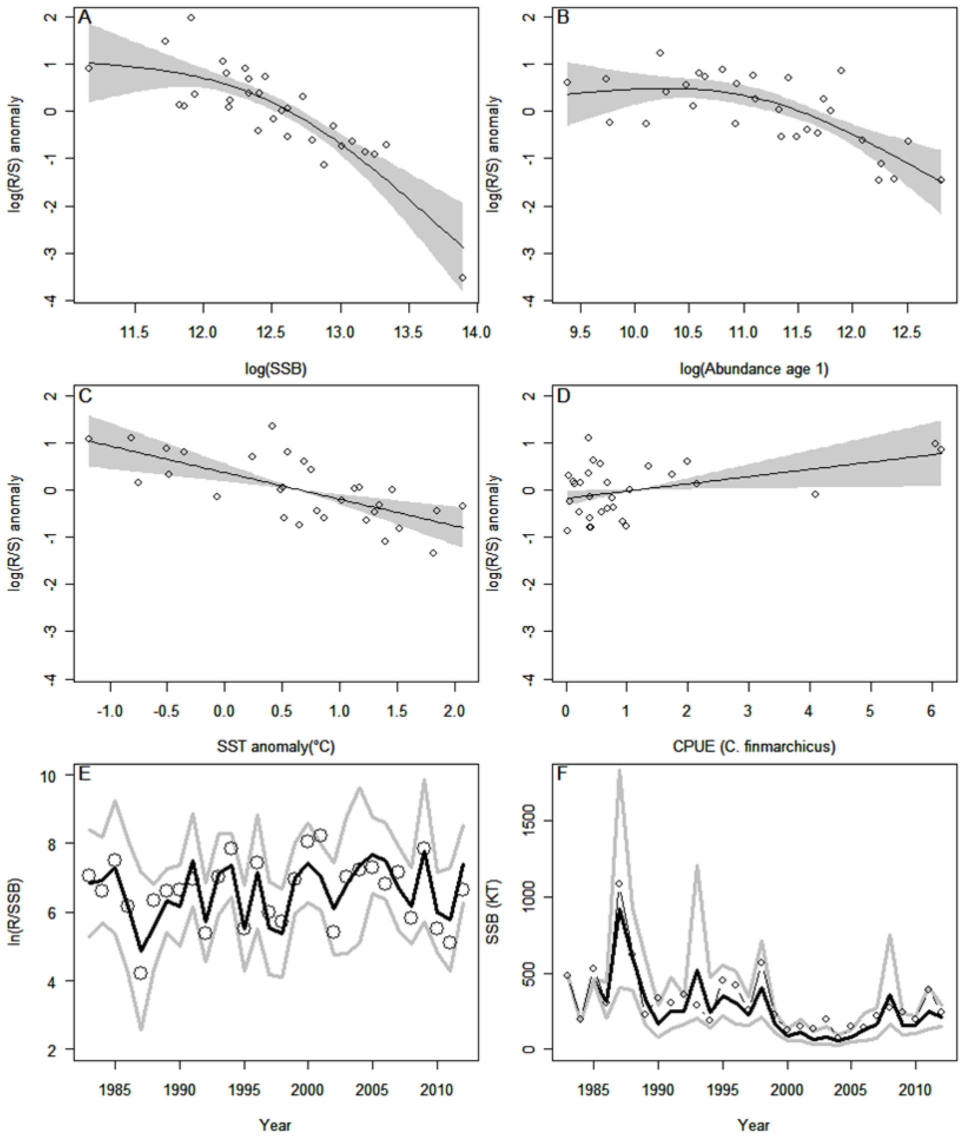

Fig. 2. The effects of final model predictors on sandeel recruitment success with 95% confidence intervals (grey), illustrating non-linear negative relationships with SSB (A) and abundance at age 1 (B), a negative linear relationships with SST (C), as well as positive effects of prey abundance (D; C. 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.

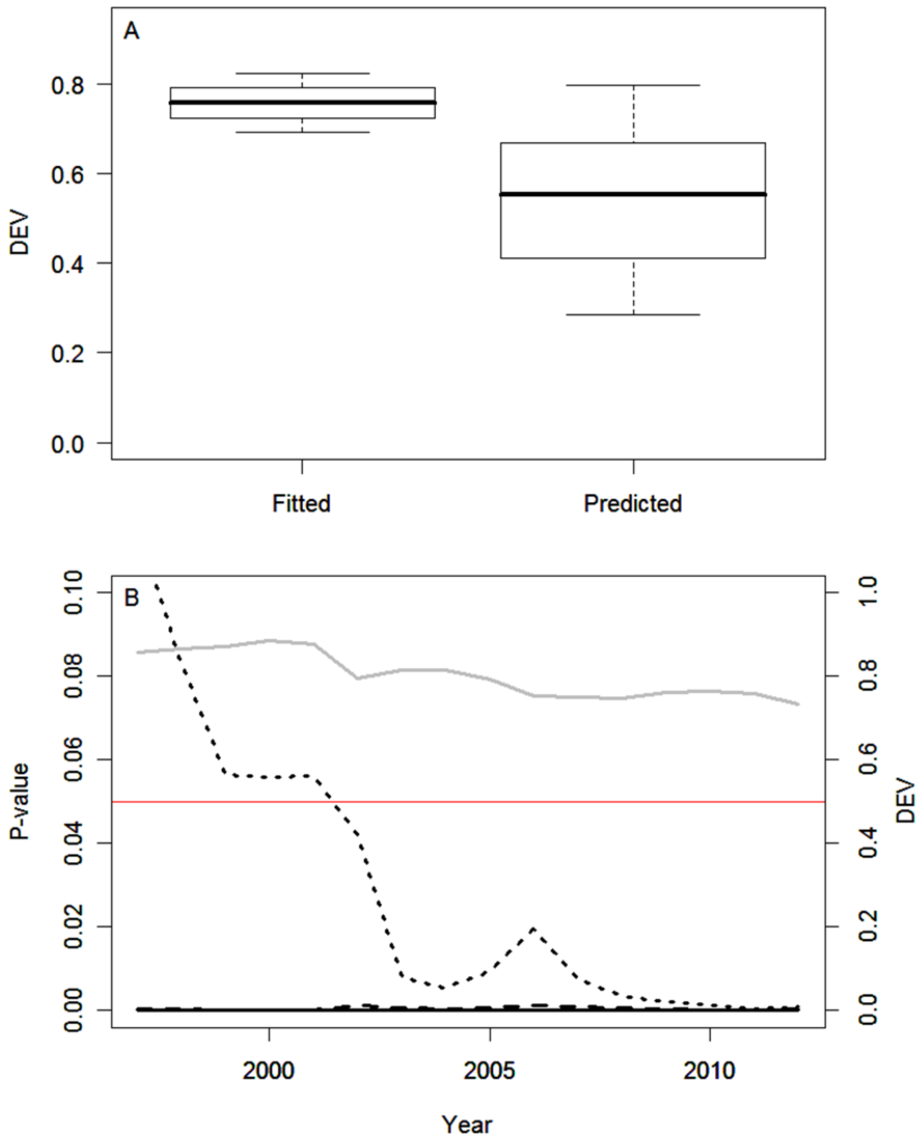

Fig. 3. (A) Boxplots of explained variance from a cross-validation analysis of model fit on a randomly selected subset, as well as the associated accuracy of predictions on the remaining data (after 1000 model iterations). (B) Overall explained deviance (grey) and p-values of the effects of SSB (solid), abundance at age 1 (dashed) and temperature (dotted) on sandeel recruitment success when successively fitting and annually updating the final model on data from 1997 to 2012.

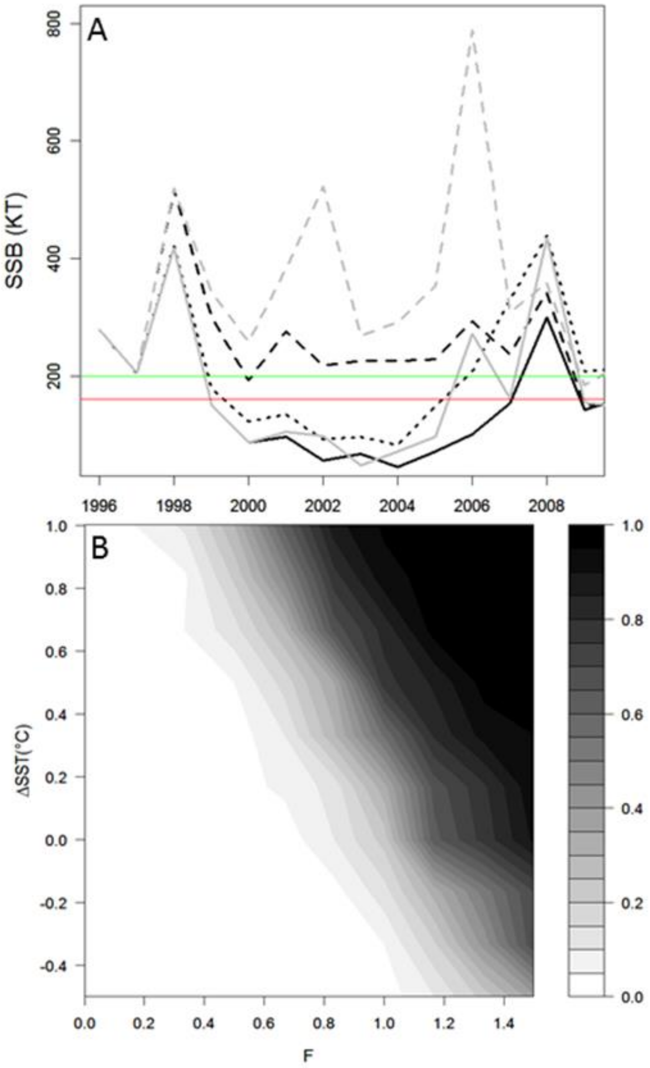

Fig. 4. (A) Hindcast simulations of sandeel SSB based on: (i) observed SST, C. finmarchicus and F values (black); (ii) reduced Fs by 50% (black dashed); (iii) reduced SST (by removing the increasing trend from late 1990s onwards; black dotted); (iv) introduced peaks in C. finmarchicus in 2000 and 2004 (grey solid); (v) and all changes (ii-iv) together (grey dashed). Solid horizontal lines mark the precautionary stock level, Bpa (green), and limiting stock level, Blim (red). (B) Probability of SSB falling below Blim given changes in mean SST (by -0.5 to 1°C) and fishing mortalities (from 0 to 1.5). Probabilities are calculated from 1000 stochastic simulations for each combination of SST and Fs.

Supporting information

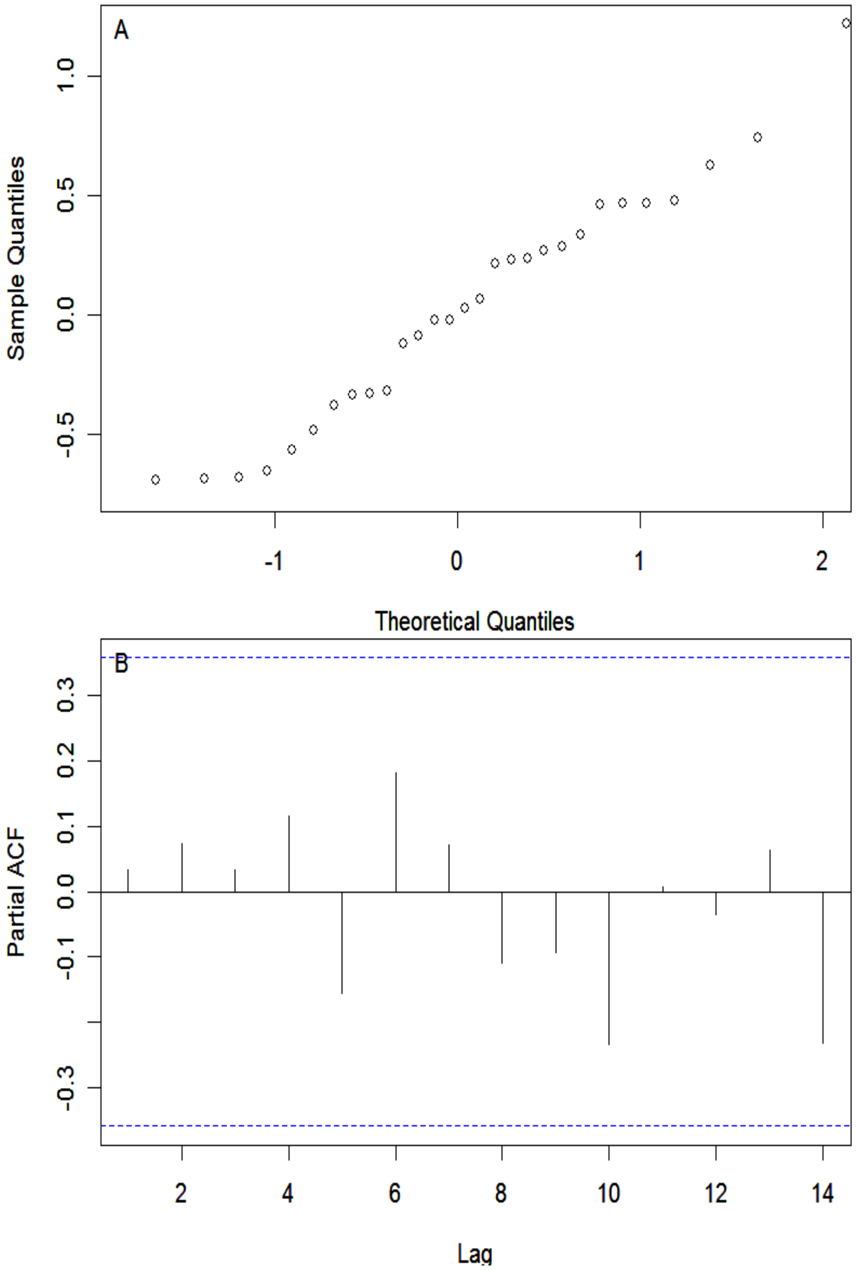

Fig. S1. (A) Normal probability plots and (B) partial autocorrelation plots of the final S-R models for sandeel recruitment success.

Acknowledgements: Fremadrettet forvaltning af tobis i Nordsøen (33113-B-15-002 European Fisheries and Maritime Fund)
Cofasp EU net-work project GOFORIT (www.goforit-cofasp.net)

WD 05 A time series of abundance of sandeel in the north-eastern North Sea estimated by acoustic surveys

Espen Johnsen

Institute of Marine Research

Background

Worldwide, acoustic trawl surveys the major source of fishery independent data to monitor pelagic fish populations (Simmonds and MacLennan, 2005). Typically, acoustic surveys use systematic transect designs where acoustic back-scattering intensity is measured using calibrated echo sounders, and the acoustic signal characteristics combined with trawl catches are used for reference when allocating acoustic densities to species. Biological samples from the trawl station are further used to transform to density of fish through a relationship between length and target strength (Simmonds and MacLennan, 2005), and the estimated number of individuals by length group can be sorted in sex and age categories using biological samples from the catches. Estimation of abundance at age from acoustic fish surveys involves many steps, like interpretation of echograms, assignment of fish samples to acoustic values (NASC) and translating acoustic values into fish density, and in 2005 Institute of Marine Research started a research survey program with objective to develop survey methodologies to measure the abundance of lesser sandeel in the north eastern North Sea (mainly NEEZ) and establishing a fishery independent survey time series to be used in the assessment of lesser sandeel. This report describes the methodology in place, and present the survey estimates for the period 2009-2016.

Sandeel distribution and behaviour - timing of survey and stratification of effort

During the feeding season, the adult sandeel burrows into the substrate at night and emerges at dawn (Winslade, 1974a) to form schools and to feed (Winslade, 1974b; Mackinson et al., 2005; Johnsen et al. 2009). The proportion of sandeels out of the sand may change within and between days (Greenstreet et al., 2006). The same diel behaviour is adopted by the juveniles when they settle in the sandeel areas in summer (Wright et al., 2000). Their strong preference for sandy habitat where the proportion of fine silt and clay particles is low (Macer, 1966; Wright et al., 2000)is reflected in large scale distribution that are spread like a patchwork in the North Sea (Jensen et. al 2011) and with a high local patchiness (Johnsen and Harbitz 2013).

The acoustic survey is carried out in the peak feeding season (about 25 April – 15 May) during daytime (between sunrise and sunset) when the sandeel form schools to feed on zooplankton. The geographical distribution of sandeel areas is reflected by the historical fishing effort (Figure 1), and the survey area cover all the known fishing ground for 11 geographical strata (Figure 2).

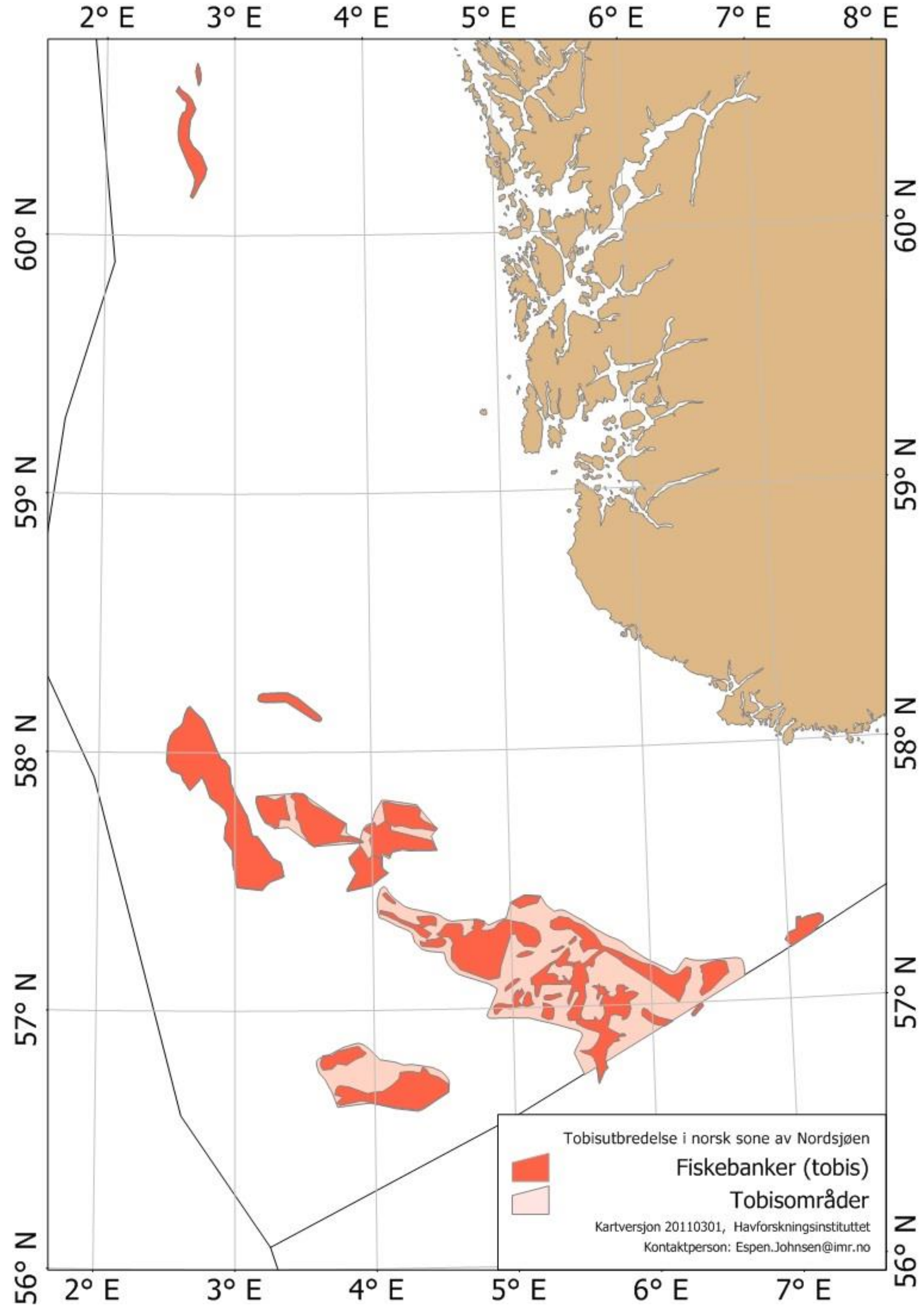

Figure 1. Map of sandeel distribution in NEEZ (light red) and sandeel fishing grounds (red).

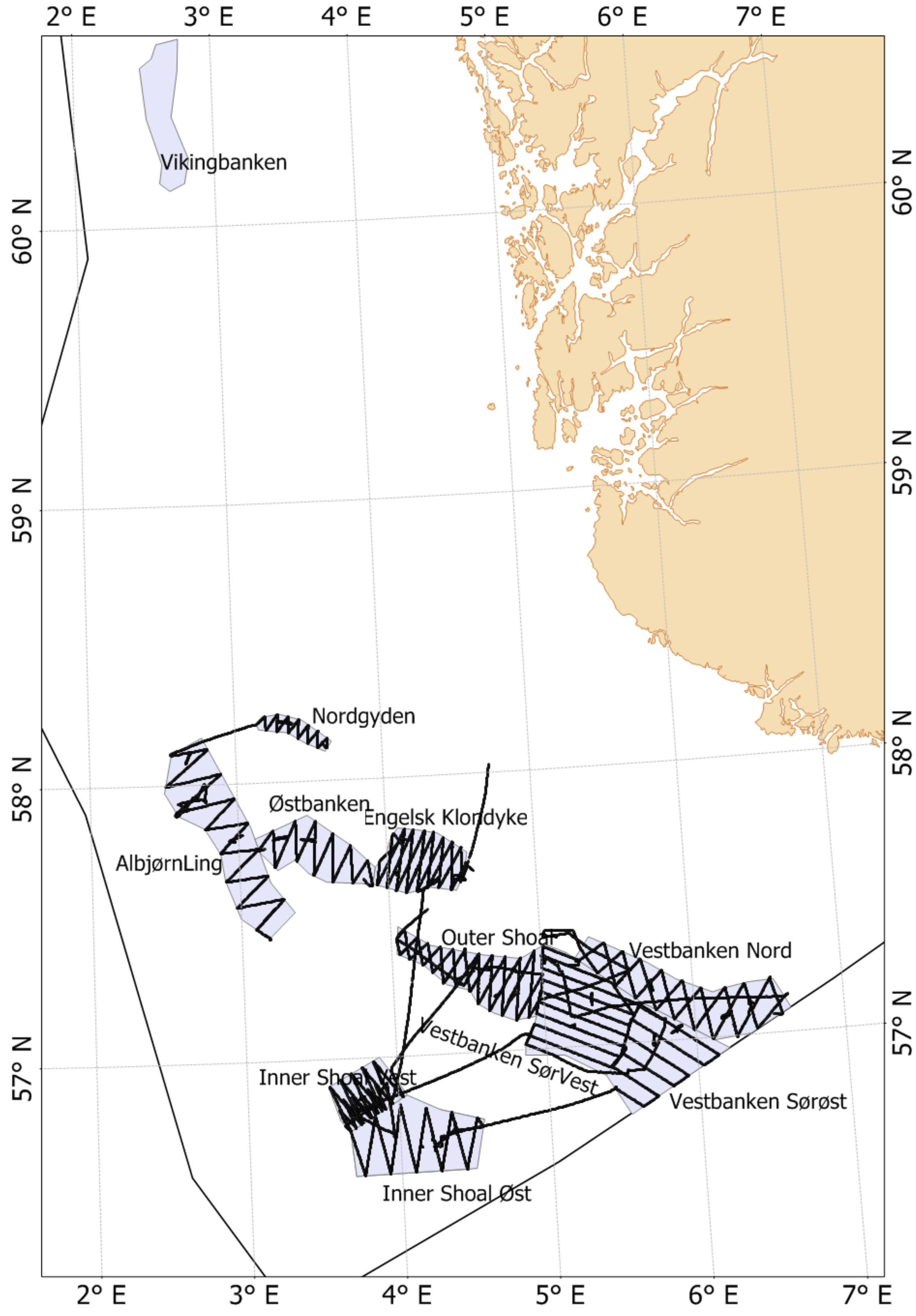

Figure 2. Map of the survey area and strata used during the acoustic surveys. The black line shows the cruise track for the 2016 survey.

Survey design

Each stratum (except AlbjørnLing see Fig 2) is small enough to be covered during one day (daylight) with a survey coverage of about 7 to aim for high precision (Aglen 1989).

Each stratum is covered by standard parallel or zig-zag transects, where each transect is defined as primary sampling unit (PSU) (Jolly and Hampton 2000; Simmonds and MacLennan, 2005). Based on abundance of sandeel observed during the first coverage and thereby the variance, the most of the strata are covered twice where the positions of the second coverage is typically between the transect of the first coverage (Vestbanken Nord, Fig 2).

The acoustic coverage is only carried out during daytime, but biological sampling using dredges and occasionally grabs (Johnsen and Harbitz 2013) are done at night. Biological sampling at daytime is mainly done by demersal trawling (sometimes pelagic trawling) on observed schools. To investigate if sandeel is burrowed in the sand at daytime dredges are used. These dredge samples shows that sandeel occurs very seldom in the sand during daytime during surveys.

Acoustic identification of sandeel

Sandeel form schools when they are out of the sand, and the survey program has developed methods to identify the acoustic backscattering of sandeel based on their acoustic-frequency responses measured at 18, 38, 120, and 200 kHz (see Johnsen et al 2009 for details). Therefore, all surveys have been carried out with research or fishing vessel with drop-keels equipped with scientific SIMRAD EK18, 38, 120 and 200 kHz mounted in accordance with the settings suggested by Korneliussen *et al*. (2008) (Figure 3). For many of the surveys, 70 and 333 kHz echosounders have been mounted on the drop-keels and used in the surveys.

Figure 3. Mounting of EK 18, 38, 70, 120, 200 and 333 kHz echousounder on the drop keel of RV G.O. Sars

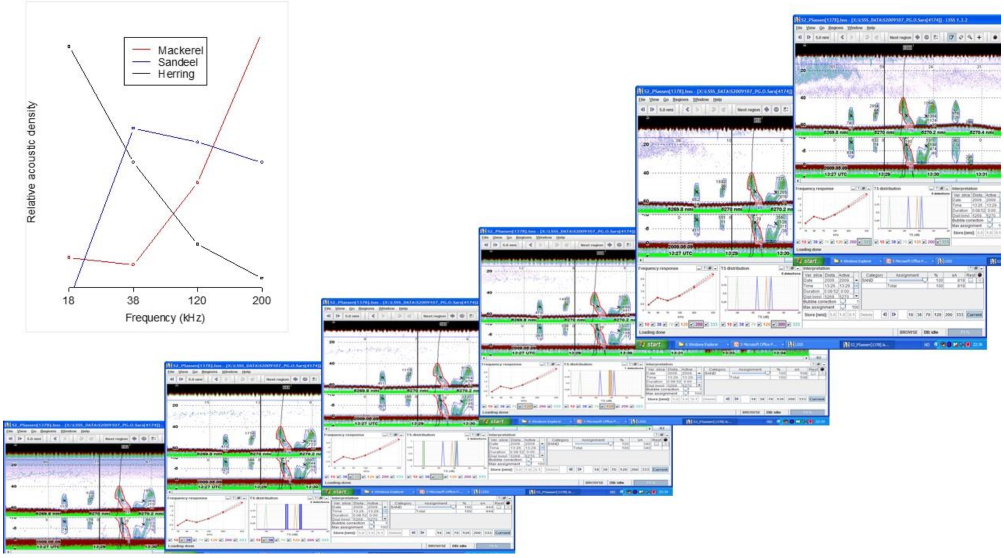

Figure 4. Identification of sandeel schools using different echosunder frequencies. Difference in acoustic frequency response between mackerel, sandeel, and mackerel is shown in topleft panel.

The acoustic EK60 recordings were interpreted using Large Scale Survey System (LSSS) (Korneliussen et al., 2016) the acoustic backscattering densities of sandeel expressed as nautical area scattering coefficients (NASC, $m^2 nmi.^{-2}$) (MacLennan et al 2002) is stored in a database by a horizontal resolution of 0.1 n.mil.

Assigning bio-stations, target strength and conversion to abundance

The conversion of mean NASC by PSU (transect) to density followed a standard procedure where trawl and/or dredge stations were assigned to a PSU assuming that these stations reflected the length distribution. Typically, as the strata are very small all transects within the same stratum had the same biostation assignments. This procedure is now also implemented for many of the acoustic surveys in the North Sea and Norwegian Sea (WGIPS). By using these length distributions, the density of herring (S) in each length group (*l*) within each PSU (*i*) is then computed as:

$$S_{l,i} = \frac{f_{l,i} \cdot NASC}{\langle \sigma \rangle}$$

Where

$$f_l = \frac{n_l L_i^2}{\sum_{l=1}^{m} n_l L_l}$$

is the "acoustic contribution" from the length group L_l to the total energy and σ is the mean backscattering cross section of the sandeel at length L_l. The target strength (TS) is used for the conversion where $\sigma = 4\pi\ 10^{(TS/10)}$ is used for estimating the backscattering cross section. Different target strengths have been tested (Kubilius & Ona 2012), but the results presented in this WD have used TS = 20 log L - 93 (Simmonds & MacLennan 2005) for 38 kHz.

To estimate the mean and variance of the sandeel density (by length) we use the methods established by Jolly and Hampton (1990) and implemented in the software StoX (http://www.imr.no/forskning/prosjekter/stox/en). For details regarding the estimation procedure in StoX see.

ftp://ftp.imr.no/StoX/Documentation/StoX%20reference%20guide%2020161003.docx

Results and discussion

The estimates are presented combined for all the southern strata (all strata Excl. Vikingbanken and Nordgyden, see Figure 2) as these covers ICES sandeel assessment area 3, and for Vikingbanken as this covers ICES sandeel assessment area 7.

Nordgyden

Nordgyden is an area with historical very low fishing effort, and as the density has been very low this area has not been covered regularly during all sandeel surveys. The highest biomass estimate of sandeel from Nordgyden was only about 300 tons in 2011.

Vikingbanken

The time series of biomass estimate for Vikingbanken (Figure 5) shows large variability between years, however, the abundance is always very low compared to the landings taken in 1995 and 1996 (ICES). Due to this very low sandeel density, it has been very difficult to catch sandeel on Vikingbanken, and the low number of biostations gives large uncertainty in the estimated abundance by length and age by survey for Vikingbanken (see Table A1-A8 in Appendix 1), nevertheless, the acoustic survey shows that the sandeel density is very low.

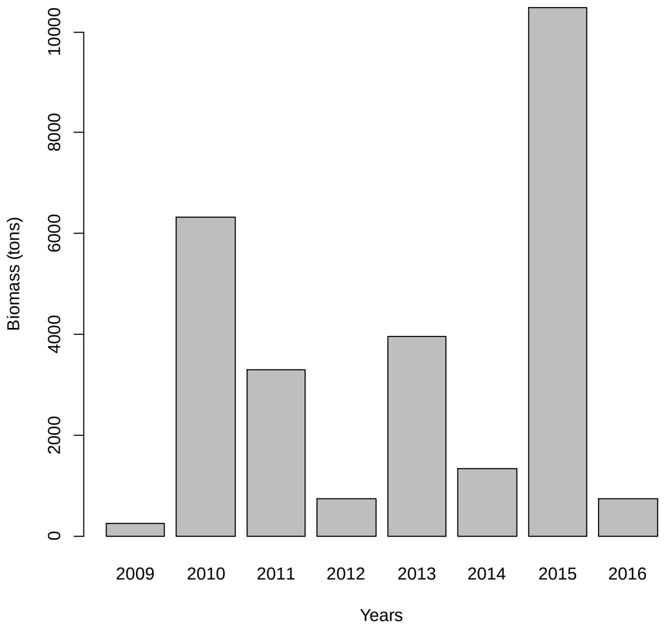

Figure 5. Biomass estimates of sandeel from Vikingbanken.

Southern NEEZ

The time series of biomass estimate for the southern sandeel grounds shows large variability between years (Figure 6), however, the variability in biomass is mainly a reflection in differences in recruitment strength (Figure 7). The survey estimates show very strong 2009 and 2013 year-classes as 1 years old fish (Figure 7 and Figure 8). The internal consistency plot (Figure 8) show that the survey follow the cohorts over several years (Figure 9). The estimated number of individuals and total stock biomass for the period 2009-2016 with confidence intervals show relatively high precision where the CV ranges from 11% to 27%

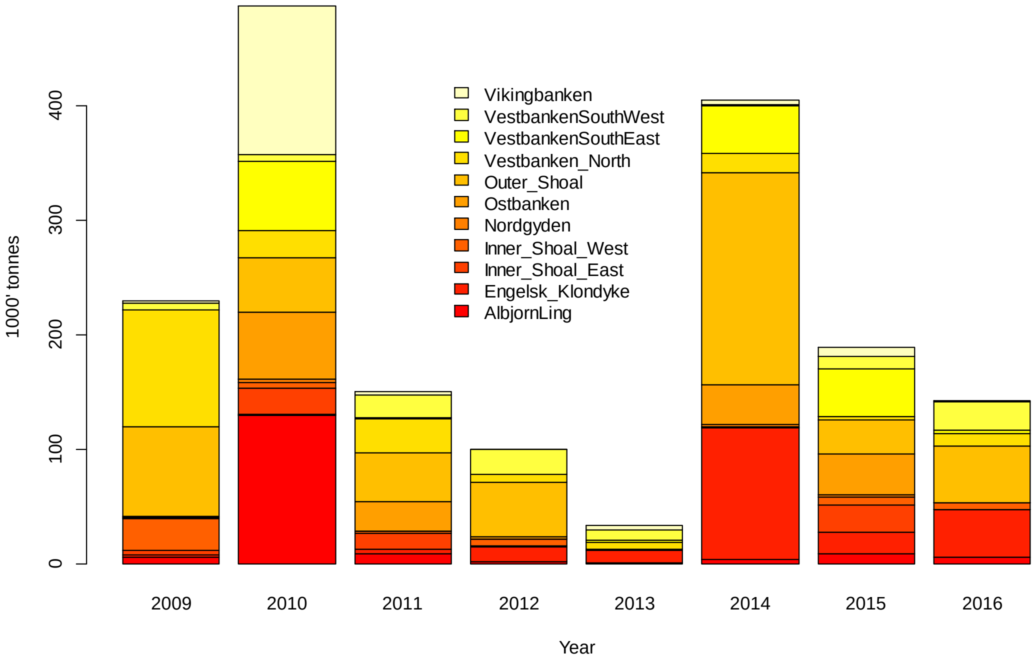

Figure 6. Biomass estimates

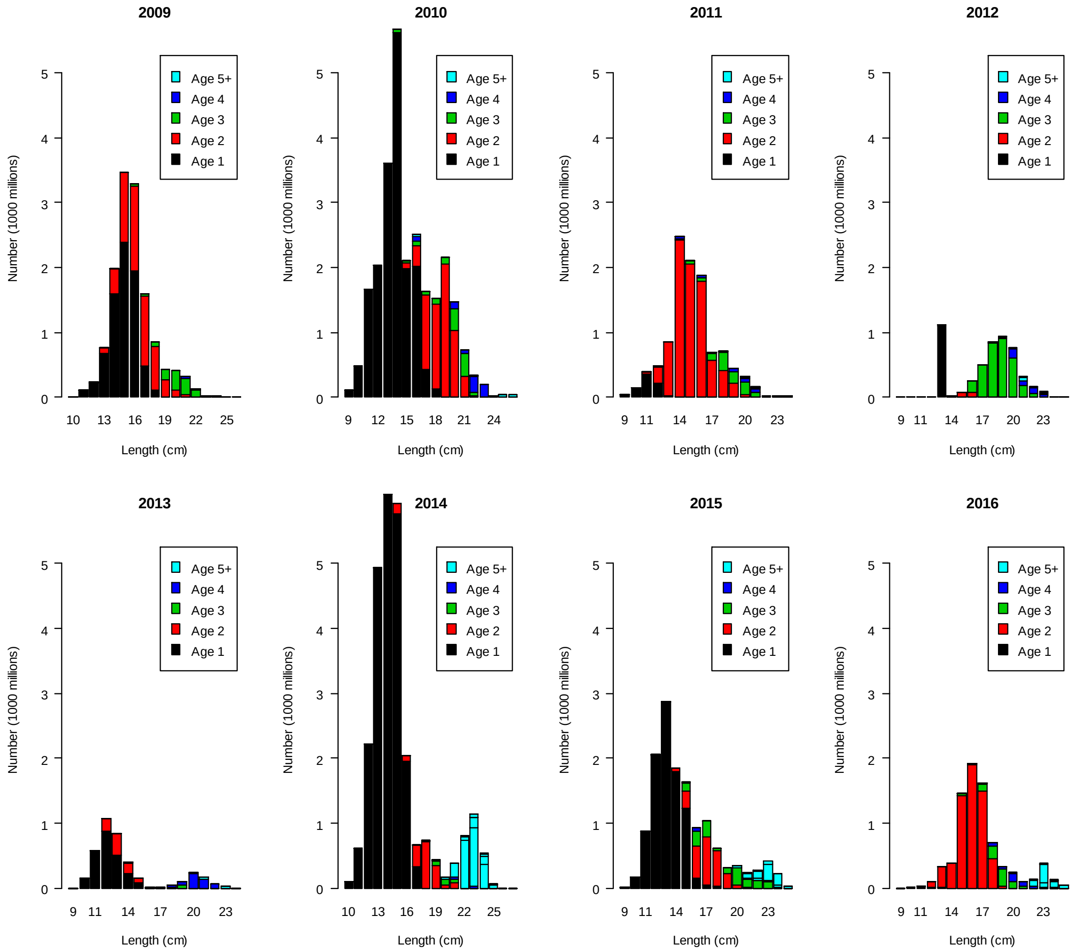

Figure 7 shows the abundance estimates by age for the southern area by year

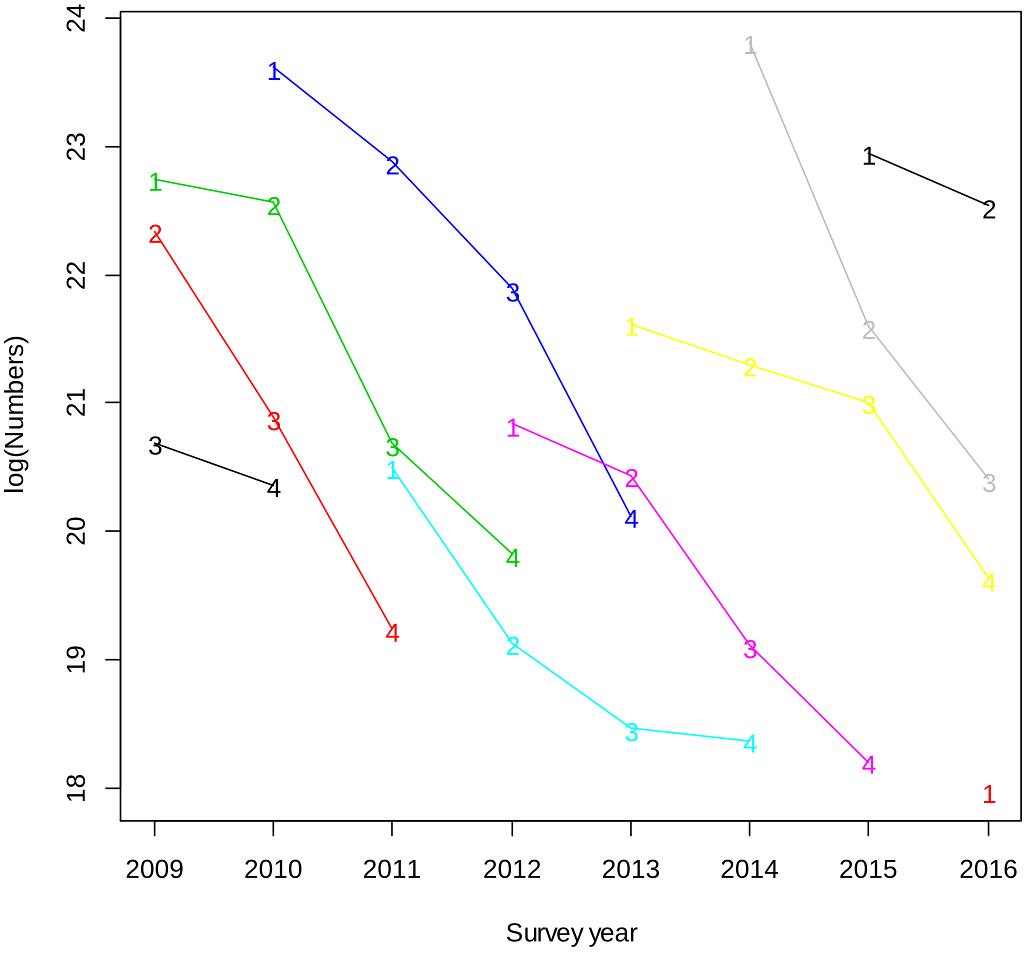

Figure 8. Estimated number of sandeel by age by survey presented by cohort.

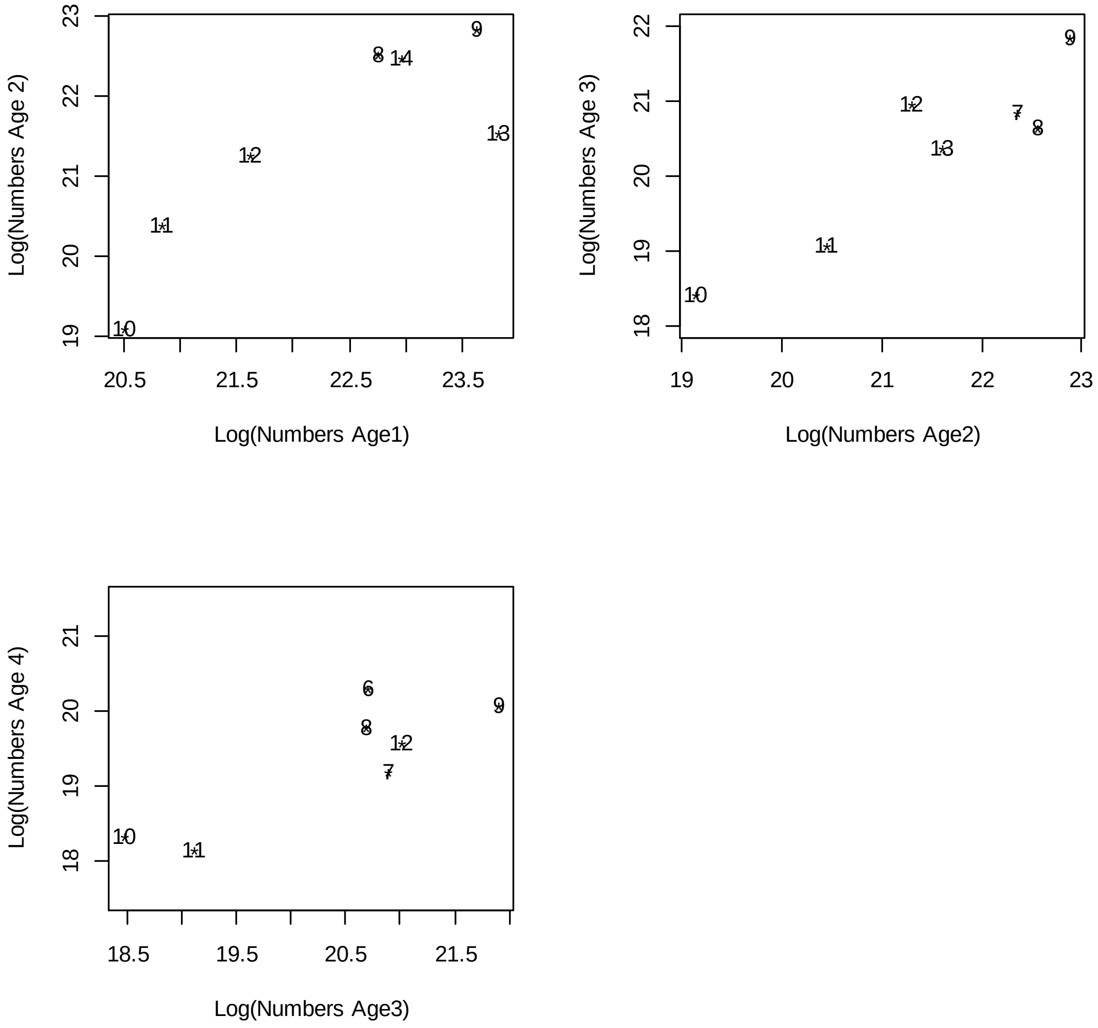

Figure 9. Plot of internal consistency (r_age1_age2=0.85, r=_age2_age3=0.92, r_age3_age4=0.86)

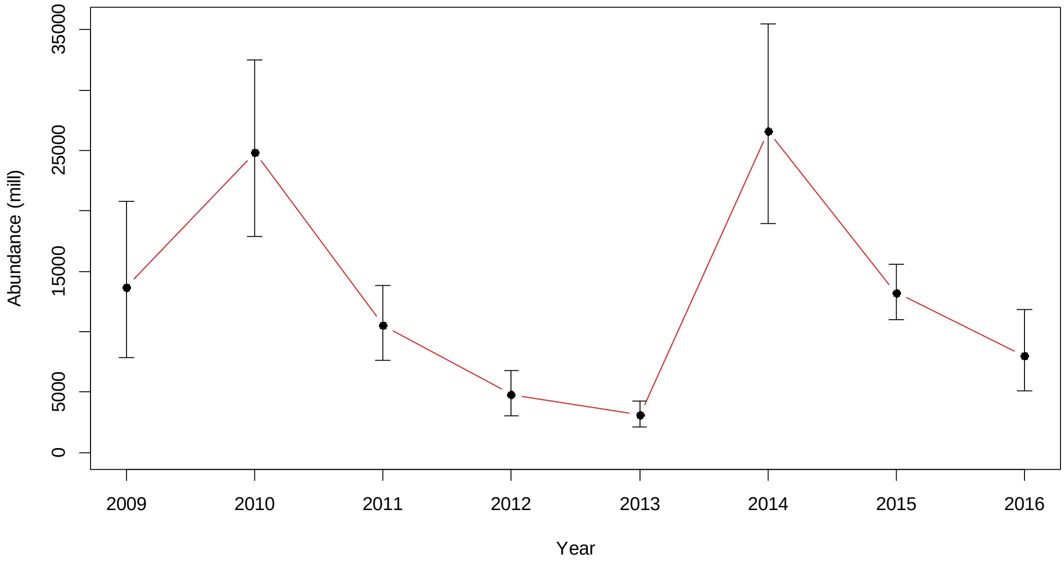

Figure 10a. Mean estimated number of individuals by survey (black dot) with confidence interval (5-95%) depicted as error bars.

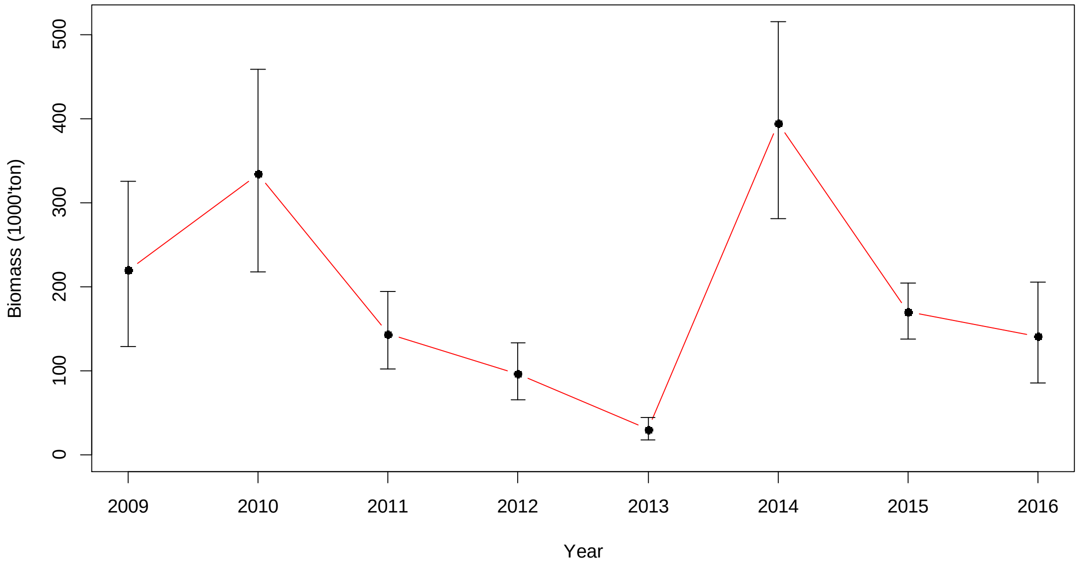

Figure 10b. Mean estimated total stock biomass by survey (black dot) with confidence interval (5-95%) depicted as error bars.

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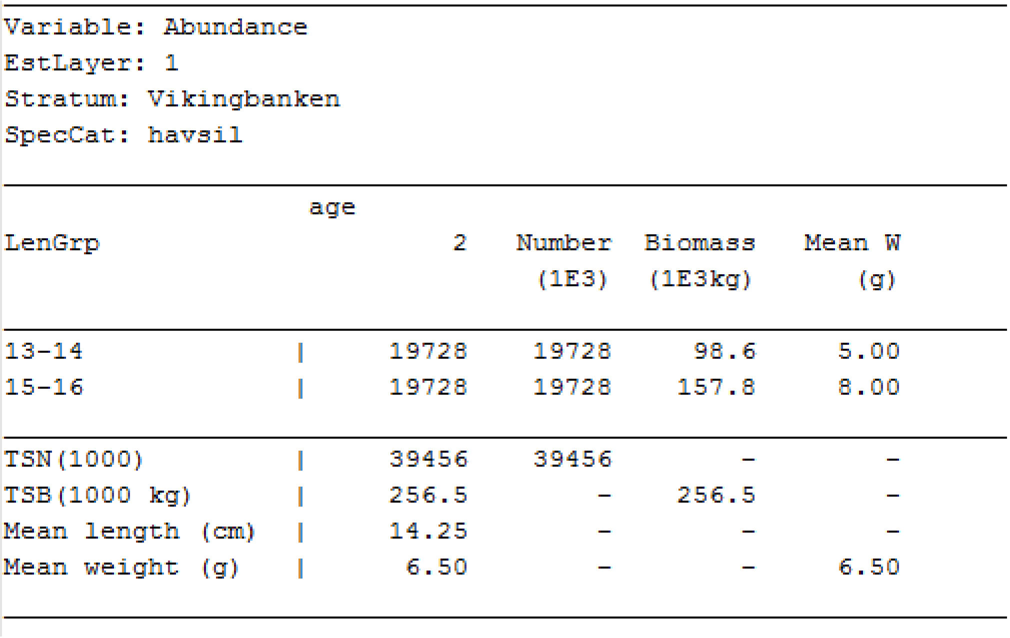
Appendix 1

Table A1. 2009 – Vikingbanken



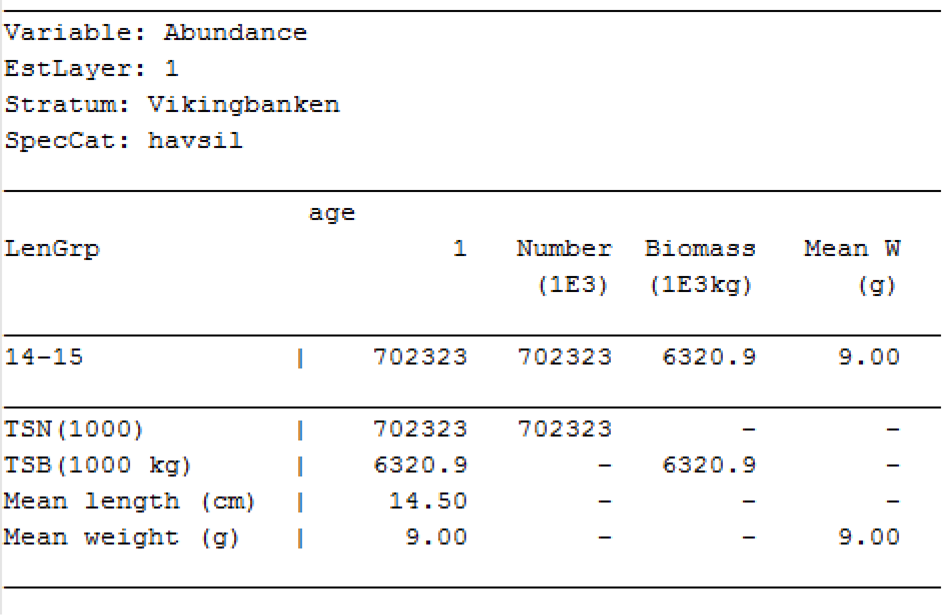
```
Variable: Abundance
EstLayer: 1
Stratum: Vikingbanken
SpecCat: havsil

                      age
LenGrp                          2    Number   Biomass    Mean W
                                      (1E3)   (1E3kg)       (g)

13-14                |      19728     19728      98.6      5.00
15-16                |      19728     19728     157.8      8.00

TSN(1000)            |      39456     39456         -         -
TSB(1000 kg)         |      256.5         -     256.5         -
Mean length (cm)     |      14.25         -         -         -
Mean weight (g)      |       6.50         -         -      6.50
```

Table A2. 2010 - Vikingbanken



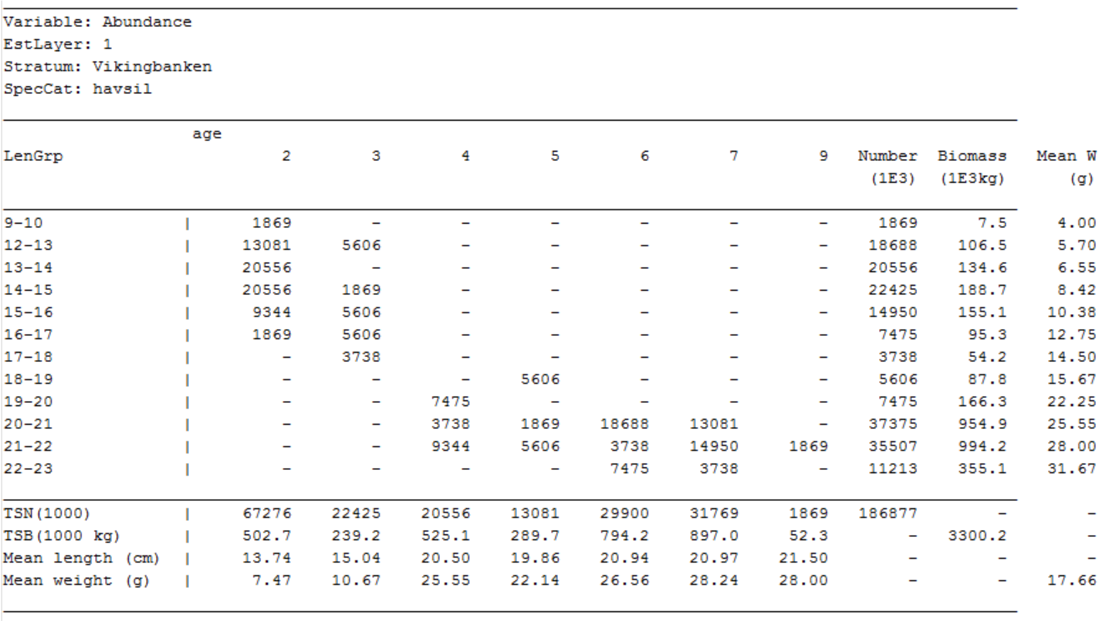
```
Variable: Abundance
EstLayer: 1
Stratum: Vikingbanken
SpecCat: havsil

                      age
LenGrp                          1    Number   Biomass    Mean W
                                      (1E3)   (1E3kg)       (g)

14-15                |     702323    702323    6320.9      9.00

TSN(1000)            |     702323    702323         -         -
TSB(1000 kg)         |     6320.9         -    6320.9         -
Mean length (cm)     |      14.50         -         -         -
Mean weight (g)      |       9.00         -         -      9.00
```

Table A3. 2011 – Vikingbanken



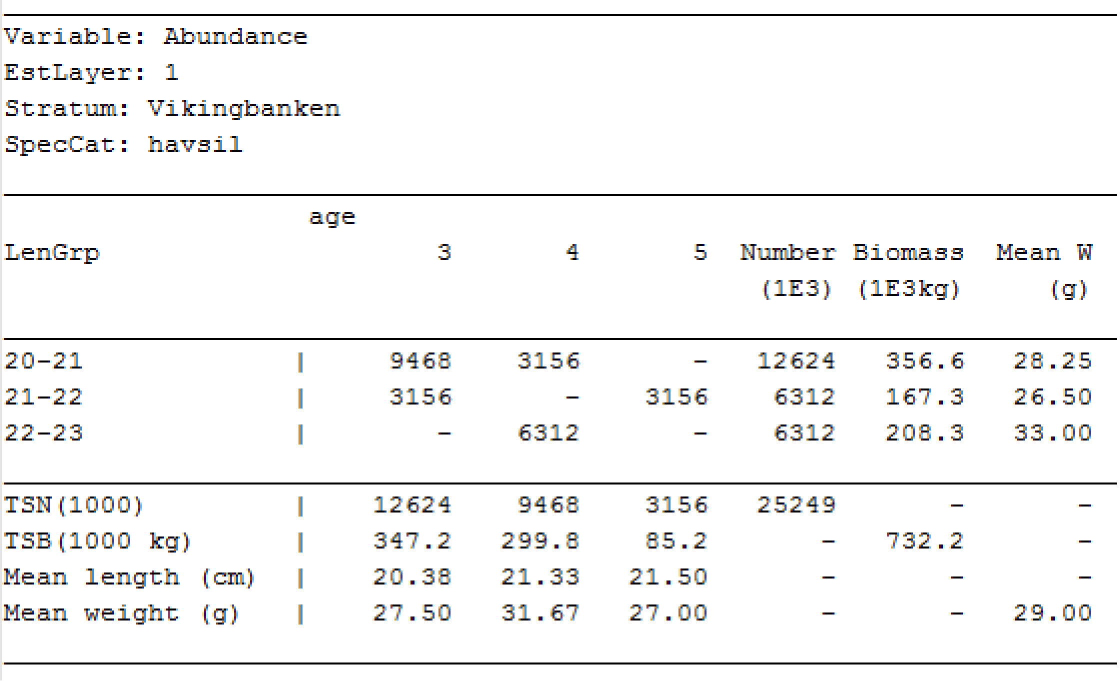
```
Variable: Abundance
EstLayer: 1
Stratum: Vikingbanken
SpecCat: havsil

                 age
LenGrp                        2         3         4         5         6         7         9    Number   Biomass    Mean W
                                                                                                  (1E3)   (1E3kg)       (g)

9-10                |      1869         -         -         -         -         -         -      1869       7.5      4.00
12-13               |     13081      5606         -         -         -         -         -     18688     106.5      5.70
13-14               |     20556         -         -         -         -         -         -     20556     134.6      6.55
14-15               |     20556      1869         -         -         -         -         -     22425     188.7      8.42
15-16               |      9344      5606         -         -         -         -         -     14950     155.1     10.38
16-17               |      1869      5606         -         -         -         -         -      7475      95.3     12.75
17-18               |         -      3738         -         -         -         -         -      3738      54.2     14.50
18-19               |         -         -         -      5606         -         -         -      5606      87.8     15.67
19-20               |         -         -      7475         -         -         -         -      7475     166.3     22.25
20-21               |         -         -      3738      1869     18688     13081         -     37375     954.9     25.55
21-22               |         -         -      9344      5606      3738     14950      1869     35507     994.2     28.00
22-23               |         -         -         -         -      7475      3738         -     11213     355.1     31.67

TSN(1000)           |     67276     22425     20556     13081     29900     31769      1869    186877         -         -
TSB(1000 kg)        |     502.7     239.2     525.1     289.7     794.2     897.0      52.3         -    3300.2         -
Mean length (cm)    |     13.74     15.04     20.50     19.86     20.94     20.97     21.50         -         -         -
Mean weight (g)     |      7.47     10.67     25.55     22.14     26.56     28.24     28.00         -         -     17.66
```

Table A4. 2012 – Vikingbanken



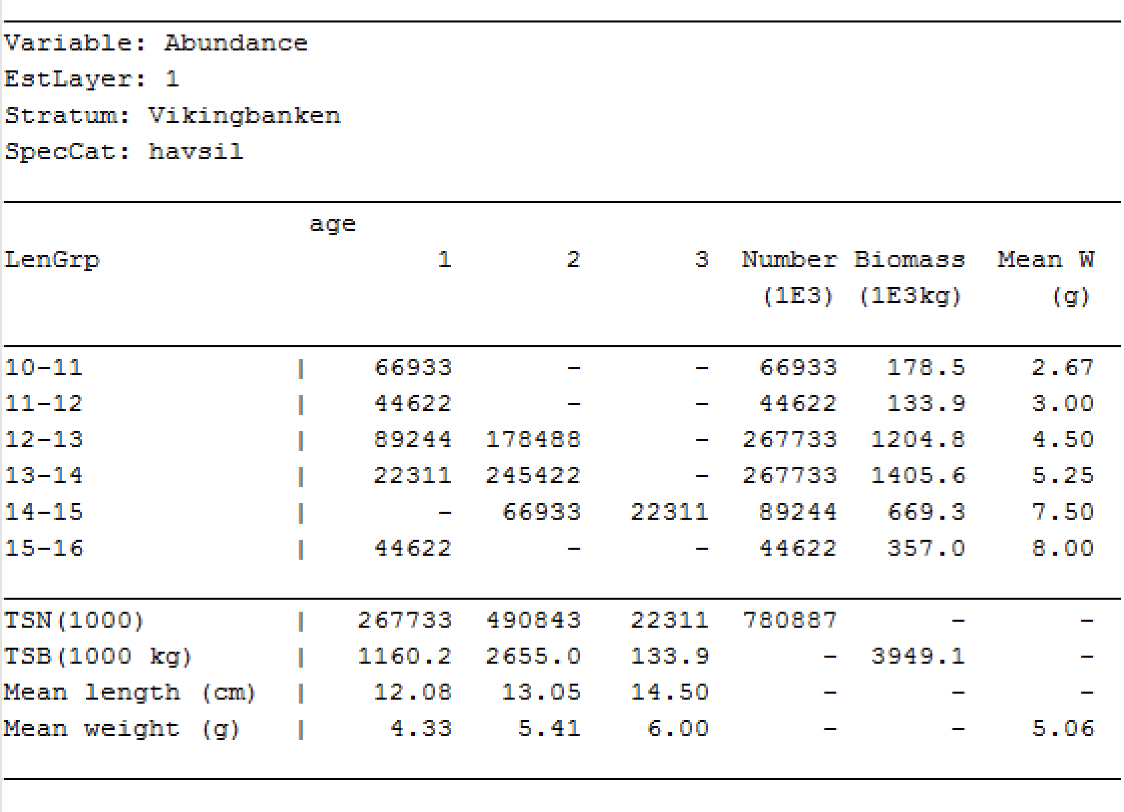
```
Variable: Abundance
EstLayer: 1
Stratum: Vikingbanken
SpecCat: havsil

                   age
LenGrp                        3         4         5    Number   Biomass    Mean W
                                                          (1E3)   (1E3kg)       (g)

20-21               |      9468      3156         -     12624     356.6     28.25
21-22               |      3156         -      3156      6312     167.3     26.50
22-23               |         -      6312         -      6312     208.3     33.00

TSN(1000)           |     12624      9468      3156     25249         -         -
TSB(1000 kg)        |     347.2     299.8      85.2         -     732.2         -
Mean length (cm)    |     20.38     21.33     21.50         -         -         -
Mean weight (g)     |     27.50     31.67     27.00         -         -     29.00
```

Table A5. 2013- Vikingbanken



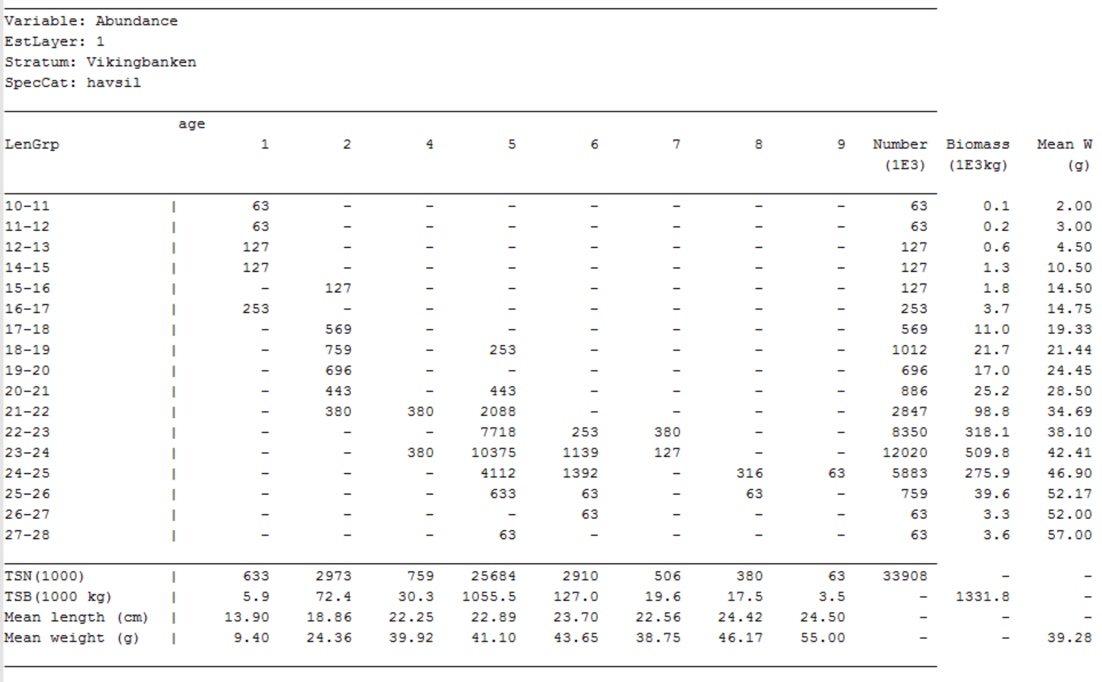
```
Variable: Abundance
EstLayer: 1
Stratum: Vikingbanken
SpecCat: havsil

                      age
LenGrp                         1         2         3   Number  Biomass    Mean W
                                                        (1E3)  (1E3kg)      (g)

10-11                 |    66933         -         -    66933    178.5     2.67
11-12                 |    44622         -         -    44622    133.9     3.00
12-13                 |    89244    178488         -   267733   1204.8     4.50
13-14                 |    22311    245422         -   267733   1405.6     5.25
14-15                 |        -     66933     22311    89244    669.3     7.50
15-16                 |    44622         -         -    44622    357.0     8.00

TSN(1000)             |   267733    490843     22311   780887        -        -
TSB(1000 kg)          |   1160.2    2655.0     133.9        -   3949.1        -
Mean length (cm)      |    12.08     13.05     14.50        -        -        -
Mean weight (g)       |     4.33      5.41      6.00        -        -     5.06
```

Table A6. 2014 – Vikingbanken



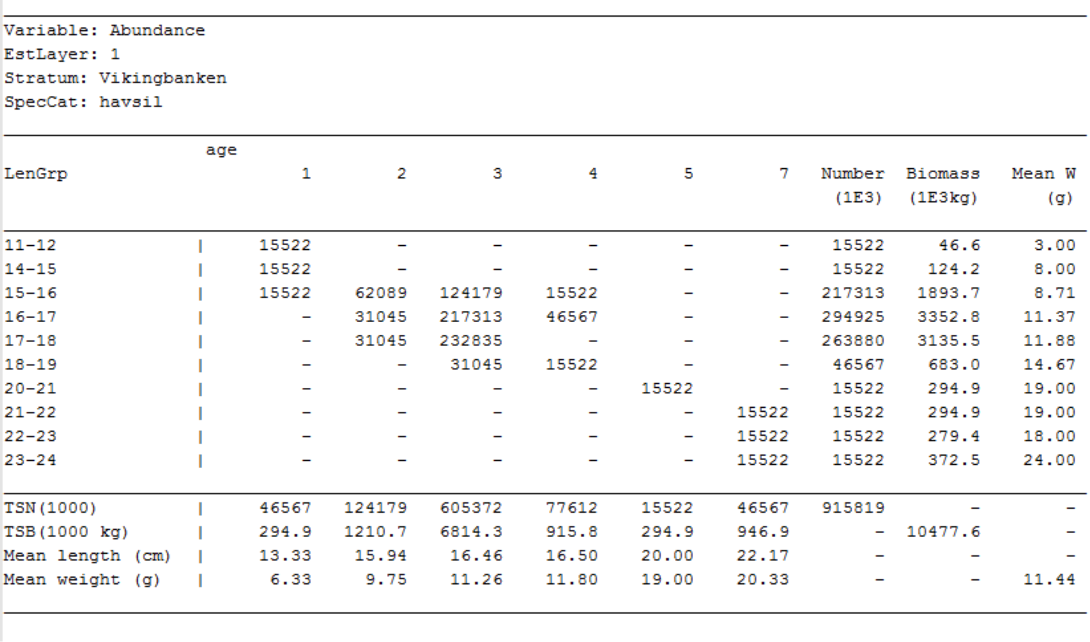
```
Variable: Abundance
EstLayer: 1
Stratum: Vikingbanken
SpecCat: havsil

                      age
LenGrp                        1        2        4        5        6        7        8        9   Number  Biomass    Mean W
                                                                                                  (1E3)  (1E3kg)      (g)

10-11                 |      63        -        -        -        -        -        -        -       63      0.1     2.00
11-12                 |      63        -        -        -        -        -        -        -       63      0.2     3.00
12-13                 |     127        -        -        -        -        -        -        -      127      0.6     4.50
14-15                 |     127        -        -        -        -        -        -        -      127      1.3    10.50
15-16                 |       -      127        -        -        -        -        -        -      127      1.8    14.50
16-17                 |     253        -        -        -        -        -        -        -      253      3.7    14.75
17-18                 |       -      569        -        -        -        -        -        -      569     11.0    19.33
18-19                 |       -      759        -      253        -        -        -        -     1012     21.7    21.44
19-20                 |       -      696        -        -        -        -        -        -      696     17.0    24.45
20-21                 |       -      443        -      443        -        -        -        -      886     25.2    28.50
21-22                 |       -      380      380     2088        -        -        -        -     2847     98.8    34.69
22-23                 |       -        -        -     7718      253      380        -        -     8350    318.1    38.10
23-24                 |       -        -      380    10375     1139      127        -        -    12020    509.8    42.41
24-25                 |       -        -        -     4112     1392        -      316       63     5883    275.9    46.90
25-26                 |       -        -        -      633       63        -       63        -      759     39.6    52.17
26-27                 |       -        -        -        -       63        -        -        -       63      3.3    52.00
27-28                 |       -        -        -       63        -        -        -        -       63      3.6    57.00

TSN(1000)             |     633     2973      759    25684     2910      506      380       63    33908        -        -
TSB(1000 kg)          |     5.9     72.4     30.3   1055.5    127.0     19.6     17.5      3.5        -   1331.8        -
Mean length (cm)      |   13.90    18.86    22.25    22.89    23.70    22.56    24.42    24.50        -        -        -
Mean weight (g)       |    9.40    24.36    39.92    41.10    43.65    38.75    46.17    55.00        -        -    39.28
```

Table A7. 2015 – Vikingbanken



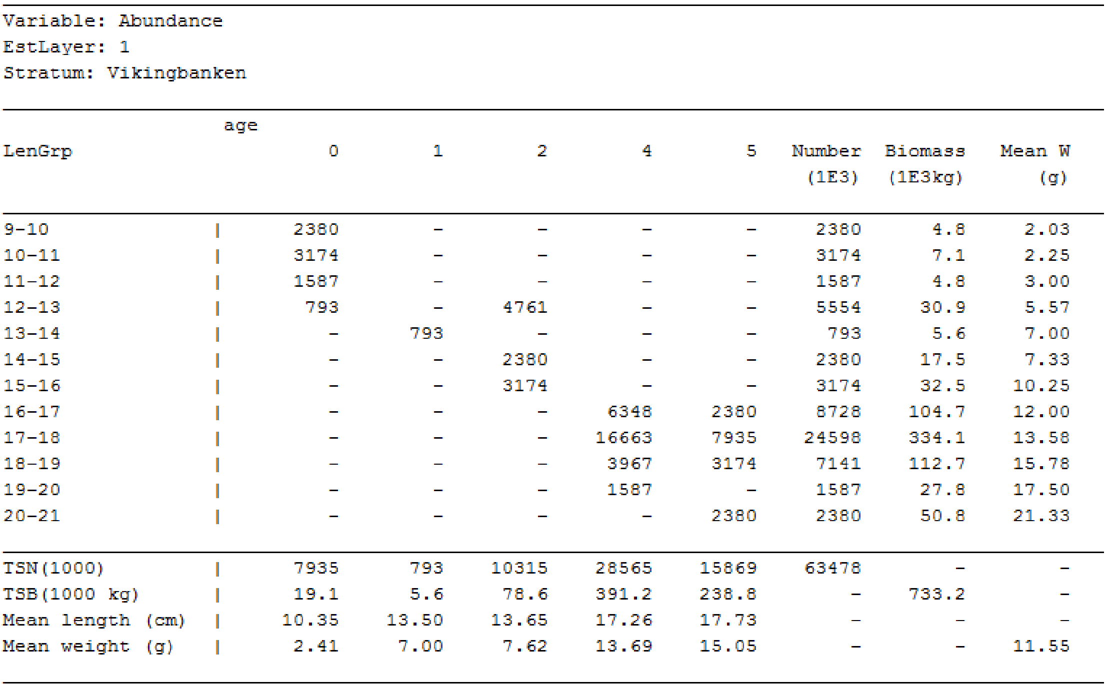
```
Variable: Abundance
EstLayer: 1
Stratum: Vikingbanken
SpecCat: havsil

                   age
LenGrp                       1        2        3        4        5        7   Number  Biomass    Mean W
                                                                               (1E3)  (1E3kg)       (g)

11-12              |     15522        -        -        -        -        -    15522     46.6      3.00
14-15              |     15522        -        -        -        -        -    15522    124.2      8.00
15-16              |     15522    62089   124179    15522        -        -   217313   1893.7      8.71
16-17              |         -    31045   217313    46567        -        -   294925   3352.8     11.37
17-18              |         -    31045   232835        -        -        -   263880   3135.5     11.88
18-19              |         -        -    31045    15522        -        -    46567    683.0     14.67
20-21              |         -        -        -        -    15522        -    15522    294.9     19.00
21-22              |         -        -        -        -        -    15522    15522    294.9     19.00
22-23              |         -        -        -        -        -    15522    15522    279.4     18.00
23-24              |         -        -        -        -        -    15522    15522    372.5     24.00

TSN(1000)          |     46567   124179   605372    77612    15522    46567   915819        -         -
TSB(1000 kg)       |     294.9   1210.7   6814.3    915.8    294.9    946.9        -  10477.6         -
Mean length (cm)   |     13.33    15.94    16.46    16.50    20.00    22.17        -        -         -
Mean weight (g)    |      6.33     9.75    11.26    11.80    19.00    20.33        -        -     11.44
```

Table A8. 2016 – Vikingbanken



```
Variable: Abundance
EstLayer: 1
Stratum: Vikingbanken

                   age
LenGrp                       0        1        2        4        5   Number  Biomass    Mean W
                                                                      (1E3)  (1E3kg)       (g)

9-10               |      2380        -        -        -        -     2380      4.8      2.03
10-11              |      3174        -        -        -        -     3174      7.1      2.25
11-12              |      1587        -        -        -        -     1587      4.8      3.00
12-13              |       793        -     4761        -        -     5554     30.9      5.57
13-14              |         -      793        -        -        -      793      5.6      7.00
14-15              |         -        -     2380        -        -     2380     17.5      7.33
15-16              |         -        -     3174        -        -     3174     32.5     10.25
16-17              |         -        -        -     6348     2380     8728    104.7     12.00
17-18              |         -        -        -    16663     7935    24598    334.1     13.58
18-19              |         -        -        -     3967     3174     7141    112.7     15.78
19-20              |         -        -        -     1587        -     1587     27.8     17.50
20-21              |         -        -        -        -     2380     2380     50.8     21.33

TSN(1000)          |      7935      793    10315    28565    15869    63478        -         -
TSB(1000 kg)       |      19.1      5.6     78.6    391.2    238.8        -    733.2         -
Mean length (cm)   |     10.35    13.50    13.65    17.26    17.73        -        -         -
Mean weight (g)    |      2.41     7.00     7.62    13.69    15.05        -        -     11.55
```

WD06 SMS, A STOCHASTIC AGE-LENGTH-STRUCTURED MULTI-SPECIES MODEL APPLIED TO NORTH SEA AND BALTIC SEA STOCKS

Working document to ICES WKMULTBAL, March 2012

By Morten Vinther and Peter Lewy

DTU Aqua.

Overview

SMS (Stochastic Multi Species model) is a fish stock assessment model in which includes estimation of predation mortalities from observation of catches, survey indices and stomach contents. Estimation of predation mortality is based on the same theory for predation mortality as defined by Andersen and Ursin (1977) and Gislason and Helgason (1985). SMS is a "forward running" model that operates with a chosen number of time steps (e.g. quarters of the year). The default SMS is a one-area model, but the model has options for spatial explicit predation mortality given a known stock distribution.

Model parameters are estimated using maximum likelihood (ML) technique. Uncertainties of the model parameters are estimated from the Hessian matrix and confidence limits of derived quantities like fishing mortalities and stock abundances are estimated from the parameter estimates and the delta-method. SMS can be used to estimate model parameters and historical stock sizes *etc.* and for forecast scenarios and Management Strategy Evaluations, where fishing mortalities are estimated dynamically from Harvest Control Rules.

This document describes the model structure and the statistical models used for parameter estimation.

Model Structure

Survival of the stocks

The survival of the stocks is described by the standard exponential decay equation of stock numbers (N).

$$\boldsymbol{N_{s,a,y,q+1} = N_{s,a,y,q}\, e^{-Z_{s,a,y,q}}}$$

or

$$\boldsymbol{N_{s,a+1,y,+1,q=1} = N_{s,a,y,q=last\ season}\, e^{-Z_{s,a,y,q=last\ season}}}$$

The instantaneous rate of total mortality, $Z_{s,a,y,q}$ by species *s*, age-group *a*, year y and season *q*, is divided into three components; predation mortality (*M2*), fixed residual natural mortality (*M1*) and fishing mortality (*F*):

$$\boldsymbol{Z_{s,a,y,,q} = M1_{s,a,q} + M2_{s,a,y,q} + F_{s,a,y,q}}$$

For non-assessment species which act as predators (e.g. grey seal and horse mackerel) stock numbers are assumed known and must be given as input.

Fishing mortality

Fishing mortality, $F_{s,a,y,q}$ is modelled from an extended separable model including age, year and season effects. However, as these effects may change over time a more flexible structure is assumed allowing for such changes for specified periods. For convenience the species index is left out in the following:

$$\boldsymbol{F_{a,y,,q} = F^1_{Y,A1}\, F^2_y\, F^3_{Y,A2,q}}$$

where indices $A1$ and $A2$ are grouping of ages, (e.g. ages 1-3, 4-7 and 8-9) and Y is grouping of years (e.g. 1975-1989, 1990-2011).

Eq. 3 defines that the years included in the model can be grouped into a number of period clusters (Y), in which the age selection (F^1) and seasonal selection (F^3) are assumed constant. $F^2$is the year effect, specifying the overall level of F for a particular year. The grouping of ages for age selection, $A1$, and season selection, $A2$, can be defined independently.

Options for year effect

Given a good relationship between F and effort the fishing mortality can be calculated from the observed effort.

$$\boldsymbol{F_{a,y,,q} = F^1_{Y,A1}\, EFFORT_y\, F^3_{Y,A2,q}}$$

Natural Mortality

Natural mortality is divided into two components, predation mortality (*M2*) caused by the predators included in the model and a residual natural mortality (*M1*), which is assumed to be known and is given as input.

M2 of a prey species with size group l_{prey} due to a predator species with size group $l_{pred}$is M2 is calculated as suggested by Andersen and Ursin (1977) and Gislason and Helgason (1985).

$$\boldsymbol{M2_{prey,l_{prey},y,q} = \sum_{pred}\sum_{l_{pred}} \frac{\bar{N}_{pred,l_{pred},y,a}\ RA_{pred,l_{pred,y,q}}\ S_{prey,pred,q}(l_{prey}, l_{pred})}{AB_{pred,l_{pred},y,a}}}$$

where RA denotes the food ration (weight) of one individual predator per time unit, where S denotes the food suitability coefficient defined in section 0 and where AB is the total available (suitable) biomass. AB is defined as the sum of the biomass of preys weighted by their suitability. This total prey biomass includes also the so-called "other food" (OF) which includes all prey items not explicitly modelled, e.g. species of invertebrates and non-commercial fish species. Other food species are combined into one group, such that the total available prey biomass becomes:

$$\boldsymbol{AB_{pred,l_{pred},y,q} = \sum_{prey}\sum_{l_{prey}} \left(\bar{N}_{prey,l_{prey},y,q}\ W_{prey,l_{prey},y,q}\ S_{prey,pred,q}(l_{prey}, l_{pred})\right) + OF_{pred,}\ S_{OF,pred,q}(l_{pred})} \quad ;$$

$M2$ cannot directly be calculated from Eq. 4 because $M2$ also is included in the right hand term in Eq. 6 to calculate $\bar{N}$.

$$\boldsymbol{\bar{N} = \frac{N\,(1 - e^{-(M1+M2+F)})}{M1 + M2 + F}} \quad ;$$

As no analytical solution for $M2$ exists, $M2$ has been found numerically. If the time step considered is sufficiently small, for instance a quarter, $M2$ becomes small and can optionally be approximated by replacing the average number during the season, $\bar{N}$, on the right hand side of Eq. 4 by the stock at the beginning of the season, N. As the right hand side of equation now is independent of $M2$ this quantity can be calculated directly from Eq. 4 where AB (Eq. 5) is modified correspondingly.

Use of size distribution by age

The equations outlined in the section above provides M2 at size groups, however, predation mortality by age is needed as well because F and catches are age-structured. If just one size group per age group of predators and preys is assumed Eq. 4 can be used directly where the age index substitute the size group index in stock numbers ($\bar{N}_{prey,a,y,q} = \bar{N}_{prey,l_{prey},y,q}$)

Given more size groups per age, the calculation of M2 at age requires age-length-keys to split N at age to N at size group.

$$\boldsymbol{N_{s,l_s,y,q} = \sum_{a} N_{s,a,y,q}\ ALK_{s,a,l_s,y,q}} \quad ,$$

where $ALK_{s,l_s,a,y,q}$ denotes the observed proportion of size group l_s for a given species and age group, i.e. $\sum_{l_s} ALK_{s,l_s,a,y,q} = 1$

Assuming that *F* and *M1* depends only of the age and that *M2* only depends of the length, *M2* at age is estimated by: (leaving out the species, year and quarter indices)

$$\begin{aligned} M2_a &= Z_a \frac{\sum_l \bar{N}_{a,l}\, M2_{a,l}}{D_a} \\ &= \log\left(\frac{N_a}{N_a - D_a}\right) \frac{\sum_l \bar{N}_{a,l}\; M2_l}{D_a} \end{aligned}$$

where

$$\begin{aligned} \bar{N}_{a,l} &= N_{a,l} \frac{1 - e^{-(F_{a,l} + M1_{a,l} + M2_{a,l})}}{F_{a,l} + M1_{a,l} + M2_{a,l}} \\ &= N_{a,l} \frac{1 - e^{-(F_a + M1_a + M2_l)}}{F_a + M1_a + M2_l} \end{aligned}$$

and where

$$D_a = \sum_l \bar{N}_{a,l}\, (F_a + M1_a + M2_l)$$

denotes the number of individuals at age died within a season.

Food suitability

As suggested by Andersen and Ursin (1977) and Gislason and Helgason (1985) the size dependent food suitability of prey entity i for predator entity j is defined as the product of a species dependent vulnerability coefficient, $\rho_{i,j}$, a size preference coefficient $\varrho_{i,j}(l_i, l_j)$., and an overlap index $o_{i,j,q}$. Suitability is then defined as:

$$\begin{aligned} & S_{pred,prey,q}(l_{pred}, l_{prey}) \\ &\qquad = \rho_{pred,prey}\;\; \varrho_{pred,prey}(l_{pred}, l_{prey})\;\; o_{pred,prey,q} \end{aligned}$$

For the “other food” part suitability is defined as

$$\begin{aligned} & S_{OF,pred,q}(l_{pred}) \\ &= \rho_{OF,pred}\;\; o_{OF,pred,q} \exp\left(\upsilon_{pred} \log\left(W_{pred,l_{pred},q} / \bar{W}_{pred}\right)\right) \end{aligned}$$

Where $\bar{W}_{pred}$ is the average size of the predator species. The overlap index may change between seasons, but is assumed independent of year and sizes.

log-normal distributed size selection

Several functions can be used for size preference. Andersen and Ursin (1977) assumed that a predator has a preferred prey size ratio and that a prey twice as big as the preferred size is as attractive as another half the prey size. This was formulated as a log-normal distribution:

$$\boldsymbol{\varrho_{pred,prey}\left(l_{pred}, l_{prey}\right) = \exp\left(-\frac{\left(\log\left(\frac{W_{l_{pred}}}{W_{l_{prey}}}\right) - \eta_{PREF\,pred}\right)^2}{2\,\sigma^2_{PREF\,pred}}\right); 0 < \varrho \leq} \qquad 0$$

Where η_{PREF} is the natural logarithm of the preferred size ratio, $\sigma^2_{PREF}$is the "variance" of relative preferred size ration, expressing how selective a predator is with respect to the size of a prey and where $W_{l_s}$is the mean weight for a species size group.

The basic size selection equation (Eq. 10) has been extended by modifying the preferred size ratio parameter to take into account a prey specific and predator size specific preference,.

$$\boldsymbol{\varrho_{pred,prey}\left(l_{pred}, l_{prey}\right) = \exp\left(-\frac{\left(\log\left(\frac{W_{l_{pred}}}{W_{l_{prey}}}\right) - \left(\eta_{PREF\,pred}\ \xi_{prey} + \varpi_{pred}\ \log\left(W_{l_{pred}}\right)\right)\right)^2}{2\,\sigma^2_{PREF\,pred}}\right)} \qquad 1$$

Uniform size selection

Alternatively, a uniform size preference can be assumed within the range of the observed size ratio and zero size selection outside that ratio:

$$\boldsymbol{\varrho_{pred,prey}\left(l_{prep}, l_{prey}\right) = \begin{Bmatrix} 1 & \text{for } \eta_{MIN_{pred,prey}} \leq \dfrac{W_{l_{pred}}}{W_{l_{prey}}} \leq \eta_{MIN_{pred,prey}} \\ 0 & \text{for values outside observed range} \end{Bmatrix}} \qquad 2$$

where η_{MIN} and η_{MAX} are the observed minimum and maximum predator/prey size ratios.

Constraint uniform size selection

The uniform size preference does not take into account that the preferred predator/prey size ratio might change by size, such that larger individuals select relatively smaller preys (Floeter and Temming, 2005; Sharft et al., 2000). A way to account for that is to assume that the fixed minimum and maximum constants, η_{MIN} and η_{MAX}, depend on the predator size:

$$\varrho_{pred,prey}(l_{pred}, l_{prey}) = \begin{cases} 1 \text{ for } U1_{pred,prey} + U2_{pred,prey} \log(W_{l_{pred}}) \leq \log\left(\frac{W_{l_{pred}}}{W_{l_{prey}}}\right) \leq U3_{pred,prey} + U4_{pred,} \\ 0 \quad \text{for values outside regression range} \end{cases} \quad 3$$

The regression parameters are estimated externally by quantile regression (e.g. Koenker and Bassett 1978) using e.g. the 2.5% and 97.5% percentiles of stomach content data. Figure 1 shows an example of such regression.

Adjustment of age-size keys and estimation of food ration

For the North Sea configuration, age length keys were obtained from the IBTS surveys where the same gear (i.e. the GOV trawl) has been used in the period considered. This allows an adjustment of the observed ALK's to account for mesh size selection. Using a logistic length dependent selection function, selection is defined as:

$$SL_s(l) = 1/\left(1 + (e^{(S1_s - S2_s * l)}\right)$$

Where $S1_s$ and $S2_s$ are species specific gear selection parameters.

The adjusted ALK can then be derived from the observed ALK by:

$$ALK_{s,l_s,a,y,a} = \text{ObservedALK}_{s,l_s,a,y,q} \; / \; SL_{s,l_s}$$

which finally has to be standardised to 1 for each age before used in EQ. 7.

Growth

Not implemented yet!

Food ration

Food ration, pr. time step given as input or estimated from mean weight by size group assuming an exponential relationship between ration and body weight W

$$RA_{pred,l_{pred},q} = \gamma_{pred,q} \; W_{pred,l_{pred}}^{\varsigma_{pred}} \quad 4$$

where the coefficient γ and ς are assumed to be known.

Body weight at size group l_{pred} is estimated from mean length within the size group and a length weight relation.

Area based SMS

SMS has three area explicit options:

1. Default one area model. Both F and M2 are calculated for the entire stock area
2. M2 by area. M2 is calculated by sub-areas, but F is assumed global
3. M2 and F by area. Both M2 and F are calculated by area (forecast only)

Stock distribution

For the area based models the stock is assumed redistributed between areas between each season time step.

$$\boldsymbol{N^{area}_{s,a,y,q} = N_{s,a,y,q} \ \ DIST_{s,a,y,q,area}}$$

Where DIST is a stock distribution key that sums up to 1

$$\boldsymbol{\sum_{area} DIST_{s,a,y,q,area} = 1}$$

The calculation of M2 for Option 1) is provided above.

The method for option 3) is very similar, but the calculations must be done by each sub-area separately.

$$\boldsymbol{Z^{area}_{a} = F^{area}_{a} + M1^{area}_{a} + M2^{area}_{a}}$$

Option 2) is the hybrid, where F is global but M is calculated by area.

$$\boldsymbol{Z^{area}_{a} = F_{a} + M1^{area}_{a} + M2^{area}_{a}}$$

$\bar{N}$ in an area is calculate in the usual way

$$\bar{N}_a^{area} = N_a^{area} \frac{1 - e^{-Z_a^{area}}}{Z_a^{area}}$$

The total number of individuals died due to predation mortality (DM2) then becomes

$$DM2_a = \sum_{area} M2_a^{area} \bar{N}_a^{area} \qquad 5$$

M2 for the whole stock can be estimated from

$$M2_a = \log\left(\frac{N_a}{N_a - D_a}\right) \frac{DM2_a}{D_a}$$

where

$$D_a = \sum_{area} DF_a^{area} + DM1_a^{area} + DM2_a^{area}$$

and DF and DM1 are the number died due to fishery and residual mortality (M1) and are calculated in similar way as specified for DM2 (Eq. 15).

Area based suitability parameters

For the "one area" SMS suitability is defined by Eq. 8.

The area based version of suitability uses an area specific vulnerability and overlap index, while the size preference (ϱ) is assumed independent of area.

$$S_{pred,prey,q}^{area} \left(l_{pred}, l_{prey}\right) = \rho_{pred,prey}^{area} \ \varrho_{pred,prey}\left(l_{pred}, l_{prey}\right) \ o_{pred,prey,q}^{area}$$

Statistical models

Three types of observations are considered: Total international catch at age; survey abundance indices and stomach content observations. 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. The probability model for these observations is modelled along the lines described by Lewy and Nielsen (2003):

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, *LCATCH*, associated with the catches is

$$L_{CATCH} = \prod_{s,a,y,q} \frac{1}{\sigma_{CATCH\;s,a,q}\sqrt{2\pi}}\; exp\left(-\frac{\left(\log(C_{s,a,y,q}) - E(\log(C_{s,a,y,q}))\right)^2}{2\,\sigma^2_{CATCH\;s,a,q}}\right) \tag{6}$$

Where

$$E(\log(C_{s,a,y,q})) = \log(F_{s,a,y,q}\,\bar{N}_{s,a,y,q})$$

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

$$\begin{aligned} l_{CATCH} &= -\log(L_{CATCH}) \\ &\propto \text{NOY} \sum_{s,a,q} \log(\sigma_{CATCH\;s,a,q}) \\ &\quad + \sum_{s,a,y,q} \left(\log(C_{s,a,y,q}) - E(\log(C_{s,a,y,q}))\right)^2 / 2\sigma^2_{CATCH\;s,a,q} \end{aligned} \tag{7}$$

Where $NOY$is the number of years in the time series.

Annual catches

Catch at age numbers by quarter have not been available for some of the demersal North Sea stocks in recent years. For use in the default SMS configuration of the North Sea, where quarterly time step is used, it is assumed that the seasonal distribution (the F^3 parameter in Eq. 3) is known and given as input. The likelihood function is modified to make use of the observed annual catches.

$$E(\log(C_{s,a,y})) = \log\left(\sum_{q} F_{s,a,y,q}\;\; \bar{N}_{s,a,y,q}\right)$$

$$L_{CATCH} = \prod_{s,a,y} \frac{1}{\sigma_{CATCH\ s,a}\sqrt{2\pi}}\ exp\left(-\frac{\left(\log(C_{s,a,y}) - E(\log(C_{s,a,y}))\right)^2}{2\ \sigma^2_{CATCH\ s,a}}\right) \qquad 8$$

Survey indices

Similarly to the catch observations, survey indices, $CPUE_{survey,s,a,y,q}$ are assumed to be log-normally distributed with mean

$$E(\log(CPUE_{survey,s,a,y,q})) \ = \ \log(Q_{survey,a}\ \bar{N}_{SURVEY\ s,a,y,q}) \qquad 9$$

where Q denotes catchability by survey and $\bar{N}_{SURVEY}$ is mean stock number during the survey period. Catchability may depend on a single age or groups of ages. Similarly, the variance of log $CPUE$, , σ^2_{SURVEY} may be estimated individually by age or by clusters of age groups. The negative log likelihood is on the same form as Eq. 16.

$$\begin{aligned} l_{SURVEY} &= -\log(L_{SURVEY}) \\ &\propto NOY_{survey,s} \sum_{survey,s,a} \log(\sigma_{SURVEY\ survey,s,a}) \\ &+ \sum_{survey,s,a,y} \left(\log(CPUE_{survey,s,a,y}) - E(\log(CPUE_{survey,s,a,y}))\right)^2 / 2\sigma^2_{SURVEY\ s,a} \end{aligned} \qquad 0$$

Stomach contents

The stomach contents observations, which are the basis for modelling predator food preference, consist of the average proportions by weight of the stomach content averaged over the stomach samples in the North Sea. The model observations $STOM_{pred,l_{pred},prey,l_{prey},y,q}$ are given for combinations of prey and predator species and size classes. In the following text we use entity i for a combination of predator species and predator size class (e.g. saithe 50-60 cm) and entity j for the combination of prey species and prey size class eaten by entity i. Model observations therefore becomes $STOM_{i,j,y,q}$

$STOM$ are assumed stochastic variables subject to sampling and process variations. For a given predator entity the observations across prey entities i are continuous variables which sum to one. Thus, the probability distribution of the stomach observations for a given predator including all prey/length groups needs to be a multivariate distribution defined on the simplex. As far as the authors know the Dirichlet distribution is the only distribution fulfilling this requirement. Leaving out the year and season index, the Dirichlet density function for a predator entity i with k observed diet proportions $STOM_{i,1}, \ldots STOM_{i,k-1} > 0$ and the parameters $p_1, \ldots, p_k > 0$ has the probability density given by

$$\boldsymbol{f_i = f\left(STOM_{i,1}, \ldots, STOM_{i,k-1} \mid p_{i,1}, \ldots, p_{i,k}\right) = \frac{\Gamma(p_i)}{\prod_{j=1}^{k} \Gamma(p_{i,j})} \prod_{j=1}^{k} STOM_{i,j}^{p_{i,j}-1}} \qquad 1$$

Where

$$p_i = \sum_{j=1}^{k} p_{i,j}$$

The mean and variance of the observations in the Dirichlet distribution are:

$$E(STOM_{i,j}) = \frac{p_{i,j}}{p_i}$$

$$\boldsymbol{Var(STOM_{i,j}) = \frac{E(STOM_{i,j})\left(1 - E(STOM_{i,j})\right)}{p_i + 1}} \qquad 2$$

The expected value of the stomach contents observations is modelled using the theory developed by Andersen and Ursin (1977):

$$\boldsymbol{E(STOM_{i,j}) = \frac{\bar{N}_j\ W_j\ S_{i,j}(l_i, l_j)}{\sum_j \left(\bar{N}_j\ W_j\ S_{i,j}(l_i, l_j)\right) + OF_i\, S_{OF,i}(l_i)} = \frac{p_{i,j}}{p_i}} \qquad 3$$

where the food suitability function, *S*, is defined by Eq. 8 and Eq. 9. We make the same assumption as made for the calculation of M2 (EQ. 4) that the small time steps used in the model, allows a replacement of $\bar{N}_j$ by N_j in Eq. 23.

Regarding the variance of stomach contents observations unpublished analyses of the present authors of data from the North Sea stomach sampling project 1991 (ICES, 1997) indicate that the relationship between the variance and the mean of the stomach contents may be formulated in the following way:

$$\boldsymbol{Var(STOM_{i,j,y,q}) = \frac{E(STOM_{i,j,y,q})\left(1 - E(STOM_{i,j,y,q})\right)}{V_{pred}\ U_{i,y,q}}} \qquad 4$$

where $U_{i,y,q}$ is a known quantity reflecting the sampling level of a predator entity, e.g. the number of hauls containing with stomach samples of a given predator/size. V_{pred} is a predator species dependent parameter linking the sampling level and variance. Equating Eq. 22 and Eq. 24 implies that

$$\boldsymbol{P_{i,y,q} = V_{pred}\, U_{i,y,q} - 1} \qquad 5$$

Insertion of Eq. 25 into Eq. 23 results in that

$$P_{i,j,y,q} = \left(V_{pred}\ U_{i,y,q} - 1\right) \frac{\bar{N}_j\ W_j\ \ S_{i,j}\left(l_i, l_j\right)}{\sum_j \left(\bar{N}_j\ \ W_j\ S_{i,j}\left(l_i, l_j\right)\right)\ +\ OF_i\, S_{OF,i}(l_i)}$$

The parameters, $p_{i,j,y,q}$ are uniquely determined through stock numbers, total mortality, suitability parameters and V_{pred}.

Assuming that the diet observations for the predator/length groups are independent the negative log likelihood function including all predators/length groups are derived from Eq. 21:

$$\boldsymbol{l_{STOM} = -\log(L_{STOM}) = -\sum_{i,j,y,q} \log\left(f_{i,j,y,q}\right)} \qquad \textbf{6}$$

Stomach contents by species

The stomach contents observations, $STOM_{prey,l_{prey},pred,l_{pred},y,q}$ are given for combinations of prey and predator species and size classes. For a diet consisting of a large proportion "other food" and several species and prey size classes, the proportion of the individual combination of species and size becomes small (less than 0.1%) for some prey entities. Very small proportions, in combination with a modest sampling size per stratum, make the estimation of parameters impossible in some cases. To overcome the problem SMS has an option to let the likelihood use proportion summed over all size classes for a given prey species such that the prey entity equals the species.

$$STOM_{i,j,y,q} = \sum_{prey} \left(STOM_{prey,j,y,q} \mid i \in prey\right)$$

The same grouping of all sizes from a prey is applied when the uniform size selection option (Eq. 12 and Eq. 13) is used, as The likelihood function is the same as used for stomach observations which include prey size.

Stock-recruitment

In order to enable estimation of recruitment in the last year for cases where survey indices catch from the recruitment age is missing (e.g. saithe), and to estimate parameters for forecast use, a stock-recruitment relationship $R_{s,y} = R\left(SSB_{s,y} \mid \alpha_s, \beta_s\right)$ penalty function is included in the likelihood function.

Recruitment to the model takes place in the same season ($recq$) and at the same age (fa) for all species. It is estimated from the Spawning Stock Biomass (SSB) in the first season (fq) of the year, and a stock recruitment relation. SSB is calculated from stock numbers, proportion mature (PM) and mean weight in the sea.

$$SSB_{s,y} = \sum_{a} N_{s,y,a,q=recq}\ PM_{s,y,a,q=recq}\ W_{s,y,a,q=recq} \qquad 7$$

At present the Ricker (Eq. 28), the Beverton & Holt (Eq. 29), segmented regression (Eq. 30) and geometric mean are implemented.

$$R_{s,y} = \alpha_s\ SSB_{s,y-fa,fq}\ e^{(\beta_s\ SSB_{s,y-fa,fq})} \qquad 8$$

$$R_{s,y} = \frac{\alpha_s\ SSB_{s,y-fa,fq}}{1 + \beta_s\ SSB_{s,y-fa,q}} \qquad 9$$

$$= \begin{cases} \alpha_s\ SSB_{s,y-fa,fq} & \text{for } SSB_{s,y-fa,fq} < \beta_s \\ \alpha_s\ \beta_s & \text{for } SSB_{s,y-fa,fq} < \beta_s \end{cases} \qquad 0$$

Assuming that recruitment is lognormal distributed, the negative log likelihood, l_{SR}, equals

$$l_{SR} = -\log(L_{SR}) \propto NOY \sum_{s} \log(\sigma_{SR\ a}) + \sum_{s,a,y} \left(\log(N_{ss,a=fa,y,q=recq}) - E(\log(R_{s,y}))\right)^2 / 2\sigma^2_{SR\ s} \qquad 1$$

Where Eq. 32 gives the expected recruitment for the Ricker case.

$$E(\log(R_s)) = \log\left(\alpha_s\ SSB_{s,y-fa,fq}\ e^{(\beta_s\ SSB_{s,y-fa,fq})}\right) \qquad 2$$

Total likelihood function and parameterisation

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

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

To ensure uniquely determined parameters it is necessary to fix part of them. For the F at age model (EQ. 3) the year selection in the beginning of each year range (Y) has been fixed to one $F^2_{y=\text{first year in each group of years}} = 1$. The season effect in the last season of all years and ages is also fixed ($F^3_{y,a,q=last\ season} = 1/\text{number of seasons}$).

Eq. 4 and Eq. 8 indicate that it is only possible to determine relative vulnerability parameters, $\rho_{pred,prey}$. We have chosen to fix the vulnerability of other food for all predators to 1.0. Similarly the biomass of other food OF_{pred} has arbitrarily been set (e.g. at 1 million tonnes) for each predators. The actual value by predator was chosen to obtain estimates of vulnerability parameters for the fish prey at around 1. Other parameters than suitability are practically unaffected of the actual choice of other food.

In the food suitability function (Eq. 8 and Eq. 9) vulnerability and overlap effects cannot be distinguished. Hence the overlap parameters were must be fixed for at least one season. In practice, several combinations of overlap have however to be fixed (at e.g. 1).

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 determined by EQ. 1 and EQ. 2.

The year effect ($F^2_{y,s}$) in the separable model for fishery mortality (EQ. 3) takes one parameter per species for each year in the time series which sum up to a considerable number of parameters. To reduce this high number of parameters, the year effect can optionally be model from a cubic spline function which requires fewer parameters. The number of knots must be specified if this option is used.

Another way to reduce the number of parameters is to substitute the parameters $\sigma_{CATCH}, \sigma_{SURVEY}$ and σ_{SR} used in the likelihood functions by their empirical estimates. This optional substitution has practically no effect on the model output and the associated uncertainty.

Appendix 1 gives an overview of parameters and variables in the model.

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. Uncertainties of functions of the estimated parameters (such as biomass and mean fishing mortality) are calculated using the delta method.

SMS forecast

SMS as specified in section 264 is a forward running model and can as such easily be used for forecast scenarios and Management Strategy Evaluation (MSE). SMS used the estimated parameters to calculate the initial stock numbers and exploitation pattern used in the forecast. Exploitation pattern are assumed constant in the forecast period, but is scaled to a specified average F, derived dynamically from Harvest Control Rules (HCR). Recruits are produced from the stock/recruitment relation, input parameters and a noise term.

Recruitment

Recruitment is estimated from the available stock recruitment relationships, f(SSB), (se section 0) and optionally a log normal distributed noise term with standard deviation std.

$$\boldsymbol{R = f(SSB)\ e^{(std\ NORM(0,1))}} \quad 3$$

Where NORM(0,1) is a random number drawn from a normal distribution with mean=0 and standard deviation 1. A default value for std can be obtained from the estimated variance of stock recruitment relationship, $\sigma^2_{SR_s}$ (Eq. 31)

Application of the noise function for the lognormal distributed recruitment gives on average a median recruitment as specified by f(SSB). Optionally, recruitment can be adjusted with half of the variance, to obtain, on average, a mean recruitment given by f(SSB).

$$\boldsymbol{R = f(SSB)\ e^{(std\ NORM(0,1))}\ e^{\left(-(std^2/2)\right)}} \qquad 4$$

Harvest Control Rules

Several HCR have been implemented, e.g. constant F and the ICES interpretation of management according to MSY for both short and long-lived species. Selected, more complex management plans in force for the North Sea and Baltic Sea species have also been implemented.

Model validation

Model validation (in the years 2004-2009) was focused on the performance of the model using simulated data from an independent model and simulated data produced by the SMS model itself. The independent model was implemented using the R-package (R Development Core Team. 2011) and include a medium complex North Sea configuration (9 species, of which 4 are predators and 8 species preys). The simulation model follows the SMS model specification with an addition of von Bertalanffy growth curves to model mean length at age. Variance around mean length at age was assumed to increase by increasing age. This combined age-length approach made it possible to simulate all the data needed for model verification. Test data set from the simulation model included 20 years of catch data, one survey times series per species covering all years and ages, and 4 quarterly stomach samples in year 10 including stomach observations for all predator length groups. Data from the independent simulation model was used to verify that the SMS model actually works as intended and to investigate model sensitivity with respect to observation errors on catch, survey CPUE and stomach data.

To test if model parameters were identifiable when "real" data were applied, the SMS model was modified to produce observations with the estimated observation noise of catch, survey and stomach data. The experiment consists of the following steps:

1. Estimate model parameters using the SMS model and available North Sea data.
2. Generate 100 set of input data from SMS output (expected catch numbers, survey indices and stomach observations) and their associated variance of these values) .
3. Let SMS estimate 100 sets of parameters from the 100 sets of input data.

This procedure results in one set of "true parameters", $\theta = (\theta_1, \dots, \theta_k)$ and 100 sets of estimated parameters, $\hat{\theta}_j = \left(\hat{\theta}_{1,j}, \dots, \hat{\theta}_{k,j}\right)$, $j = 1, \dots$,. Whether he estimated parameters are unbiased estimates of θ was examined by comparing θ and $\bar{\hat{\theta}}$ and: Based on the 100 repetitions and for each of the k parameters the mean and the standard deviation of the mean $\bar{\hat{\theta}}_i$ and s_i and hence the 95% confidence limits, was calculated. Finally the proportion of the parameters was calculated for which θ_i lies in the 95% confidence interval of $\bar{\hat{\theta}}_i$.

The test showed that parameters are identifiable for most "real" North Sea configurations. For some species with relatively few diet observations, size selection parameters

(Eq. 11) and the variance parameter (V) linking the stomach sampling level to the variance of Dirichlet distribution (Eq. 24 and Eq. 25) , were outside the 95% confidence interval of $\bar{\bar{\theta}}_i$. (MORE TEXT to be added)

A more informal testing of the model has been done by simply using the model. SMS has been applied to produce the so-called key-run for both the species rich North Sea (10 species with stock number estimation including 7 prey species, and 16 species of "other predators") system (ICES WGSAM 2011) and the species poor Baltic Sea (cod, herring and sprat, one predator and three prey species) (WGSAM, 2008, WKMAMPEL 2009). In addition the model has been used in single species mode for the ICES advice of blue whiting in the North East Atlantic (WGWIDE, 2011) since 2005 and several sandeel stocks in the North Sea since 2009 (WGNSSK, 2011). For MSE purposes the model has been applied for sandeel and Norway pout in the North Sea( ), blue whiting () and pelagic stocks in the Baltic (WKMAMPEL 2009) in both single and multi species mode.

Implementation

The SMS-OP has been implemented using the AD Model Builder (Fournier et al., 2011), which is 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.

SMS configurations may contain more than 1000 parameters of which less than 5% are related to predation mortality. It is not possible to estimate all parameters simultaneously without sensible initial parameter values. Such values are obtained in three phases:

1. Estimate "single species" stock numbers, fishing mortality and survey catchability parameters assuming that natural mortality (M1+M2) are fixed and known (i.e. as used by the ICES single species assessments).
2. Fix all the "single species" parameters estimated in step 1 and use the fixed stock numbers to estimate initial parameter values for the predation parameters.
3. Use the parameter values from step 1 and 2 as initial parameter values and re-estimate all parameters simultaneously in the full model including estimation of predation mortality M2.

Optimisation might potentially be dependent on the initial parameter values, however the same final result was obtained using the three steps above or using a configuration where step two is omitted. Using step two however in general makes the estimation process more robust as extreme values and system crash are avoided.

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Appendix 1. Notation.

Indices

a	age
$area$	area with specific predation mortality
A_1, A_2	group of ages
Fa	first age group in the model
i	prey entity, combination of prey species and prey size group
j	predator entity, combination of predator group and predator size group
l	species size class
l_{pred}	predator size class
l_{prey}	prey size class
$other$	other food “species”
$pred$	predator species
$prey$	prey species
q	season of the year, e.g. quarter
recq	recruitment season
s	species
$survey$	survey identifer
y	year
Y	group of years

Parameters and variables

AB	available (suitable) prey biomass for a predator
ALK	proportion at size for a given age group. Input
C	catch in numbers. Observations
$CPUE$	catch in numbers per unit of effort. Observations
D	number died
DM1	number died due to M1
DM2	number died due to M2
DF	number died due to F
F	instantaneous rate of fishing mortality.
F^1	age effect in separable model for fishing mortality. Estimated parameter
F^2	year effect in separable model for fishing mortality. Estimated parameter
F^3	season effect in separable model for fishing mortality. Estimated parameter
$M1$	instantaneous rate of residual natural mortality. Input
$M2$	instantaneous rate of predation mortality estimated in the model
N	stock number
$N_{s,a,y=first\ year,q=1}$.	Stock number in the first year of the model. Estimated parameters.
$N_{s,a=fa,q=recq}$.	Stock numbers at youngest age (recruitment). Estimated parameter.
OF	Biomass of other food for a predator. Input
Q	catchability, proportion of the population caught by one effort unit. Estimated
$R_{s,y}$	recruitment calculated from stock recruitment model
RA	food ration, biomass consumed by a predator. Input
S	suitability of a prey entity as food for a predator entity
$S1, S2$	mesh selection parameters. Estimated
SSB	spawning stock biomass
$STOM$	weight proportion of prey i found in the stomach of predator j. Observations
U	sampling intensity of stomachs. Observation

V	variance of diet observations in relation to sampling intensity. Estimated Parameter
W	body weight. Input
Z	instantaneous rate of total mortality
α	stock recruitment parameter. Estimated
β	stock recruitment parameter. Estimated
ϱ	prey size preference of a predator. Estimated parameter
γ	food ration coefficients. Input
ς	food ration exponent. Input
υ	parameter for size dependent preference for other food. Estimated parameter
η_{PREF}	natural logarithm of the preferred predator prey size ratio. Estimated parameter
η_{MIN}	observed minimum relative prey size for a predator species. Input
η_{MAX}	observed maximum relative prey size for a predator species. Input
o	spatial overlap between predator and prey species. Estimated parameter
ϱ	coefficient of species vulnerability. Estimated parameter
σ_{CATCH}	standard deviation of catch observations. Estimated parameter
σ_{PREF}	parameter expressing how particular a predator is about the size of its prey. Parameter
σ_{SR}	standard deviation of stock recruitment estimate. Estimated parameter
σ_{STOM}	standard deviation of stomach content observations (used with log normal distribution)
σ_{SURVEY}	standard deviation of survey cpue observations. Estimated parameter

Appendix 1. Option file for SMS.

This appendix shows an option file for Baltic Sea SMS.

```
# SMS.dat option file
# the character "#" is used as comment character, such that all text
and numbers
#  after # are skipped by the SMS program
#
########################################
# Produce test output (option test.output)
#  0 no test output
#  1 output file SMS.dat and  file fleet.info.dat as read in
#  2 output all single species input files as read in
#  3 output all multi species input files as read in
#  4 output option overview
#
# 11 output between phases output
# 12 output iteration (obj function) output
# 13 output stomach parameters
# 19 Both 11, 12 and 13
#
0
########################################
# Produce output for SMS-OP program. 0=no, 1=yes
1
########################################
# Single/Multispecies mode (option VPA.mode)
# 0=single species mode
# 1=multi species mode, but Z=F+M (used for initial predation parm.
estimation)
# 2=multi species mode, Z=F+M1+M2
0
########################################
# Number of areas for multispecies run (default=1)
1
#&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&
&
# single species parameters
#&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&
&
#
## first year of input data (option first.year)
1974
########################################
## last year of input data (option last.year)
2010
########################################
## last year used in the model (option last.year.model)
2010
########################################
##  number of seasons (option last.season). Use 1 for annual data
4
########################################
## last season last year (option last.season.last.year). Use 1 for an-
nual data
4
########################################
## number of species (option no.species)
3
########################################
# Species names, for information only. See file species_names.in
#  Cod Herring Sprat
########################################
## first age all species (option first.age)
0
########################################
## recruitment season (option rec.season). Use 1 for annual data
```

```
3
########################################
## maximum age for any species(max.age.all)
8
########################################
## various information by species
# 1. last age
# 2. first age where catch data are used (else F=0 assumed)
# 3. last age with age dependent fishing selection
# 4. Esimate F year effect from effort data. 0=no, 1=yes
# 5. Last age included in the catch at age likelihood (normally last
age)
# 6. plus group, 0=no plus group, 1=plus group
# 7. predator species, 0=no, 1=VPA predator, 2=Other predator
# 8. prey species, 0=no, 1=yes
# 9. Stock Recruit relation, 1=Ricker, 2=Beverton & Holt, 3=Geom mean,
#                            4= Hockey stick, 5=hockey stick with
smoother,
#                           >100= hockey stick with known breakpoint
(given as input)
##
8 2 5 0 8 1 1 1 95000  # 1 Cod
8 1 5 0 8 1 0 1 1  # 2 Herring
7 1 4 0 7 0 0 1 1e+06  # 3 Sprat
########################################
## use input recruitment estimate (option use.known.rec)
#   0=estimate all recruitments, 1=yes use input recruitment from file
known_recruitment.in
0
########################################
## adjustment factor to bring the beta parameter close to one (option
beta.cor)
#          Cod     Herring       Sprat
         1e+06       1e+06       1e+06
########################################
## year range for data included to fit the R-SSB relation (option
SSB.R.year.range)
# first (option SSB.R.year.first) and last (option SSB.R.year.last)
year to consider.
# the value -1 indicates the use of the first (and last) available
year in time series
# first year by species
#          Cod     Herring       Sprat
          1989          -1        1990
# last year by species
#          Cod     Herring       Sprat
            -1          -1          -1
########################################
## Objective function weighting by species (option objective.func-
tion.weight)
# first=catch observations,
# second=CPUE observations,
# third=SSB/R relations
# fourth=stomach observations
##
1 1 1 1  # 1 Cod
1 1 1 0  # 2 Herring
1 1 1 0  # 3 Sprat
########################################
## parameter estimation phases for single species parameters
# phase.rec (stock numbers, first age) (default=1)
1
# phase.rec.older (stock numbers, first year and all ages) (default=1)
1
# phase.F.y (year effect in F model) (default=1)
1
# phase.F.y.spline (year effect in F model, implemented as spline
function)
```

```
-1
# phase.F.q (season effect in F model) (default=1)
1
# phase.F.a (age effect in F model) (default=1)
1
# phase.catchability (survey catchability) (default=1)
1
# phase.SSB.R.alfa (alfa parameter in SSB-recruitment relation) (de-
fault=1)
1
# phase.SSB.R.beta (beta parameter in SSB-recruitment relation) (de-
fault=1)
1
########################################
## minimum CV of catch observation used in ML-estimation (option
min.catch.CV)
0.1
########################################
## minimum CV of catch SSB-recruitment relation used in ML-estimation
0.1
########################################
## Use proportion landed information in calculation of yield (option
calc.discard)
#    0=all catches are included in yield
#    1=yield is calculated from proportion landed (file propor-
tion_landed.in)
#          Cod     Herring       Sprat
             1           0           0
########################################
## use seasonal or annual catches in the objective function (option
combined.catches)
# do not change this options from default=0, without looking in the
manual
#    0=annual C with annual time steps or seasonal C with seasonal
time steps
#    1=annual C with seasonal time steps, read seasonal relative F
from file F_q_ini.in (default=0)
0
########################################
## use seasonal or common combined variances for catch observation
(option seasonal.combined.catch.s2)
# seasonal=0, common=1 (use 1 for annual data)
#          Cod     Herring       Sprat
             0           0           0
#####################################C
# catch observations: number of separate catch variance groups by spe-
cies
#         Cod     Herring       Sprat
           3           3           4
#  first age group in each catch variance group
2 3 7  #  Cod
1 2 3  #  Herring
1 2 3 4      #  Sprat
########################################
##
# catch observations: number of separate catch seasonal component
groups by species
#         Cod     Herring       Sprat
           2           3           2
#  first ages in each seasonal component group by species
2 3    #  Cod
1 2 3  #  Herring
1 2    #  Sprat
########################################
## first and last age in calculation of average F by species (option
avg.F.ages)
4 7  # Cod
3 6  # Herring
```

```
3 5  # Sprat
########################################
# catch observations: number of year groups with the same age and sea-
sonal selection
#         Cod     Herring       Sprat
           3           3           3
#  first year in each group
1975 1996 2005      #  Cod
1975 1990 2000      #  Herring
1975 1983 1996      #  Sprat
########################################
##
# number of nodes for year effect Fishing mortality spline
# 1=no spline (use one Fy for each year), >1 number of nodes
#         Cod     Herring       Sprat
           1           1           1
#  first year in each group
1976   #  Cod
1976   #  Herring
1976   #  Sprat
########################################
## year season combinations with zero catch (F=0) (option
zero.catch.year.season)
# 0=no, all year-seasons have catchs, 1=yes there are year-season com-
binations with
# no catch. Read from file zero_catch_seasons_ages.in
0
########################################
## season age combinations with zero catch (F=0) (option
zero.catch.season.ages)
# 0=no, all seasons have catchs, 1=yes there are seasons with no
catch. Read from
# file zero_catch_season_ages.in
0
########################################
## Factor for fixing last season effect in F-model (default=1)
(fix.F.factor))
#          Cod     Herring       Sprat
             1           1           1
########################################
## Uncertanties for catch, CPUE and SSB-R observations (option
calc.est.sigma)
#  values: 0=estimate sigma as a parameter (the right way of doing it)
#          1=Calculate sigma and truncate if lower limit is reached
#          2=Calculate sigma and use a penalty function to avoid lower
limit
#  catch-observation, CPUE-obs, Stock/recruit
           2            2            2
########################################
# Read HCR_option file (option=read.HCR) default=0
#  0=no  1=yes
1
########################################
#
#&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&
&
#
# multispecies parameters
#
#&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&
&
#
# Exclude year,season and predator combinations where stomach data are
not
# included (option incl.stom.all)
#   0=no, all stomach data are used in likelihood
#   1=yes there are combinations for which data are not included in
the likelihood.
```

```
#     Read from file: incl_stom.in
1
########################################
##  N in the beginning of the period or N bar for calculation of M2
(option use.Nbar)
#  0=use N in the beginning of the time step (default)
#  1=use N bar
0
########################################
## Maximum M2 iterations (option M2.iterations) in case of use.Nbar=1
5
########################################
## convergence criteria (option max.M2.sum2) in case of use.Nbar=1
#  use max.M2.sum2=0.0 and M2.iterations=7 (or another high number) to
make Hessian
0
########################################
## stomach contents variance model (option stomach.variance)
#  1=log normal distribution
#  2=normal distribution
#  3=Dirichlet distribution
3
########################################
## Usage of age-length-keys for calc of M2 (option simple.ALK))
#  0=Use only one sizegroup per age (file lsea.in or west.in)
#  1=Use size distribution per age (file ALK_all.in)
0
########################################
## Usage of food-rations from input values or from size and regression
parameters (option consum)
#  0=Use input values by age (file consum.in)
#  1=use weight at age (file west.in) and regression parameters (file
consum_ab.in)
#  2=use length at age (file lsea.in), l-w relation and regression pa-
rameters (file consum_ab.in)
#  3=use mean length at size class (file ALK_all.in), l-w relation and
regression parameters (file consum_ab.in)
0
########################################
## Size selection model based on (option size.select.model)
#  1=length:
#      M2 calculation:
#         Size preference:
#           Predator length at age from file: lsea.in
#           Prey     length at age from file: lsea.in
#         Prey mean weight is weight in the sea from file: west.in
#      Likelihood:
#         Size preference:
#           Predator mean length per length group (file:
stom_pred_length_at_sizecl.in)
#           Prey mean length per ength group (file stom-
len_at_length.in
#         Prey mean weight from mean weight per prey length group
(file: stomweight_at_length.in
#  2=weight:
#      M2 calculation:
#         Size preference:
#           Predator weight at age from file: west.in
#           Prey     weight at age from file: west.in
#         Prey mean weight is weight in the sea from file: west.in
#      Likelihood:
#         Size preference
#           Predator mean weight is based on mean length per predator
length group (file: stom_pred_length_at_sizecl.in)
#              and l-w relation (file: length_weight_relations.in),
#           Prey mean weight per prey length group (file: stom-
weight_at_length.in)
```

```
#         Prey mean weight from mean weight per prey length group
(file: stomweight_at_length.in
#  3=weight:
#       M2 calculation: Same as option 2
#       Likelihood:
#         Size preference:
#           Predator mean weight is based on mean length per predator
length group (file: stom_pred_length_at_sizecl.in)
#              and l-w relation (file: length_weight_relations.in),
#           Prey mean weight per prey length group (file: stom-
len_at_length.in) and l-w relation (file:length_weight_relations.in)
#         Prey mean weight from prey mean length per prey length group
(file: stomlen_at_length.in) and l-w relation (file: length_weight_re-
lations.in)
#  4=weight:
#       M2 calculation:
#         Size preference:
#           Predator mean weight from file lsea.in (length in the sea)
and l-w relation (file: length_weight_relations.in)
#           Prey mean weight from file lsea.in (length in the sea) and
l-w relation (file: length_weight_relations.in)
#       Likelihood:  Same as option 3
#  5=weight in combination with simple.ALK=1:
#       M2 calculation:
#         Size preference:
#           Predator weight based on length from file ALK_all.in
(length distribution at age) and l-w relation (file: length_weight_re-
lations.in)
#           Prey     weight based on length from file ALK_all.in
(length distribution at age) and l-w relation (file: length_weight_re-
lations.in)
#         Prey mean weight based on length from file ALK_all.in
(length distribution at age) and l-w relation (file: length_weight_re-
lations.in)
#       Likelihood: Same as for option 2
#  6=weight in combination with simple.ALK=1:
#       M2 calculation: Same as option 5
#       Likelihood: Same as option 3
2
########################################
# Adjust Length at Age distribution by a mesh selection function (op-
tion L50.mesh)
#  Please note that options simple.ALK shoud be 1 and option size.se-
lect.model should be 5
# L50 (mm) is optional given as input. Selection Range is estimated by
the model
# L50= -1 do not adjust
# L50=0, estimate L50 and selection range
# L50>0, input L50 (mm) and estimate selection range
# by VPA species
#          Cod     Herring       Sprat
            -1          -1          -1
########################################
## spread of size selection (option size.selection)
#   0=no size selection, predator/preys size range defined from obser-
vations
#   1=normal distribution size selection
#  11=normal distribution size selection, but sum of all prey sizes
used in
#     likelihood
#   3=Gamma distribution size distribution
#   4=no size selection, but range defined by input min and max re-
gression parameters
#      (file pred_prey_size_range_param.in)
#   5=Beta distributed size distribution, within observed size range
#   6=log-Beta size distributed, within observed size range
#
# by predator
```

```
#          Cod
            0
########################################
## other food suitability size dependency  (option
size.other.food.suit)
#  0=no size dependency
#  1=yes, other food suitability is different for different size clas-
ses
#          Cod
             0
########################################
## Minimum observed relative stomach contents weight for inclusion in
ML estimation (option min.stom.cont)
#          Cod
        0.0001
########################################
## Maximum number of samples used for calculation of stomach observa-
tion variance
#          Cod
          300
########################################
## Max prey size/ pred size factor for inclusion in M2 calc
#          Cod
           0.3
########################################
## use overlap input values by year and season (use.overlap)
#   0: overlap assumed constant
#   1: overlap index from file overlap.in (assessment only, use over-
lap from last year in forecast)
#   2: overlap index from file overlap.in (assessment and forecast)
0
########################################
## parameter estimation phases for predation parameters
#  the number gives the phase, -1 means no estimation
#
#  vulnerability (default=2) (phase phase.vulnera)
2
# other food suitability slope (default=-1) (option
phase.other.suit.slope)
-1
# prefered size ratio (default=2) (option phase.pref.size.ratio)
-1
# predator size ratio adjustment factor (default=-1)
-1
# prey species size adjustment factor (default=-1)
-1
# variance of prefered size ratio (default=2) (option
phase.var.size.ratio)
-1
# season overlap (default=-1) (option phase.season.overlap)
-1
# Stomach variance parameter (default=2) (option phase.Stom.var)
2
# Mesh size selection of stomach age length key (default=-1)
-1
########################################
```

WD07 Real time monitoring of Area-1 sandeel

By Anna Rindorf and Morten Vinther

Using commercial catch rates for real time monitoring of sandeel

In the years from 2004 onwards, the sandeel catch advice was updated within the season based on catch rates in the commercial fishery in April. Originally initiated as a result of the perceived low security of the recruitment forecast, which was by then based on catch rates of 0-group sandeel in the 2nd half of the year, the method was continued even after the introduction of the dredge survey and the resulting much improved estimates of recruitment. 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.' (WKSAN, 2010). 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 aim of the RTM is to estimate 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). This information is then used as a stock abundance index together with similar information for the period since 1999 as a 'survey' time series in the assessment, forming the basis for an updated TAC estimate after the completion of the RTM period.

This document outlines data and method used for the 2012 and 2016 RTM along with an investigation of the effect of spatial and temporal coverage of the RTM fishery on results.

Data and methods

Stock abundance 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, *Daysabsent* 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 AgriFish 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 (Figure 1 and 2) and shows a reasonable consistency between years (Figure 3). There is no trend in the relationship between dredge and RTM recruitment estimates.

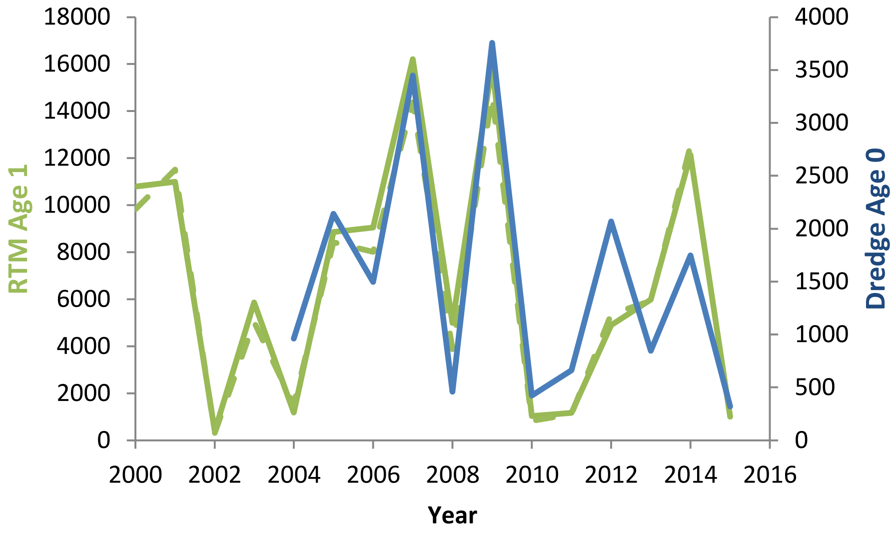


Figure 1. Temporal development RTM Age 1 and dredge Age 0 of the 2000 to 2015 cohorts. Solid green line denotes RTM CPUE April 15th to May 6th, hatched green line denotes RTM CPUE April 1st to May 6th, blue solid line is the dredge index. Years before 2000 had insufficient biological samples to use for the RTM time series.

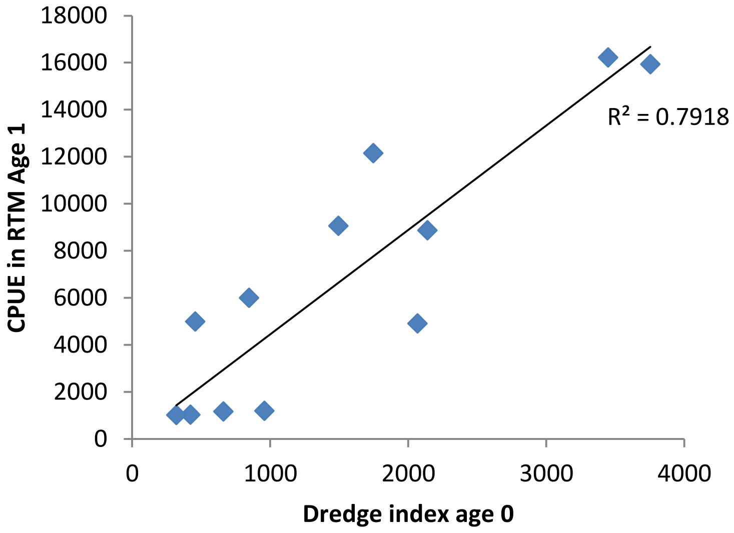


Figure 2. CPUE in the 2016 RTM period (15th April to 6th May) of the incoming yearclass (Age 1) as a function of the dredge index at age 0 of the same cohort.

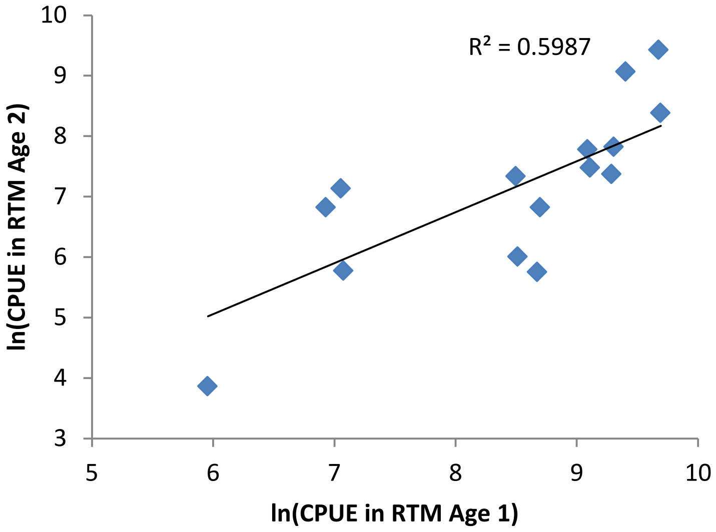


Figure 3. Internal consistency of the 2016 RTM series.

In 2012 and 2016, the default ICES assessment did not include the time series of CPUE in April. This lead to some minor differences between the assessment used for advice in the beginning of the year and the assessment used together with the RTM data.

Survey residuals for the Dredge survey in the 2012 RTM assessment showed a very similar picture compared to the default assessment (ICES 2012). The RTM index showed a good correlation between CPUE in April and year class strength. The CV of the catchability of the RTM age 1 index (0.32) was lower than the CV for the 0-group from the dredge survey (0.53).

Survey residuals for the Dredge survey in the 2016 RTM assessment showed a very similar picture compared to the default assessment (ICES 2016). The RTM index showed a good correlation between CPUE in April and year class strength. The CV of the catchability of the RTM age 1 index (0.36) was slightly higher than the CV for the 0-group from the dredge survey (0.30).

Effects of changes in spatio-temporal coverage of the fishery in the RTM period

To investigate whether specific demands should be made with respect to the spatial and temporal coverage of an RTM data series, the relation between the residual variation of a model describing CPUE by year, square, week and vessel size was investigated. Neither the residual variation nor the average catch rate was significantly related to the number of days fished in the RTM period (Fig. 4, correlation 0.01 and 0.23, P=0.9607 and 0.2001). The same was true of the number of statistical rectangles fished in the RTM (Fig. 5, correlation 0.08 and 0.29, P=0.6621 and 0.1063).

There was a clear tendency for greater variation in catch rates between rectangles in years with lower than average catch rates (Fig. 6, correlation -.,56, P=0.0010). Three rectangles (39F1, 38F1 and 37F1, all at Dogger) are fished in all years except one (and this year only lacked data for 37F1). Using these rectangles only to estimate catch rates provides an index with a correlation of 0.81 (P<0.0001) with the index based on all rectangles.

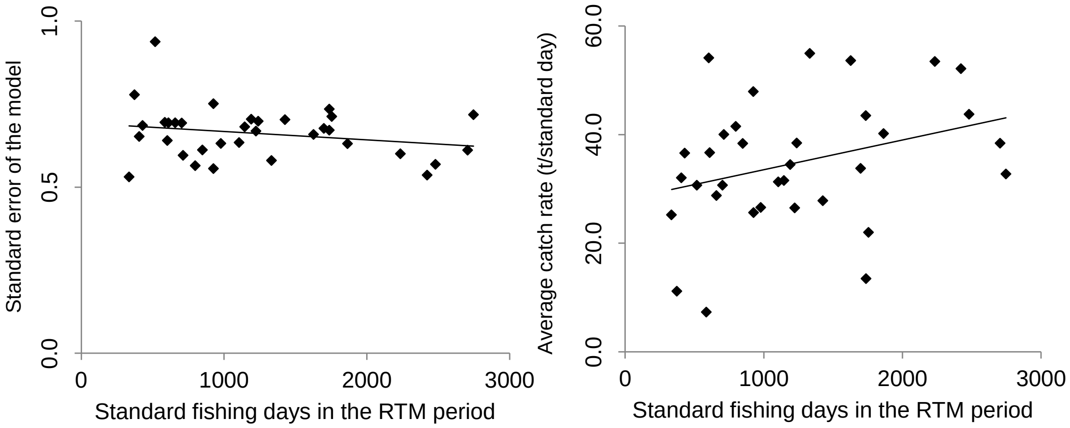


Fig. 4. Standard error of the model used to estimate average catch and average catch rate as a function of the number of standard fishing days in the period. Note that the time period is longer than the RTM time series used above as the data above are restricted to years with sufficient age samples.

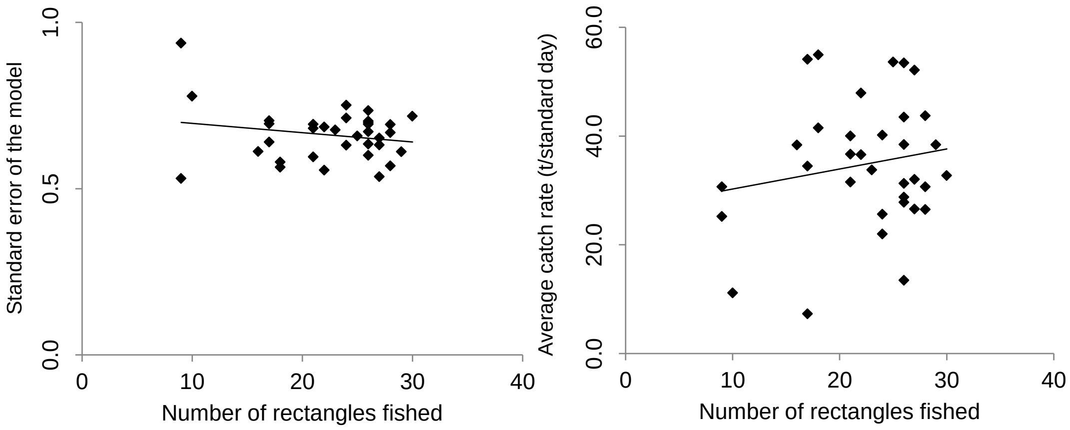


Fig. 5. Standard error of the model used to estimate average catch and average catch rate as a function of the number of statistical rectangles fished in the RTM period. Note that the time period is longer than the RTM time series used above as the data above are restricted to years with sufficient age samples.

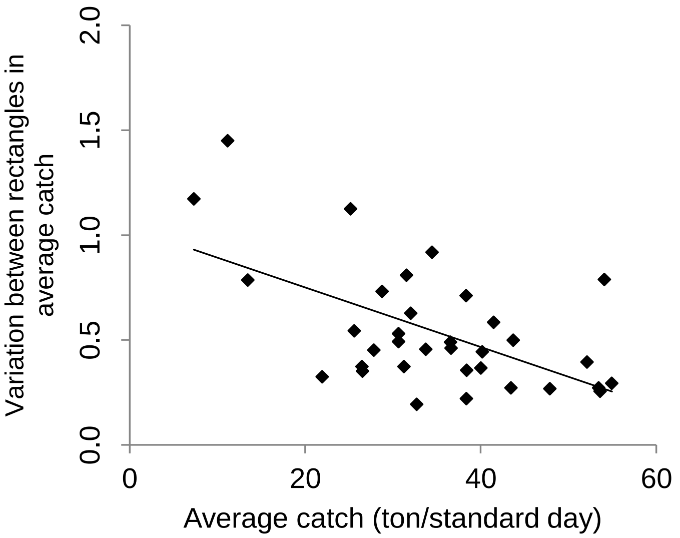


Fig. 6. Relationship between variation between rectangles in average commercial catch rate and average catch rate.

Historical comparisons of original and updated TAC estimates

The current version of RTM has been used on two occasions, in 2012 and 2016. The original advice, the updated advice and the realized catch, all in '000 ton can be seen in the table below.

YEAR	ORIGINAL TAC	TAC FOLLOWING RTM	REALISED CATCH
2012	<23	0	46
2016	0, monitoring TAC of 5	0	12

References

ICES 2010. Report of the Benchmark Workshop on Sandeel. ICES CM 2010/ACOM: 57

WD08 Ageing Small Sandeel Individuals caught during the 2016 Acoustic Sandeel Survey

OTOLITH MICROSTRUCTURE OF THE LESSER SAND EEL JUVENIL (AMMODYTES MARINUS, RAITT) FOR AGE DETERMINATION

Åse Husebø and Espen Johnsen

Otolith microstructure has been demonstrated in several studies to be a useful tool for investigating hatching time, growth rate and survival, since otoliths may provide a chronological record of early growth and life-history events (Campana & Neilson, 1985).

Materials and methods

During the acoustic sandeel survey conducted 25 April – 15 May 2016 (see WD_Acoustic Survey for details)., large schools of sandeel juveniles were acoustically observed on several sandeel grounds in during the survey (see Appendix 1). Several trawl stations confirmed that these schools consisted of small sandeel (6.5-8.5 cm), which are very seldom observed during the survey carried out in this period. Typically, 1-year old individuals are much larger, and young of the year (YOY) individuals are considerably smaller (< 6 cm).

Therefore, to analyses the age of these abundant individuals we used otolith microstructure for ageing validation of these sand eel juveniles. We investigated the otoliths increment periodicity and made a comparison between otolith microstructure and morphological development.

In this study, we used individuals (Figure 1) collected from one trawl station in the North Sea the 5 May 2016.

The following biological parameters were included from each Juvenile: total body length (cm), weight (g) and age (from otoliths) (Table 1).

In addition, the sagitta otoliths were removed from the fish head using a stereoscope and tweezers, the otoliths were carefully rinsed from tissue, before mounted with thermoplastic resin (Buehler Thermoplastic Cement no. 40-8100) on glass slides, for further microstructure analyse (Secor et al. 1992; Mosegaard and Madsen 1996). A photo was taken of each otolith using a Nikon SMZ25 with Nikon camera DS-Fi2 (Nikon Corporation, Tokyo) 9.0x magnification (2560x1920 pixels) and the otolith length (mm), and otolith width (mm) were recorded using NIS element D software (Table 1 and Figure 2) .

The otoliths were then grinding and polishing on both sides. The otoliths were polished using a series of grinding and polishing films with decreasing grain sizes (Buehler, grit 600 - 1200) to optimize the visual resolution at a focal plane through the otolith. The Otolith were examined and through a Leica DMLB light microscope (Leica Microsystems, Wetzlar, Germany) with x20 and x40- objective lens, transmitted light. The pictures (2560x1920 pixels) were taken with a Nikon DS-Fi2 digital camera with the, Image Pro Plus 7.0 software (version Media Cybernetics, Bethesda, MD20814) was used to analyse the daily increment width and increment number along predefined standard axis (Figure 3).

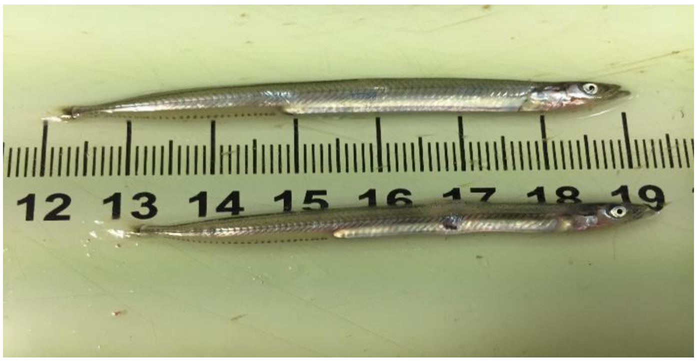


Figure 1. Picture of the large 0 group Sand eel juvenile found in the North Sea may 2016.

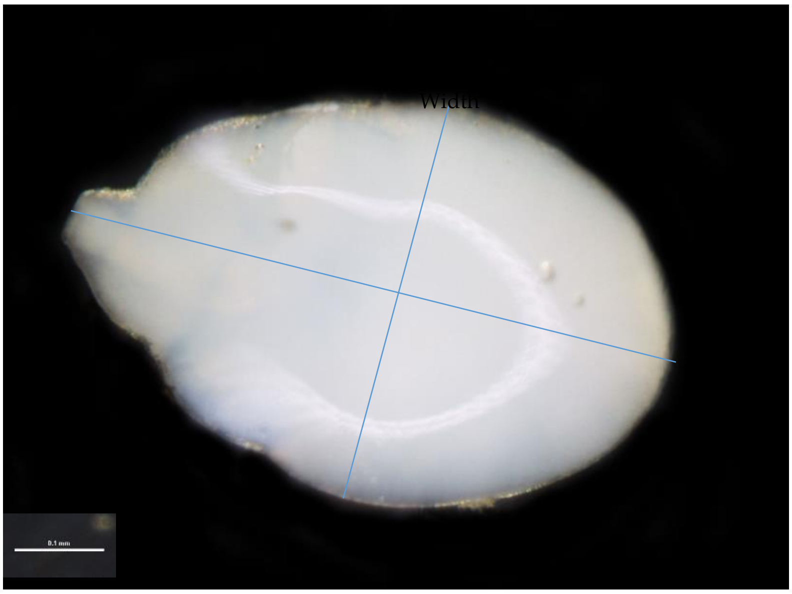


Figure 2. Sand eel juvenile ototlith, the blue line showing were the width and length measurement were recorded.

Table 1. Biological samples and otolith measurements. a = right b=left otoliths

							Otolith right mm		Otolith left mm			
Ship	**Date**	**Station no**	**Fish no**	**Fish weight g**	**Fish length cm**	**image name**	**Length**	**Width**	**Length**	**Width**	**Increment no. Direction a**	**comments**
Eros	05.05.2015	37299	1	1.1235	6.9	37299_01.tif	0.77	0.52				
Eros	05.05.2015	37299	2	0.9391	6.9	37299_02.tif	0.72	0.49				
Eros	05.05.2015	37299	3	1.0351	7	37299_03a.tif	0.74	0.44	0.76	0.49		
Eros	05.05.2015	37299	4	0.965	7.2	37299_04.tif	0.78	0.53				
Eros	05.05.2015	37299	5	0.8274	6.8							Lost the otoliths
Eros	05.05.2015	37299	6	0.7073	6.5	37299_06a.tif	0.68	0.41	0.65	0.43		
Eros	05.05.2015	37299	7	0.9685	7.1	37299_07b.tif	0.78	0.44	0.81	0.49		
Eros	05.05.2015	37299	8	0.744	6.6	37299_08a.tif	0.71	0.39	0.67	0.44		
Eros	05.05.2015	37299	9	0.9855	7.2	37299_09a.tif	0.73	0.48	0.75	0.52		
Eros	05.05.2015	37299	10	0.8842	6.8	37299_10a.tif	0.7	0.44	0.65	0.46		
Eros	05.05.2015	37299	11	0.7346	6.5	37299_11a.tif	0.68	0.52	0.71	0.5		
Eros	05.05.2015	37299	12	0.7505	6.8	37299_12.tif	0.72	0.44				
Eros	05.05.2015	37299	13	0.8995	6.8	37299_13.tif	0.67	0.48				
Eros	05.05.2015	37299	14	0.809	7.1	37299_14.tif	0.75	0.43				
Eros	05.05.2015	37299	15	0.627	6.9	37299_15a.tif	0.69	0.45	0.68	0.46		
Eros	05.05.2015	37299	16	0.8221	6.5	37299_16.tif	0.66	0.45				
Eros	05.05.2015	37299	17	0.992	6.8	37299_17.tif	0.8	0.5				

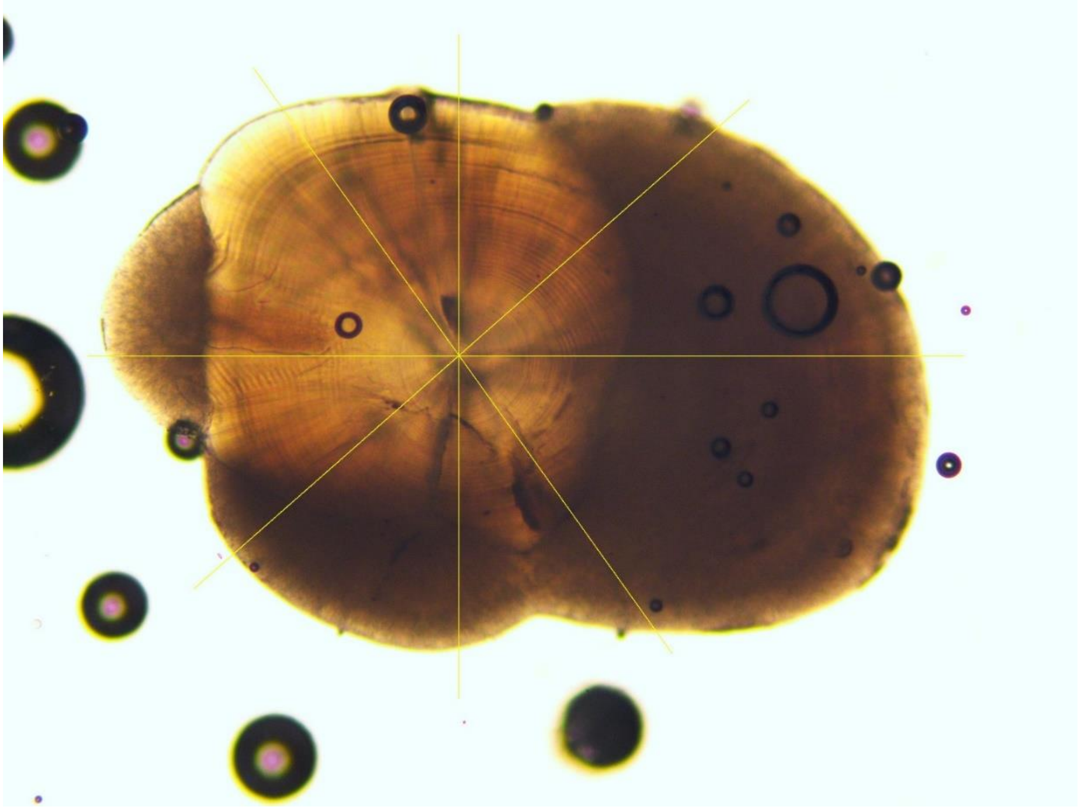


Figure 3. Predefined lines were the examinations of daily increments in sand eel otoliths were investigate.

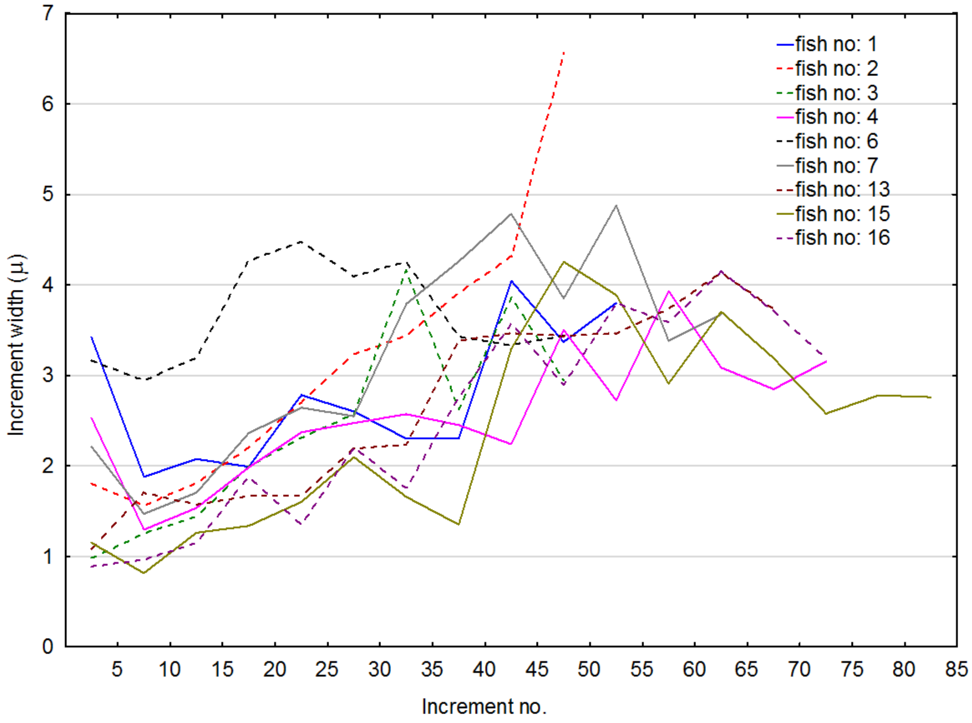


Figure 4. Showing the mean increment width at different increment number (the expected age in days) along the predefined lines 12 for all the juvenile.

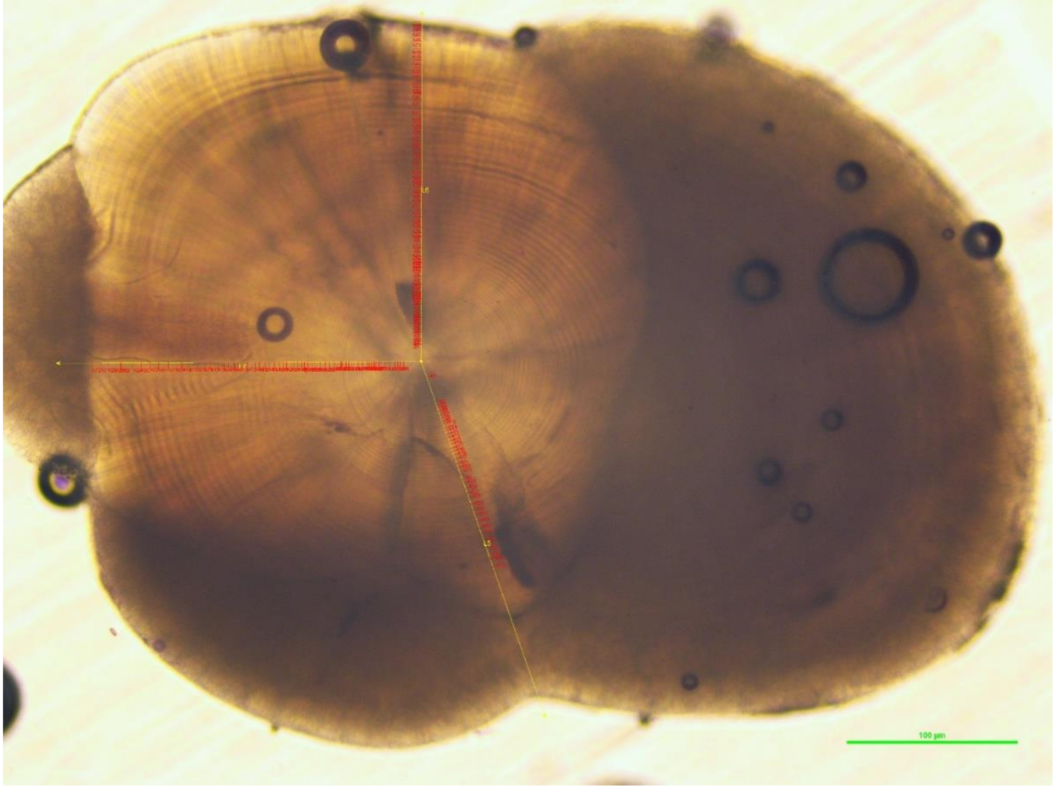


Figure 5. Otolith showing analysis of increment position using image pro pluss direction 12, 5 and 9.

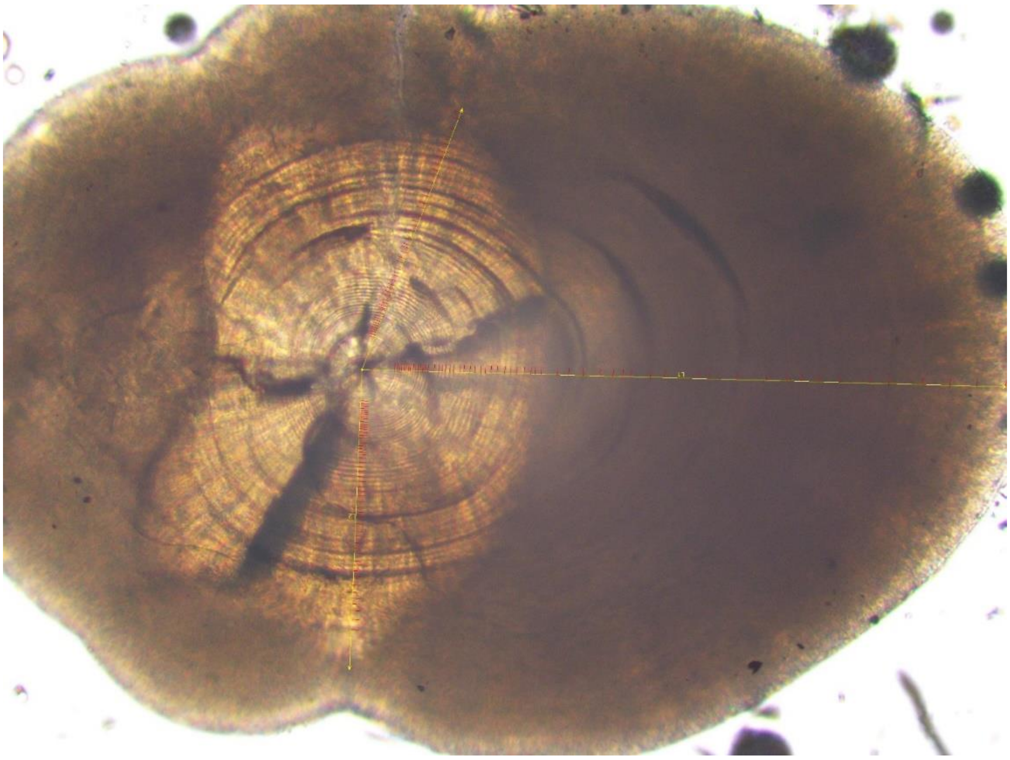


Figure 6. Otolith showing analysis of increment position using image pro pluss direction 1, 3 and 6.

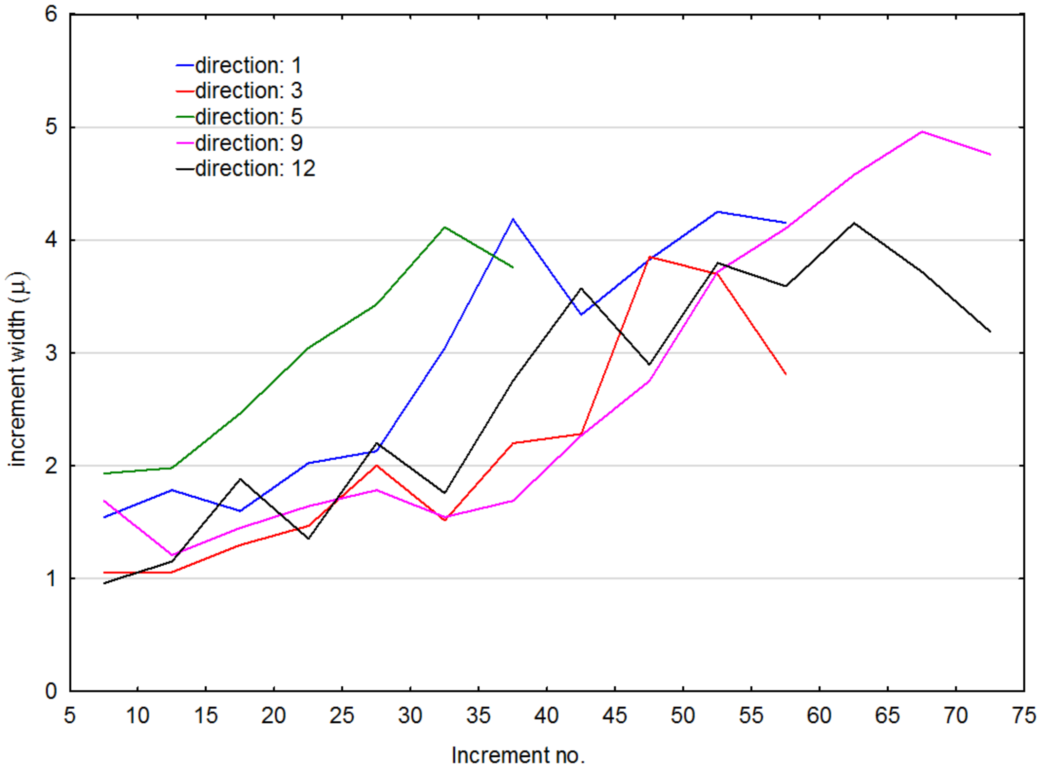


Figure 7 Showing the mean increment width at different increment number (the expected age in days) for fish no 12 along the predefined lines1,3,5,9 and 12.

Result

The analyses show that all indiviuals were YOY-individals, which had a large growth. The hatching check was found a proximal 10 micron from the nucleus in all the otoliths. When mean increment width was plotted against increment number no general trends were found, but fish no 6 showed increment width over 3 microns already at age of 5 days (increment no 5) (figure 4).

Discussion

The appearance of the otolith microstructure is much influenced by the environmental conditions, such as temperature (Folkvord et al., 2004) and food availability (Johannessen et al.,2000), experienced in the first larval phase, so caution is necessary if environmental regimes in the spawning areas change over time.

Literature

Folkvord, A., Johannessen, A., and Moksness, E. 2004. Temperature-dependent otolith growth in Norwegian springspawning herring (Clupea harengus L.) larvae. Sarsia, 89: 297–310.

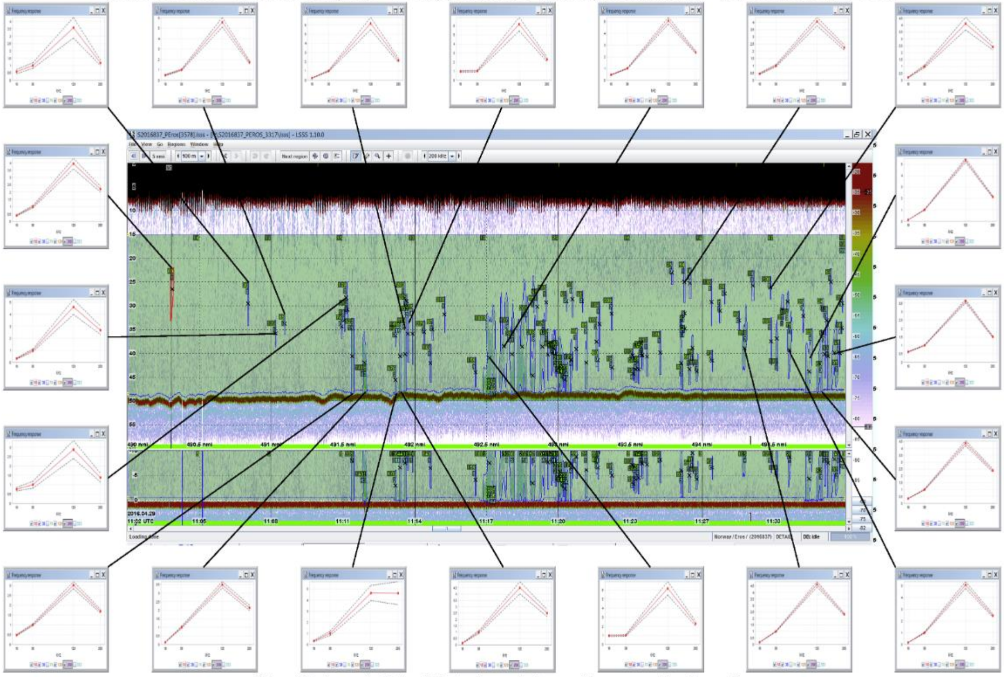
Husebø, A˚ ., Slotte, A., Clausen, L. A. W., and Mosegaard, H. 2005. Mixing of populations or year class twinning in Norwegian spring spawning herring? Marine and Freshwater Research, 56: 763 – 772.

Johannessen, A., Blom, G., and Folkvord, A. 2000. Differences in growth between spring and autumn spawned herring (Clupea harengus L.) larvae. Sarsia, 85: 461 – 466.

Wright, P. J. 1993. Otolith microstructure of the Lesser Sandeel, Ammodytes. Marinus Journal of the Marine Biological Association of the United Kingdom, Volume 73, Issue 1 pp. 245-248 DOI: http://dx.doi.org/10.1017/S0025315400032793

Appendix 1

2016837 Eros - Frekvens Respons - 0 Gruppe Havsil (*Ammodytes marinus*) - Inner Shoal Sør (2016)



© Ronald Pedersen, Institute of Marine Research, Bergen - Norway. ronald.pedersen@imr.no

WD 09: F_{cap} for sandeel area 1 – 4

Mikael van Deurs 12. December 2016

Background

During MSYREF2 it was evaluated to which extent the escapement strategy (using B_{pa} as target; $B_{pa} = B_{lim} * \exp(1.645*std)$) is sustainable according to the criteria put forward by ICES (i.e. the accepted probability of having the spawning biomass (SSB) falling below B_{lim} is less than 5%). The conclusion was that the strategy is only sustainable if an upper level on F is applied (F_{cap}) (i.e. the probability exceeded 5% unless an F_{cap} was implemented or B_{pa} was increased; the former resulting in a higher long-term yield). This upper level on F is needed to ensure that the stock is not overexploited in years when the uncertainty of the incoming year class is not accounted for by the B_{pa} buffer.

For illustration, we provide a hypothetical example of the forecast and MSE models here. To simplify the comparison, the example is based on a stock with no recruitment to SSB, no growth and no natural mortality. That means that in case of no fishery the “escaped” SSB the following year would be the same as the initial SSB at the beginning of the year. As the distribution of estimated initial SSB is log-normal, subtracting a TAC aiming exactly at B_{pa} results in a case where the uncertainty of escaped SSB is increasing with initial stock size (left panel in fig. 1), hereby increasing the risk to Blim with initial SSB. Introducing a cap on F provides a ‘quick fix’ to this issue but still results in a situation where the risk to Blim varies with initial stock size (middle panel in fig. 1) and a risk to overfish the stock. If the statistical distribution of the distribution at the end of the year is well known, the ideal situation is to determine F in the TAC year such that the risk to Blim after fishing is exactly 5% (right panel in fig. 1). However, as the exact method by which to perform this analysis is still not entirely clear, the present document addresses the task of providing a value of F-cap that ensures that the average risk of falling below Blim in a long term simulation is 5%.

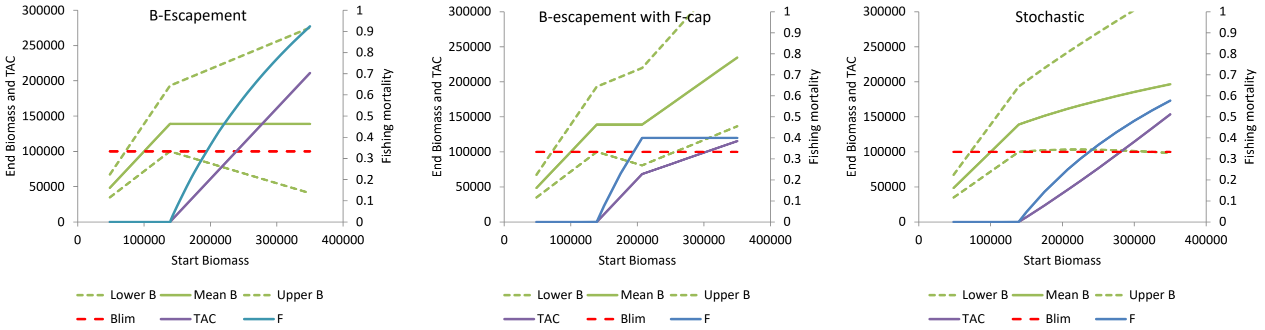


Fig. 1.

In this working document, we present F_{cap} for each of the new areas (1-4) derived from a Management Strategy Evaluation (MSE). The MSEs were carried out in accordance with ICES guidelines. The model used here is the “light” version of the MSE framework, in which the estimated uncertainties in the assessment model are used to simulate observation error, rather than running the full assessment model in each iteration loop on simulated data. The following default settings were applied: Long-term geom. recruitment, ten year average weight-at-age and maturity-at-age (the latter is constant in the assessment model), ten year average natural mortality (M) for the period where variable M is available (2003-2012, variable M is updated only until 2012), and the exploitation pattern is the same as that estimates in the agreed assessment model for the most recent separability period (see stock Annex about separability periods). Assessment uncertainty are derived as output from the SMS assessment model. Recruitment (R) uncertainty/variability is log-normal distributed and estimated based on the observed recruitment time series. F_{cap} is particularly sensitive recruitment (reflecting stock productivity) and assessment uncertainty in relation to numbers of age-1 fish. It should be noted that the assessment uncertainty (age-1) is very high in area 3 and 4 and the geometric mean R has decreased in the new area 8 assessment compared to the former area 1 assessment.

Results

The estimated values of F-cap required to obtain a long term average risk of 5% to Blim are given in the table below. They are somewhat lower than previous values (which were around 0.6 for areas 1 and 3) due to the higher recent natural mortality.

Area	F_{cap}	Mean future F (predicted in MSE)	Mean future TAC (1000t) (predicted in MSE)	Average (and max) F in assessment (2010-2015)	Observed SSB & R (assess. model) vs. simulated future SSB & R	F_{cap} vs. probability of falling below B_{lim}
1r	0.49	0.43	213	0.42 (0.62)	Fig. 1a,b	Fig. 5
2r	0.44*	0.31	82	0.31 (0.51)	Fig. 2a,b	Fig. 6
3r	0.29	0.26	114	0.30 (0.56)	Fig. 3a,b	Fig. 7
4	0.15	0.09	30	0.01 (0.03)	Fig. 4a,b	Fig. 8

* Negative trend in recruitment time-series in the assessment summery table

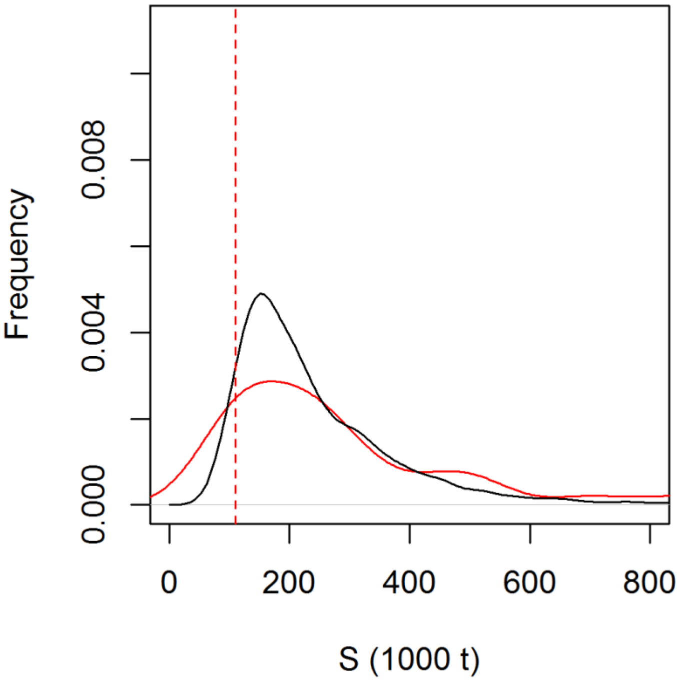


Fig. 1a. (area 1r) SSB as estimated by the assessment (Red solid) and as used by MSE (Black solid). Red dashed: B_{lim}.

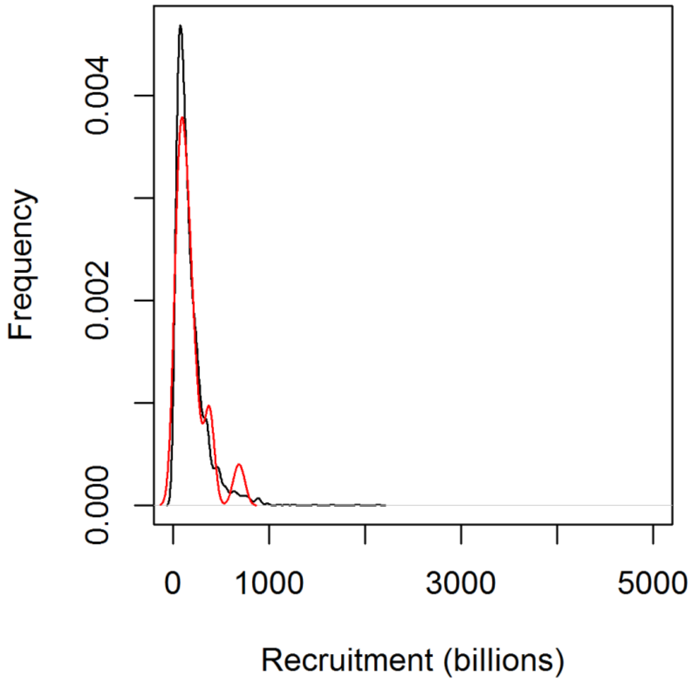


Fig. 1b. (area 1r) Recruitment as estimated by the assessment (Red solid) and as used by MSE (Black solid).

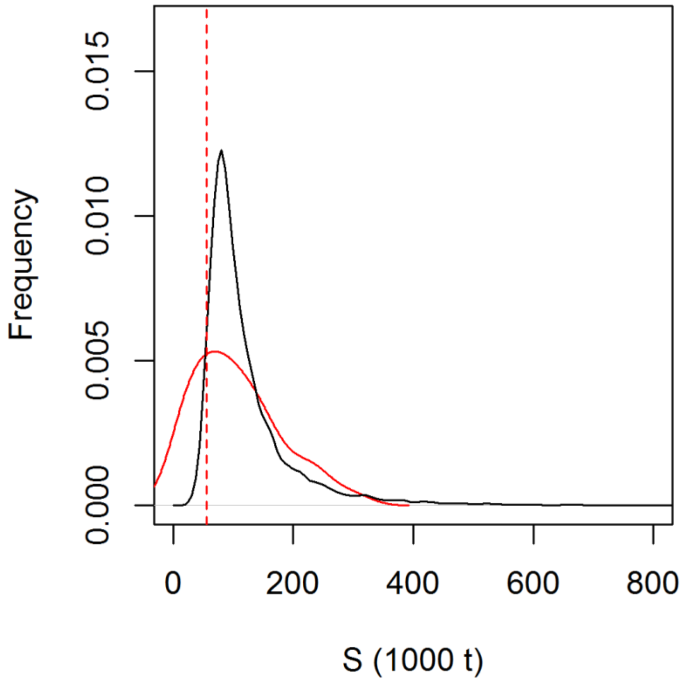


Fig. 2a. (area 2r) SSB as estimated by the assessment (Red solid) and as used by MSE (Black solid). Red dashed: B_{lim}.

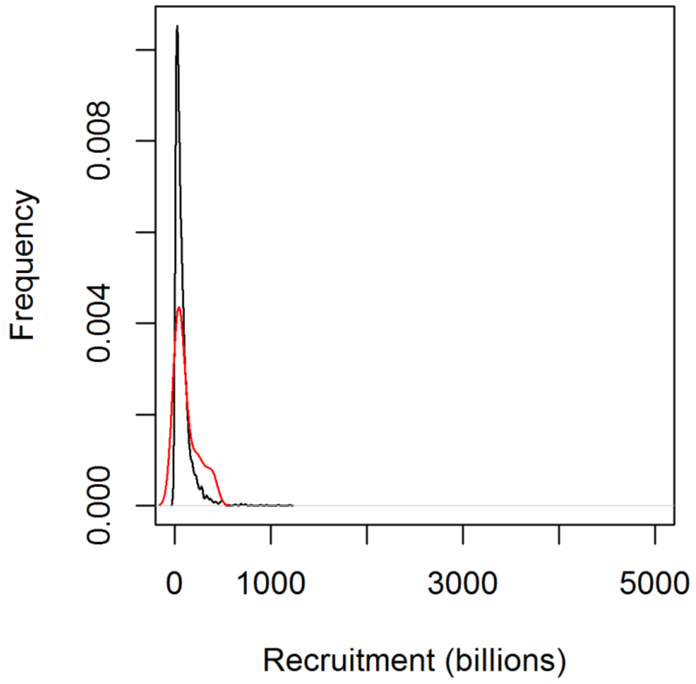


Fig. 2b. (area 2r) Recruitment as estimated by the assessment (Red solid) and as used by MSE (Black solid).

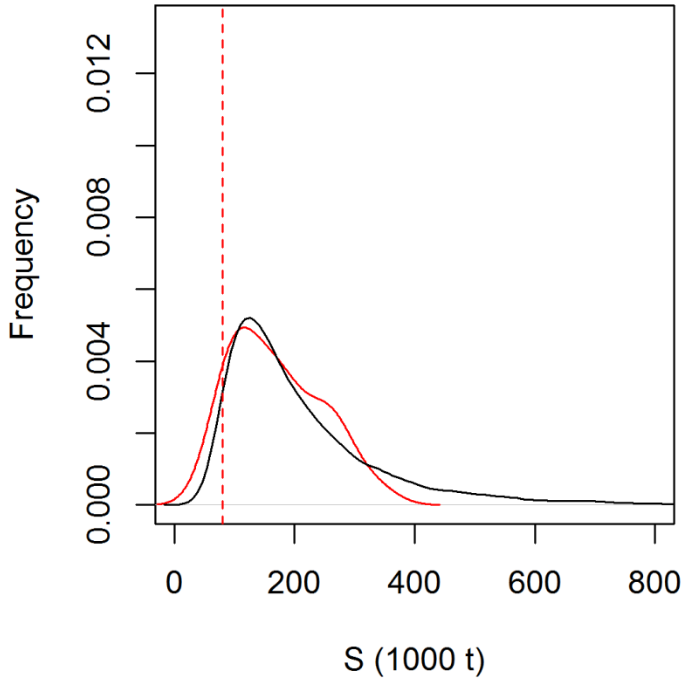


Fig. 3a. (area 3r) SSB as estimated by the assessment (Red solid) and as used by MSE (Black solid). Red dashed: B_{lim}.

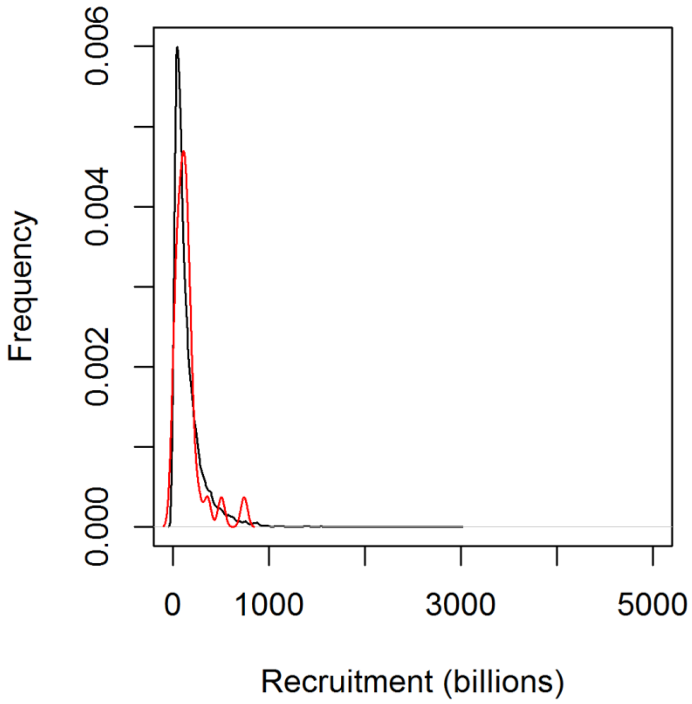


Fig. 3b. (area 3r) Recruitment as estimated by the assessment (Red solid) and as used by MSE (Black solid).

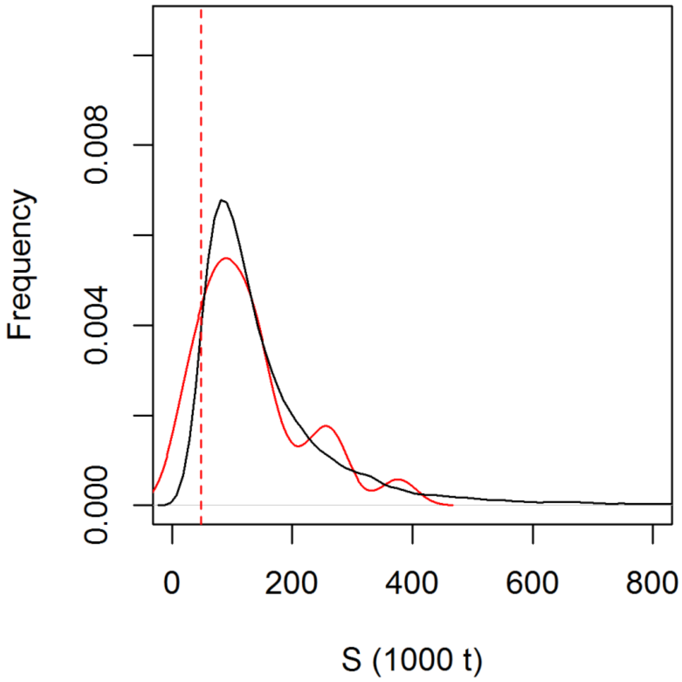


Fig. 4a. (area 4) SSB as estimated by the assessment (Red solid) and as used by MSE (Black solid). Red dashed: B_{lim}.

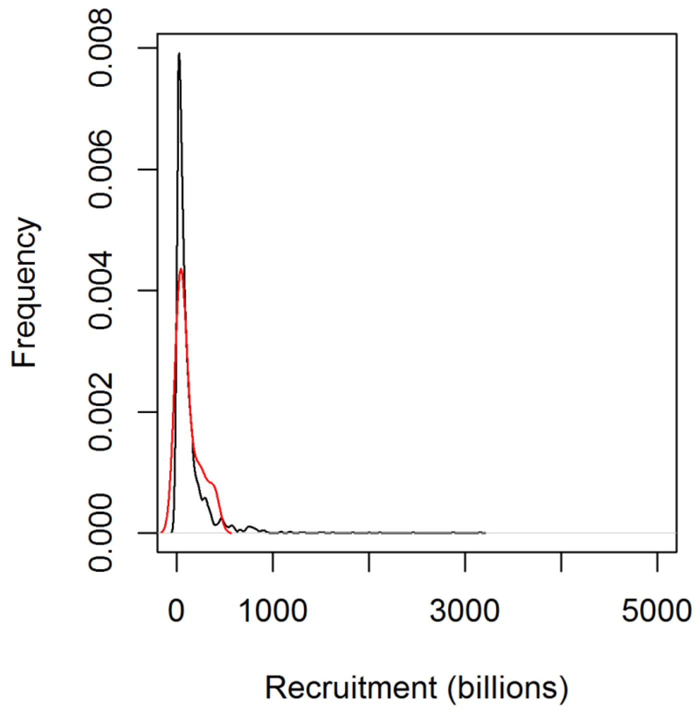


Fig. 4b. (area 4) Recruitment as estimated by the assessment (Red solid) and as used by MSE (Black solid).

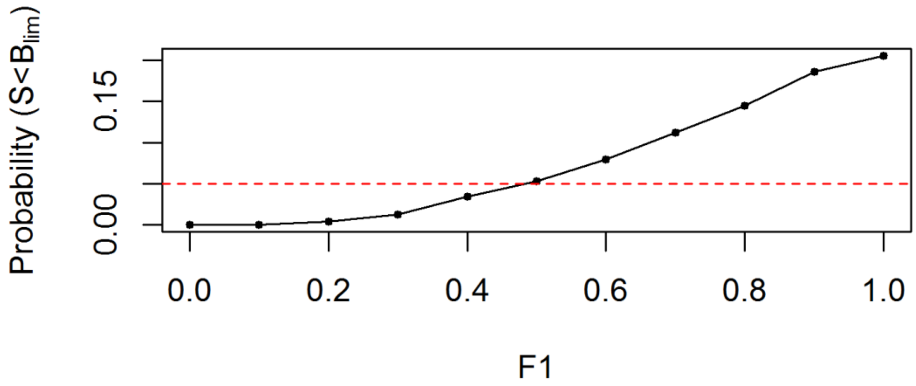


Fig. 5. (area 1r) The X-axis (F1) represents different F_{cap}-values and the Y-axis display the probability of dropping below B_{lim} when using the F_{cap}- value given on the X-axis.

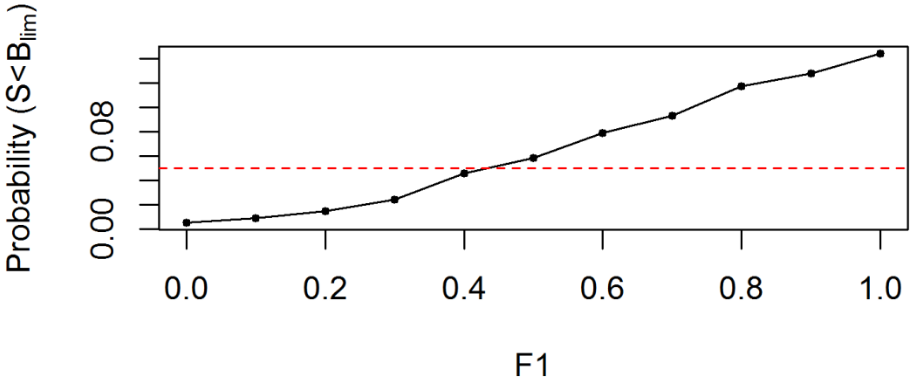


Fig. 6. (area 2r) The X-axis (F1) represents different F_{cap}-values and the Y-axis display the probability of dropping below B_{lim} when using the F_{cap}- value given on the X-axis.

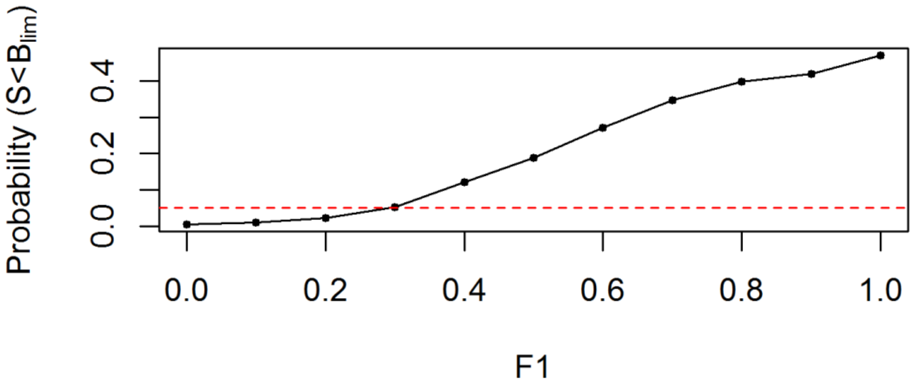


Fig. 7. (area 3r) The X-axis (F1) represents different F_{cap}-values and the Y-axis display the probability of dropping below B_{lim} when using the F_{cap}- value given on the X-axis.

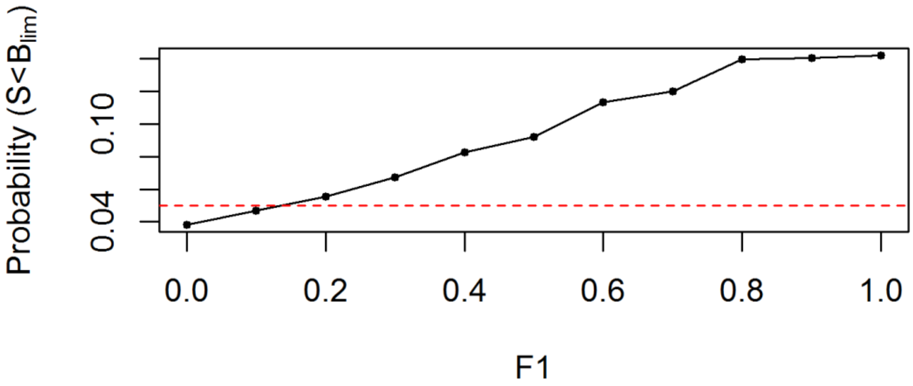


Fig. 8. (area 4) The X-axis (F1) represents different F_{cap}-values and the Y-axis display the probability of dropping below B_{lim} when using the F_{cap}- value given on the X-axis.