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Report of the *Ad Hoc* Group on Sandeel

27–28 February 2007

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Executive summary

The Ad hoc Group on Sandeels (AGSAN) was set up to implement a real time monitoring system for the North Sea sandeel stock in 2007. The primary aim of the meeting was to agree on the implementation procedure for a previously established harvest control rule. The overall objective of the HCR is to ensure that fishing is limited in 2007 so that SSB in 2008 will be above B_{lim} with a high (95%) probability. Fishing in 2007 will be dependent on the size of the 2007 year-class. The estimate of the 2007 numbers is to be derived from real-time monitoring using a regression between historical CPUE observations and "bias-corrected" stock numbers at age 1. This report gives a summary of the agreed methodology and the procedure for combining data from the Norwegian and EU monitoring fisheries. A time table of when data and model estimates will be made available is given. The *Ad Hoc* Group will work in correspondence in order to provide an estimate of the 2007 year-class numbers to ICES ACFM by the 10 May allowing ICES to report by the 15 May.

In addition to this years management advice the group was asked to consider feasible options for future management arrangements. The group agreed that it is essential to account for sub-stock structuring in future management. This is because the past management regimes have failed to avoid local depletion in many areas and account for regional differences in productivity and catch rates. For example, work on regional CPUE during the meeting indicated that a fishery restricted to the area around Dogger Bank could inflate the stock estimate of year-class strength.

The Ad hoc Group was not in the position to come up with a definite proposal for future management plans because of limitations in the knowledge base, although ongoing research is addressing this. Nevertheless, some changes can be suggested for 2008 based on available information and the results of a recruit survey late in 2007. The *Ad Hoc* Group therefore recommends that the sandeel advice for 2008 is postponed until January 2008 when the survey results become available. The group also outlined some feasible management strategies in the context of management aims and recent understanding of population biology. It will require modelling and simulation work well beyond what has been common practise for other stocks. The group recommends that this process be initiated without delay, as the current regime is not satisfactory.

1 Opening of the meeting

The *Ad Hoc* Group on Sandeel met at ICES in Copenhagen from 27–28 February, 2007. Delegates were welcomed to ICES by Michala Ovens. A complete list of participants is given at Annex I of this report.

2 Adoption of the agenda

Terms of reference

The purpose of this meeting was to establish a real time monitoring system for the North Sea sandeel stock. To deal with this a special group (Chair Peter Wright) met at ICES Headquarters 27–28 February 2007 to:

1. Compile all pertinent information of relevance for the implementation of a real-time monitoring system for the stock of North Sea sandeel. In compiling this information consider the arrangements between the Community and Norway on the 20 000 tonnes allocated to the "experimental fishing" both in Community and Norwegians waters;
2. Suggest methods, on the basis the information compiled under point 1, for a further improvement of the real time monitoring system for the stock of North Sea sandeel that by early May 2007 can provide an unbiased estimate of the size of the 2006 year class of sandeel;
3. Outline feasible options for future management arrangements, taking into account the biological characteristics of the stock as well as future availability of relevant data.

and work by correspondence to provide an estimate of the size of the 2006 year class of North Sea sandeel at age 1 as early as possible in May and no later than 15 May 2007.

2.1 Advice and regulation for the 2007 sandeel fishery

As an answer to the request from the European Community and Norway "*advice on management measures for the sandeel and Norway pout fisheries in the North Sea and Skagerrak 2007*", ICES suggested (not advised) a management procedure for 2007, where the following conditions should apply.

1. The aim of management in 2007 should be to rebuild SSB in 2008 above Blim with a high (95%) probability;

2. The total kilowatt-days for fisheries for sandeel in 2007 may initially be set at no more than 30% of the total kilowatt-days applied in 2005. This effort may be used for exploratory fishing in April and early May 2007;

3. A TAC for 2007 and the maximum number of kilowatt-days shall be determined, as early as possible based on advice from ICES on the size of the 2006 year class of North Sea sandeel in accordance with the following rules:

a. TAC 2007= $-597 + 4.073 \times N1$ *(N1 is the real-time estimate of age group 1 in billions, derived from an exploratory fishery in April and early May 2007; the TAC is expressed in 1000 t),*

b. If the TAC calculated in point 3a) exceeds 400 000 t the TAC shall be set at 400 000 t,

c. The number of kilowatt-days for 2007 shall not exceed the effort in 2005;

4. The fishery shall be closed 1 August 2007.

The relationship between the TAC and the real-time recruitment estimate is conditional on the October 2006 assessment of age group 2 and older at the start of 2007 (Figure 6.3.3.4.3 and ICES, 2006b).

The real-time monitoring estimate should be based on a regression between CPUE observations and "bias-corrected" stock numbers at age 1. ICES has applied a bias correction to the assessment output by calculating a bias factor from the terminal estimates of a series of retrospective runs divided by the "true value" as estimated in the most recent assessment. The application of the bias factor gave a 50% lower estimate of SSB in 2007. ICES considers that the bias correction reduces the concern about assessment bias for management of the sandeel fishery in 2007.

This suggestion from ICES was later accepted into the regulation of the 2007 fishing opportunities in Community waters (Council Regulation (EC) No 41/2006 of 21 December 2006 - OJ L15 of 20 January 2007 p 1).

In the agreed record from the fishery consultations between EU and Norway for 2007, point 4.4.1 states that the parties shall convene a scientific meeting before the end of March 2007 so as to agree on a methodology for combining data from the Norwegian monitoring fishery and the monitoring fishery conducted by the EU in order that mutually agreed real-time estimate of age 1 can be obtained in May 2007. Moreover, Table 3 in the agreed record allows the parties to fish 20 000 tonnes of sandeel in each others zones. These quotas are primarily for an experimental fishery, but fishing against these quotas can continue if the commercial fishery becomes opened.

2.2 Structure of the report

The group decided to use the present methodology for real time management (RTM) in 2007, adjusted by the suggestions made by ICES (2006b). Section 3 outlines the methodology and gives details on the Norwegian data input and on how these are to be used in the method (ToR 1 & 2). Outlines of a feasible future management arrangement (ToR 3) are presented in section 4.

3 Data and methods

The sandeel fishery and the stock are in most years dominated by 1-group for which very little information exists before the fishery is opened. In 2004–2006 the information on the 1 group abundance were obtained from the real time monitoring of the fishery in the start of the fishery. The basic idea for the applied real time monitoring of sandeel is the assumption that the observed catch rates in the fishery represents the stock size. To obtain the stock size of the 1-group from the catch rates the following steps are taken:

- effort standardisation, which allows comparison of CPUE (total catch weight/effort) from both the historical and the present fishery;
- compilation of biological samples and CPUE to obtain a CPUE in number of the 1-group sandeel;
- translation of the real-time estimate of CPUE of the 1-group into a stock estimate from a historical relation between CPUE and stock N estimated from the assessment.

The individual steps are described further in the following text.

3.1 CPUE data

Danish log-book data (1987–2006) and Norwegian data (2002–2006) were used to determine landings weight and effort (days absent from harbour) at the trip level. All data for 1990 have been removed from the analysis due to a very low level of biological sampling (4 samples) this year. Trips were considered valid if sandeel comprised more than 70% of the catch by weight, where the gear deployed was an otter trawl. Trip lengths of more than 14 days duration were assumed to be errors and were removed from the analysis. Historically, the sandeel fishing season generally starts around the beginning of March (week 10), although this early fishery is often combined with fishing for sprat. Dedicated sandeel fishing has generally commenced by week 12. Since 2005 sandeel fishing was only allowed from 1st of April.

Details on the extraction of the Danish log-book data can be found in previous STECF SG on sandeels reports (STECF, 2005a).

Norwegian logbook data from the sandeel fleet are not available and so-called "pseudo logbooks" had to be constructed based on landings (catch) and VMS data (effort). Landings data (based on sales slips) exist on a trip-by-trip level, while the VMS data comprise hourly records of position and time for each vessel. The principal methodology was to estimate time at sea for each fishing trip that ended with a sandeel landing by summarizing the (VMS) time observations from the so-called sandeel area (Figure 1) between the sandeel landing and the previous landing, irrespective of what was landed from here. A time observation is the time in minutes between consecutive VMS records, and the belonging position is taken from the first of these two records. Since the landings data has a trip-by-trip resolution all catch and effort data for a given trip could only be allocated to a single ICES rectangle (if a vessel has fished in different rectangles during a trip it is assumed that it recorded the rectangle where the majority of the landing was taken). Moreover, the time at sea in minutes was converted to days at sea by dividing by 1440 and rounding this number upwards to the nearest day. Since the Norwegian VMS started in July 2001, pseudo logbooks for March-May could only be constructed from 2001 onwards. In 2007, the Norwegian catch and effort data will be based on real logbook data with a haul-by-haul resolution.

Total Danish and Norwegian effort over all available years by GT class is shown in Figure 2. The size distribution of vessels has clearly changed over the period and hence some form of effort standardisation is required.

The effect of including Norwegian log book data in procedure of estimating the stock size of age-0 sandeels was negligible. This is due to the low effort and landings of the Norwegian vessels compared to the Danish vessels. The Norwegian log book data used from 2001 to 2006 up to week 20 represent total landings on 215 000 t from 773 trips, whereas Danish log book data from the same period represent landings on 914 000 t from 3027 trips.

3.1.1 Standardisation of effort

Standardisation of effort was made with the assumption that CPUE in a given year is a function of sandeel abundance and vessel size:

1) $$CPUE_y = a_y \times GT^b$$

or in a log transformed form:

2) $$\log(CPUE_y) = a_y + b \times \log(GT)$$

Where a_y denotes the abundance in year y and GT the vessel size measured as Gross Tonnage (GT)

Log transformation is required to stabilise the variance in CPUE to fit the model although it does result in a more skewed distribution of GT leading to the smaller vessels receiving a higher weight in the subsequent regression. Figure 3.3 shows some examples of log(CPUE) against log(GT), where GT has been binned at 25 tonnes intervals. The assumption of a linear relationship appears reasonable for vessels between 50 and 600 GT. The log transformation of GT results in more weight being given to the smallest vessels in the regression and hence the truncation at 50 GT. The linear relationship appears to break down with the very largest vessels and as there are relatively few landings coming from the vessels over 600GT, these data area also removed from the regression.

Alternative measure of effort, e.g. KW-days, have been considered by the STECF *ad hoc* WG on sandeel fisheries (STECF, 2004a, 2005a), but CPUE based on Gross Tonnage gave the best model fit.

The R-square of the model fit of model 2) using data from the first half-year is rather low (0.21), however given the large number of observations in the data set, the model parameter b is estimated with very high precision.

Effort (and CPUE) was standardised to a 200 GT vessel using the following equation:

$$StdEffort = effort \times \frac{GT^b}{200^b}$$

The b parameter, estimated from cumulative data since the start of the fishing season, changes slightly as the time period expands (Table 3.1). It seems that a value of 0.40 could have been used for the weeks 15–19, however the b parameter for the individual weeks are used for standardisation.

3.2 Biological Data

Data on the species and age distribution of the catches are obtained from biological samples of sandeel landings taken by the Fishery Inspectorate in Norway and Denmark. Samples are analysed by the national fisheries institutes. Biological data sampled in Norway will be used for 2007, however these data have not been used for the historical analysis.

3.2.1 Data screening

Both historical and "real time monitoring" samples are screened for quality by the following process.

Filter 1. Samples with less than 50% sandeel weight are not used:

Industrial samples include samples from the sandeel fishery and other industrial fisheries e.g. the Norway pout or the sprat fishery, which can have a by-catch of sandeel. Samples (landings) with a less than 50% sandeel are assumed to be biased with respect to the length distribution and are not used.

Filter 2. Individual records of Hyperoplus lanceolatus are discarded.

Since the year 2000 species identification has been greatly improved in Denmark. Previously, all sandeels were treated as one species, with the exception that some *H. lanceolatus* were sorted out. *Ammodytes tobianus* and *Gymnammodytes semisquamatus* have mainly been sorted out in the last three years, but probably not all individuals were identified. Data used in the ICES assessment exclude data on *H. lanceolatus* for the construction of length and age distribution keys and it is assumed that all "sandeel" landed are *A. marinus.* The same principle is used here; all "sandeel" data except *H. lanceolatus* data are used to construct age distribution of the catch.

Filter 3. Data outside area IV and in the closed part of the Firth of Forth area are discarded.

Similar to the ICES assessment, data from area IV, except the Shetland area and the closed area of Firth of Forth, are used.

Filter 4. Samples with obvious errors have been excluded.

A GLM model: log(weight) = month + year + b × log(length) was used to spot outliers with respect to an assumed length-weight relationship. Length-weight observations outside the 95% confidence interval for an individual prediction were identified. Samples with more than 50% outliers (length weight records) were excluded. Age information from samples where various problems have been encountered was excluded as well.

For 2004–2006 the number of Danish accepted samples has been around 200 per month in both April and May.

3.2.2 Data compilation

It is assumed that the sampling from landings represents the total catch in an unbiased way. Total catches within a week are complied with samples from the same week, if available. If samples are missing for a week with landings, samples from the previous week are used.

Analysis of monthly landings and sampling intensity in 2004–2006 has shown that the realised sampling by ICES rectangle is proportional to the catches in the area (STECF, 2004b, 2005b; 2006).

Biological data were used to provide the proportion of 1-group sandeel (by weight) and the 1-group CPUE (in terms of numbers) was determined by:

$$CPUE_1 = \frac{landings}{StdEffort} \times \frac{Pw_1}{W_1}$$

where Pw_1 is the weight proportion of 1-group sandeel and W_1 is the mean weight of a 1-group sandeel.

3.3 Relationship between CPUE and assessed N_1

This relationship is based on historical data. In the analyses, a regression was made between the N_1 from the most recent SXSA assessment and the CPUE of the 1-group ($CPUE_1$). This was done week by week for the early phase of the fishery, to find an appropriate duration of the fishery before a decision could be taken. The $CPUE_1$ for each week was the cumulated sum of the catch numbers of age 1, until the end of that week, divided by the cumulated sum of the normalised effort in the same period.

The regression was done on log-transformed data, ($\log(N_1) = a+b*\log(CPUE_1)$) which gave a more uniform distribution of the residuals. In the first year of real-time monitoring (2004), the regression was done on all assessment year classes. It became evident, however, that the relation was not linear, as the CPUE for large year classes was relatively smaller than for small year classes, leading to too optimistic estimates of small year classes. This was explained by a saturation effect. Since the smaller year classes are the important ones in the present context, large year classes (1989, 1992, 1995, 1997, 2002) were left out from the analysis. Likewise, years with very high SSB were excluded (1987, 1988, 1993, 1995, 1996, 1998), because the fishery in these years may have been directed more at older fish than at age 1. Finally, 1990 was excluded due to poor sampling that year. The years used were then 1991, 1994, 1999, 2000, 2001, 2003 and 2004, 2005.

Figure 4 and Table 3.2 show the regression week by week with the year-classes used. It appears that the fit improved until week 18. From week 18 onwards, the slope in the regression stabilised. Hence, week 18 emerged as a relevant week for terminating the monitoring fishery and deciding on a TAC for the rest of the year. Using this selection of data leads to a CV for the estimate of N1 due to the regression at 11%.

3.3.1 Translating the estimate of N1 abundance to a TAC

The estimate of N1 in 2007 will be translated into a TAC using the results from the stock SXSA assessment for age 2 and older, the estimate of age 1 from the real time monitoring and the target of obtaining a SSB in the beginning of 2008 above Bpa. The initial numbers of age 2 and older are adjusted for bias in the assessment, which is a known problem in the assessment of this stock. The bias correction was made by deriving a multiplier as the mean ratio of bias factors for the years 2000–2005. The bias factors were derived from a retrospective analysis of the last ICES assessment (ICES, 2006a) as the estimate of the stock numbers at age in the 2006 assessment relative to the estimate for the last assessment year in previous assessments.

The catch that in this prediction leads to an SSB in 2008 of 600 000 tonnes turns out to be (practically) linearly related to N1 (see Figure 5). The relation is expressed as TAC = -597 + 4.073*N1. (see Figure 6.3.3.4.3.lower in ACFM response to spec. rec: ICES, 2006b).

The TAC that is derived according to this rule is sensitive to decisions on both the selection of years included in the regression between CPUE and N1 (see e.g. Annex 1 to ICES, 2006b – special request response), and on the bias correction of the initial numbers in the prediction (See Section 4.6 in the WGNSSK report (ICES, 2006a)). These decisions have been made very carefully in a long process, that probably represents the best possible use of the catch and CPUE data, and are largely on the conservative side.

The harvest rule outlined above was suggested by ICES for 2007, but was not given as final advice from ICES. Nevertheless, it was later adopted by the EU to set TACs for EU waters. In addition to EU regulations of the fishery there is a fishery in the Norwegian zone under Norwegian management. The suggestion by ICES applies to the whole North Sea, including Norwegian waters. Therefore, the total removal from the stock may exceed the amounts suggested by ICES.

3.4 Special conditions for an "experimental fishery" in 2007

In the fishery consultations between EU and Norway for 2007, the agreed record allows the parties to fish 20 000 tonnes of sandeel in each others zones. These quotas are primarily for an experimental fishery, but fishing against these quotas can continue if the commercial fishery becomes opened. Advice on the conditions for this "experimental fishing" is part of ToR 1.

The *Ad Hoc* Group interpreted the term "experimental fishery" as being equivalent to the Real Time Monitoring (RTM) fishery designed to estimate the strength of the 2006 year class. Regarding the 20 000 tonnes catch in its respective zones, the group recommends that any additional regulations (apart from the effort limitation recommended by ICES) are avoided. The reason for this is that CPUE in 2007 must be comparable with CPUE from the previous years in order to obtain an unbiased RTM-estimate of age 1 abundance.

3.4.1 Protocol for 2007

The group recommends that DIFRES is assigned the responsibility for compiling relevant data and to conduct the agreed scientific analyses (e.g. weekly CPUE and real time estimates of age 1 abundance). Norway will submit 1) catch and effort data and 2) biological samples taken from commercial landings, on agreed formats on the agreed days (see Table 3.3). The final real time estimate of 1-group abundance will be based on logbook data up to and including week 18, and biological samples up to and including at least week 17.

During the real time monitoring DIFRES will make 3 reports (the release days are shown in Table 3.3) that will be made available to members of ICES and STECF. These preliminary reports will mainly contain sampling statistics and give qualitative statements about the age 1 abundance (no preliminary TAC). DIFRES will also publish selected results from the reports on its website, and IMR, ICES or others may then put links to this information on their respective websites.

The final report from the *Ad Hoc* Group on Sandeel will be submitted to the ICES Share Point on May 10 (at the end of the day).

Table 3.1. Weekly b parameters (using cumulated data) from the effort standardisation using data from 1987–2006 (excluding 1990).

Week no.	b
12	0.073
13	0.364
14	0.307
15	0.377
16	0.383
17	0.388
18	0.406
19	0.379
20	0.395
21	0.404
22	0.403
23	0.345
24	0.368
25	0.367
26	0.372

Table 3.2 Result of the VPA 1-group vs CPUE 1-group regression. VPA estimates in billions, CPUE estimates in millions.

Week no.	Intercept	Slope	Adj Rsq
12	4.68	0.41	0.95
13	3.84	0.79	0.85
14	4.31	0.60	0.83
15	4.39	0.57	0.91
16	4.34	0.59	0.88
17	4.22	0.63	0.89
18	4.14	0.71	0.95
19	3.99	0.76	0.98
20	3.99	0.75	0.98
21	3.96	0.77	0.95
22	3.94	0.77	0.94
23	3.99	0.77	0.95
24	4.04	0.75	0.93
25	4.13	0.71	0.91
26	4.14	0.71	0.89

Table 3.3 Time table for the real time monitoring of the sandeel fishery 2007.

Month	Week	Day		Collection of samples	Data deadline	Report deadline	Comment
April	15	9	Monday				Easter Monday
		10	Tuesday	From landing week 14			
		11	Wednsday				
		12	Tuesday				
		13	Friday				
		14	Saturday				
		15	Sunday				
	16	16	Monday				
		17	Tuesday	From landing week 15	Up to and incl. week 14 (bio) and week 15 (log book)		
		18	Wednsday				
		19	Tuesday			1st Report	
		20	Friday				
		21	Saturday				
		22	Sunday				
	17	23	Monday				
		24	Tuesday	From landing week 16	Up to and incl. week 15 (bio) and week 16 (log book)		
		25	Wednsday			2nd Report	
		26	Tuesday				
		27	Friday				
		28	Saturday				
		29	Sunday				
	18	30	Monday				
May		1	Tuesday	From landing week 17	Up to and incl. week 16 (bio) and week 17 (log book)		
		2	Wednsday			3rd Report	
		3	Tuesday				
		4	Friday				
		5	Saturday				
		6	Sunday				**End of monitoring period**
	19	7	Monday				
		8	Tuesday	From landing week 18	Up to and incl. week 17 (bio) and week 18 (log book)		
		9	Wednsday				
		10	Tuesday			Final Report	
		11	Friday				
		12	Saturday				
		13	Sunday				
	20	14	Monday				
		15	Tuesday				ACFM/STECF advice
		16	Wednsday				

3.5 Spatial variation in CPUE

Whilst the *Ad Hoc* Group was not in a position to further develop the regression method, some consideration was given to the potential influence of spatial differences in CPUE on the relationship between CPUE and estimated year-class strength. Danish catches from the central Dogger area (defined as the ICES rectangles: 37F2, 39F1, 39F2, 38F1, 38F2, 36F1, and 36F2) have constituted 39.6% of the total Danish landings of sandeel from 1983 to 2006. Catch rates from the central Dogger area were compared to those obtained from the Firth of Forth area (defined as ICES rectangles: 44E8, 43E8, 42E8, 41E8, and 40E8). While the Dogger area makes up a sizeable fraction of the catch, the Firth of Forth area only makes up 2.9% of total landings, and is recognised as an unusually productive area. However, variations between the Dogger Bank and the rest of the North Sea are of greater concern, due to the significant contribution of this region. The results of the analysis are shown in Table 3.5.

AREA	CPUE (TONNES/DAY)	$CPUE_{AREA}$ / $CPUE_{REST\ OF\ NORTH\ SEA}$
Firth of Forth	151 ± 34	3.51
Dogger Bank	65 ± 9	1.52
Rest of North Sea	43 ± 4	1.00

Table 3.5. Variation in Sandeel CPUE data with fishing areas in the North Sea. Errors are a 95% confidence interval based on all available data (1983–2006). The catch areas are defined in the text.

Catch per unit effort (CPUE as t/day) was, on an annually-averaged basis, significantly higher in the Dogger area than in the rest of the North Sea (paired t-test df=23, t=7.34, p=9.14E-08). The comparison of CPUEs for the years selected in the regression estimating N1 (1991, 1994, 1999, 2000, 2001, 2003, 2004, and 2005) gave a similar result with significantly higher values for the Dogger area (paired t-test df=7, t=3.42, p=0.0055). Similarly, the Firth of Forth region has a CPUE that is more than 3 times that the rest of the North Sea, and twice that of even the Dogger Bank. These differences can be best understood in terms of differences in habitat suitability and bathymetric features that locally concentrate individuals (Wright et al.,1998a).

The contribution of the Dogger Bank area to the total Danish landings is variable, with its proportion varying between 15% and 65%. Figure 6 plots the fraction of total landings obtained in the Dogger Bank area as a function of the total landings for the year and a statistically significant negative correlation (r^2=0.185, t=2.23, df=22, p=0.036) can be shown to exist between these variables. Thus, as the stock size decreases, the proportion of the total landings coming from the Dogger region increases *i.e.* the Dogger region is fished in preference to other regions in the North Sea, a conclusion that is supported by elevated Dogger Bank CPUE shown in Table 3.5.

These results have important implications for the regression model as changes in the spatial exploitation pattern of the species within a season can potentially bias the real time estimate of the N1-population. Specifically, if the more abundant regions (*e.g.* the Dogger Bank) are fished first, as seems reasonable, the perceived CPUE will be positively biased leading to an overestimate of the total population. Similarly, in times of poor stock-size the Dogger area will make up a larger proportion of the total catch, again artificially inflating the perceived Sandeel population.

We thus conclude that spatial heterogeneity in this ecosystem has the potential to bias the assessment procedure and can easily lead to overestimation of the available stock, and subsequent overfishing and stock depletion. Future management schemes must thus take care to avoid this potential pitfall.

4 Options for future management arrangements

4.1 Background

The knowledge on the population structure and dynamics of the sandeel in the North Sea and on the fisheries on the stock has increased significantly over the last ten years. This includes both a better understanding of the population structure and spatial behaviour of sandeel, and a better understanding of how various management regimes can be evaluated and how they can be expected to work.

This *Ad Hoc* Group considers the current management plan is not suitable as a long term management measure for the sandeel fishery. The group proposes that future management plans should take account of the spatial structure of sandeels. A key reason for this is the sub-stock structure identified in North Sea sandeels (Wright *et al.*, 1998a). The North Sea stock is comprised of several different aggregations with very limited exchange between those in ICES areas IVb west, IV b east and IVc. This is because sandeel distribution is limited by the highly fragmented nature of the sediment that they bury in following settlement (Wright *et al.*, 1998b; 2000). Further once settled sandeels do not migrate over large distances (Gauld, 1990; Popp Madsen unpublished information). As sandeel eggs are demersal and the larvae are only pelagic for a relatively short period (50–90 days) prior to the appearance of strong density driven currents there is very limited exchange across the North Sea (Proctor *et al.*, 1998; Munk *et al.*, 2002). As a result the North Sea stock can be considered as a complex of local populations and that therefore sandeels will not freely redistribute in response to regional variation in exploitation.

Dredge surveys conducted by DIFRES and IMR have demonstrated that the decline in the North Sea stock has been accompanied with several areas with very low abundance. Further, local declines in abundance have in certain areas been found to be related to fishing (ICES 2006a Working group report). This is contrary to ICES advice that local depletion of sandeel aggregations should be prevented, especially in those areas where predators congregate (ICES 2003). Marked differences in size and maturity at age between local populations may also affect regional responses to exploitation (Jensen, 2001; Boulcott *et al*., 2007). Regional differences in catch rates (see Section 3.5) emphasise the need for spatial management. Furthermore, as noted in Section 3.3, the performance of the current in-year monitoring management regime is highly sensitive to assumptions that have to be made at several steps in the deriving of a TAC. Therefore, a key requirement for future management is to implement measures that promote replenishment of grounds with a low sandeel density.

As the current management regime is considered insufficient, there is a need to explore future management arrangements which may have other elements both with regard to the information that is used for tactical decisions, and the instruments that are be used for implementing the management.

Developing a future management will require an extensive process where all aspects of sandeel biology, data availability and trade-offs between objectives will have to be taken into account. The *Ad Hoc* Group is not in the position to come up with a definite proposal for a future management, but suggests that the process is initiated. In the following some elements that should be taken into account are outlined, and the pros and cons of some alternative management strategies are discussed briefly.

4.2 Input to the development of a future management plan

4.2.1 Points that need to be taken into account

Sandeel has some characteristics that should be taken into account when designing a management strategy:

1) It is a short lived species where both the catches and the spawning stock are dominated by 1–2 year classes. A prediction of the development of the stock, even in the short term, will be strongly dependent on assumptions about incoming year classes. Accordingly, following the standard procedure for setting a TAC from assessment and prediction requires precise knowledge of the recruitment. The recruitment is highly variable and unpredictable, and there are at present no reliable measures of the recruiting year classes before they enter the fishery.

2) Sandeel is distributed in distinct grounds where the bottom conditions are favourable. The larvae are pelagic and the only life stage where large-scale exchange is likely. Hence, the potential for exchange between sandeel grounds is largely a function of larval transport and the subsequent settlement to grounds by early juveniles. Estimates of the scale of transport suggest that most exchange is < 100 km although this of course varies among years. Therefore, most of the recruitment comes from parents from the same aggregation of grounds and it cannot be assumed that areas with a low sandeel density can be readily re-populated from other areas. In that sense, the North Sea sandeel should be regarded as a set of sub-stocks with limited exchange. Several sandeel grounds have experienced a large decline in abundance in recent years (Figure 7 ; ICES 2006a), so the sandeel is now concentrated on much smaller areas than previously.

3) Sandeel tends to cluster, i.e. the concentration can be very high in small areas (Wright *et al.,* 1998a). That leads to a potentially very high catchability for the fishing gears. Because of this, the relation between effort and fishing mortality is poor, and CPUE at a local scale may give a too optimistic interpretation about local abundance. Furthermore, it has been demonstrated that the CPUE relative to abundance is higher in some areas than in others (See section 3.5).

4) Recruitment has been poor in recent years, and the stock is now not in a good shape. The reason for that is not clear, and causes other than the fishery may have contributed. Nevertheless, the fishery has to adapt to this situation.

4.2.2 Management objectives

The management objectives as stated in the request to ICES include maximum sustainable yields, consistency with the precautionary approach, prevention of local depletion of sandeel aggregations and taking into account the role of sandeel in the ecosystem. Furthermore, the performance of a management strategy with respect to objectives or preferences from the industry may have to be considered in the developing process. Such preferences may include stable and predictable conditions on one hand and maximising long term yield on the other.

4.3 Outline of some management strategies

In this section, we outline some common designs of management strategies and discuss their applicability to the North Sea sandeel.

4.3.1 Extended effort regulation

One alternative management regime could include the combination of a strong access control to limit the effort, and a TAC derived from real-time monitoring. Under normal circumstances this TAC should be non-constraining and the fishery would effectively be effort regulated, but it would come into effect if there are indications that incoming year classes are poor. Previous simulations conducted to show the performance of in year monitoring (ICES, 2006a) has covered some of this kind of strategy, as they showed that having a constraint on both fishing mortality and TAC would be necessary in addition to the in year TAC regime, to avoid risk to the SSB limits. In such regimes, it is necessary to ensure that the effective effort, which generates the fishing mortality, does not increase even if the nominal effort is kept constant. Likewise, it may be necessary to adjust the effort according to the development of the stock. Hence, part of such a regime, a rule to adjust the effort, should be in place, probably based on analytic assessments. The design of such a rule is not trivial, because too strong adjustments may amplify the noise in the assessments.

The advantage of this kind of regime would be that it allows the fleet to operate freely, and that the management would be less dependent on uncertain assessments. Two major disadvantages are apparent. One is that it does not take the substructure of the sandeel stock into account, and that even a strong limitation of participation in the fishery probably may not prevent local depletion. The other is that the relation between effort and fishing mortality is poor for sandeel. Hence, regulating effort may not be a straightforward way of controlling fishing mortality. Therefore, a simple effort control regime is hardly relevant for this stock, although effort control to limit the fishing mortality, may be worth considering as one out of several elements in a management strategy.

4.3.2 Area closures

To take the sub-structure of the stock into account, local measures will be necessary. In principle, this would require separate management for each sandeel area. A first step in that direction would be to close areas where local abundance is low. A further step would be to establish area closures as a regular instrument in a management strategy.

Assessment based management for each sandeel ground is unlikely to be relevant. It would require a massive effort both to collect data and to assess a large number of sub-stocks, and may easily break down due to assessment uncertainty. Hence, area-wise management would in practise imply closure of certain areas. This can be done either on a permanent or almost permanent basis, which would lead to an MPA regime, or as temporary closures guided by survey information.

By reducing mortality MPAs could locally enhance sandeel numbers so long as environmental conditions were favourable for recruitment. An example of this was seen in the early years of the precautionary closure off the north east UK (Wright *et al*., 2002). If properly designed a network of MPAs may also function as reserves to provide supplements of sandeel to the open areas. Such networks would have to account for the limited transport and active movement of sandeels among grounds. Some areas are already effectively closed to the sandeel fishery because the areas of suitable sediment are too interspersed with rougher ground to make trawling viable. However, based on the distribution of suitable sediments there are probably not large areas such potential refuge (Wright *et al*., 1998). Improvements in technology may allow fishing in some such areas. The effects of such changes in the fishery were not further discussed by the *Ad Hoc* Group. Permanent closures of some areas may not avoid local depletion of open areas, especially given that effort will be displaced.

The temporary closing of areas may be a better option than permanent closures to enable recovery of locally depleted fishing grounds. A regime with temporal closures would have to consider how effort is reallocated, as well as criteria for closing and opening areas, and ways of monitoring the state of the stock within the closed areas. The extent to which a sandeel ground can be repopulated from neighbouring areas varies. Hence, the motive for closing a ground may be to protect the ground itself from overfishing, but also to ensure supplements of recruits to neighbouring grounds.

Addressing these questions will require in-depth studies of the spatial dynamics of the stock. Model tools to elucidate the effects of closing areas are under development, and seem promising for the purpose, but are not yet ready for regular use (see Section 4.6).

The *Ad Hoc* Group considers that some kind of local management is necessary as part of a management strategy for sandeel. Most likely, that would be rules for opening and closing areas. The criteria for opening and closing, as well as the need for additional general management measures, will need further consideration, and will require a considerable amount of work, although this is being considered in ongoing research (see Section 4.6).

4.3.3 Indicator based management

Indicators are any kind of information – qualitative or quantitative - about the stock that does not go directly into an analytic assessment. The use of such indicators as part of a management strategy has attracted considerable interest in recent years, in particular in the context of ecosystem management, but also for fisheries management (See SGMAS 2007, Section 3 (ICES, 2007)). A management plan based on simple indicators is fundamentally suited to a strategy that can prioritize stability in yield over optimization of exploitation. Indicator-based harvest rules will then typically imply rules for change in regulations (e.g. TACs, effort etc.) rather than explicit levels. Given the rapid dynamics and uncertain recruitments typical of sandeel, applying this paradigm face value is not promising. Nevertheless, indicators may be considered as a supplement to analytic assessments in a management strategy. Indicators could be used to modify a TAC or effort level that is derived primarily on the basis of an analytic assessment or as part of an in-year monitoring. For example, a more conservative TAC may be decided if surveys indicate a shrinking of the distribution area. Candidate indicators could then be:

•Early CPUE

•Area distribution

- Dredge survey
- Acoustic survey

•Environmental drivers

- Temperature,
- plankton

•Environmental consequences

4.3.4 Fixed quotas

Setting quotas that remain unchanged indefinitely unless there are strong indications to change, has been discussed to make the management less dependent on noisy assessments, and give more predictable conditions for the industry, in particular in data-poor situations. To reduce the risk, the fixed TAC will have to be conservative, and may imply a substantial loss in long term yield. The loss is greater if the stock is short lived, the recruitment is variable and the stock is depleted when the regime is introduced (Skagen, 2007). Hence, the sandeel stock may not be a promising candidate for this kind of management, unless stability has very high priority over maximum yield.

4.3.5 Self-regulation

In previous years, the fishery for sandeel has been more or less self-regulated. When the CPUE became too low, the fishery stopped for economical reasons. There were no restrictive quotas and no direct control over effort until 2005 in the EU. In Norway, there is a licensing scheme but no constraints on the fishery beyond that until recent years. The incentive for stopping fishing has been related to the stock abundance through CPUE, and to economics through the price of sandeel, which is sensitive to market prices for alternatives to fish meal.

With the present poor recruitment, the self regulation has not prevented a reduction in the overall abundance of sandeel or local depletion of several sandeel grounds.

4.3.6 Conclusion

Some common management strategy designs have been outlined and discussed in the context of the sandeel management. None of these seem feasible in their standard form. Hence, combining elements from several of these options, *inter alia* taking the stock structure of the sandeel into account, should be considered.

That implies that the process of developing management strategies will be more complex than for many other stocks. It will involve trade-off between a range of candidate objectives, and it will require modelling and simulation work well beyond what has been common practise for other stocks. The group recommends that this process be initiated without delay, as the current regime is not satisfactory. It further recommends that it involves a broad participation of scientists, managers and stakeholders, and that sufficient time and manpower is allocated to the process.

4.4 Fisheries independent information on sandeel abundance

Due to the highly variable and unpredictable recruitment of sandeels and influence it has on stock size and the fishing opportunities there is a large demand for information that can be used to estimate the size of the incoming year-class. However, as commercial CPUE is a poor predictor of year-class strength only fishery independent surveys can provide such information. The need for such information has increased due to the drastic decline in the North Sea sandeel stock in recent years.

No fishery independent surveys on sandeels abundance are used in the assessment of sandeels in the North Sea. Sandeels are not caught during the ICES routine surveys and dedicated sandeel surveys have only been established in recent years to provide large scale abundance estimates of sandeels. A comparison of the methods used for measuring abundance of post-settled sandeels (juvenile and older sandeels) has been carried out by Greenstreet *et al.* (2006). This analysis showed that survey indices of sandeels must take account of the highly variable fraction of sandeels that may reside in the seabed during the time of survey, in order to provide unbiased estimates of sandeel abundance.

Since 2003 DIFRES has used a modified scallop dredge to measure the relative abundance of sandeels in the seabed. The survey is conducted in November/December, after the time that 0-group sandeels have been recruited to the adult population and the whole of the population is assumed to reside in the seabed. Sampling is carried out at fixed positions on known sandeel habitat at some of the most important fishing banks in the North Sea from the Little Fisher Bank in the North Eastern North Sea, to the Dogger Bank area in the south western North Sea. In 2006 additional positions were sampled in the Norwegian EEZ. This survey has the potential to establish a time series of indices that can be used for tuning the historic assessment, and to estimate the size of the incoming year-class all ready in January, before the decisions about how the fishery will be managed have to be made. The survey was able to predict a decrease in local abundance from 2004 to 2005 and an increase from 2005 to 2006, as suggested by the fishing pattern and the assessment. Preliminary information from the cruise in December 2006 indicates that the 2006 year class is well below average.

The Institute of Marine research (IMR) will conduct two surveys in 2007, one in April/May 2007 to measure the abundance 1+ and another to assess the abundance of 0-group sandeels in August/September. These cruises will combine acoustic estimates of sandeel abundance in the water column during daytime, and a modified scallop dredge (Danish type) to sample sandeels in the seabed during night. The April/May survey has the potential to provide an estimate of stock size of age-1+ sandeels and consider availability to fishing vessels. Further, the survey in the autumn has the potential to provide an early estimate of the size of the incoming year class. Both surveys can be used for identifying areas of low stock abundance.

4.5 Management arrangements for 2008

The scientific basis for developing a long-term management strategy for the sandeel fisheries in accordance with the objectives of maximum sustainable yields and sustainable development of the stock, taking into account the role of sandeel in the ecosystem may, as described in Section 4.6, be available within a few years. However, the *Ad Hoc* Group does not consider it possible to have a long-term approach developed and implemented before the start of the 2008 fishing season. The *Ad Hoc* Group therefore recommends that the starting point for developing the management advice for 2008 be the management strategy suggested by ICES for 2007.

The management strategy applied for 2007 does, however, not address the issue of local depletion of sandeel aggregations. The low stock size observed in recent years may increase the risk of local depletion, and there is a need to manage the fisheries on a finer spatial scale than currently applied. The present knowledge on defining sub-populations is too limited to recommend management measures by sub-population for 2008. The information to be compiled during 2007 may, however, make it possible to identify fishing grounds where continued fishing may prevent replenishment of the local aggregations.

The information that may be used as basis for recommendations on closures is:

- results of the real time monitoring,
- spatial distribution of landings,
- updated stock assessment,
- results from an acoustic/dredge spring survey, a spring larval survey and a December dredge survey.

The results of the December dredge survey has in recent years been consistent with the results of the real time monitoring system and may provide a good estimate of the recruitment. To allow the results of the survey to be used when providing the advice on possible closures of the sandeel fisheries in 2008 the *Ad Hoc* Group recommends that the sandeel advice is postponed until January 2008 when the survey results become available.

4.6 Recent progress in modelling of sandeel in the North Sea

Modelling of the sandeel life cycle in the North Sea ecosystem is progressing along different lines and is supported by EU and national research projects e.g. PROTECT, BECAUSE and the Danish sandeel fishery forecast model. The major components are:

- A 3D-hydrographically coupled Sandeel Larval Advection Model including temperature driven growth provides a year by year transport matrix between all known sandeel banks in the North Sea (SLAM) (see Annex 2 for further details).
- A spatially resolved Sandeel Population Analysis Model (SPAM) (see Annex 2).

- A number of supporting activities supply basic information and sub-models as input for SLAM and SPAM.

A final major component is a fisheries bio-economic model (BEMCOM) that analyse cost and earnings in the industrial fleet based on the sandeel population dynamics and fishing economy. The model estimates the economic consequences of different management scenarios and changes fleet behaviour following from changes in management.

The *Ad Hoc* Group considered this to be a promising approach that primarily needs further model development and testing. The approach provides two main areas of application 1) scenario modelling of management measures and 2) short term predictions of local fishing opportunities. Scenario modelling may build on available historical data, whereas the parameterization for model short term predictions require data from real time hydrographical model output as well as recent information of local catches and their composition supported by 0-group surveys that estimate the latest recruitment pattern and abundance.

To make the approach operational model predictions should be formulated into objective functions that match observed data.

Potential candidates for objective functions to estimate different parameters may be 1) the time series of estimated biomass per bank matched against the time series of observed annual bank specific CPUE; 2) bank resolved age and length distributions that may be matched against unbiased dredge samples of the total buried bank population; 3) age resolved per bank harvest that may be matched against population analysis on selected banks with sufficient in season sampling; 4) estimated larval distribution and abundance from combined SLAM and SPAM matched against different surveys covering the larval drift period.

The framework for developing the approach is the national and international research projects where a beta version of an operational model is an important deliverable within the project reporting period.

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Figures

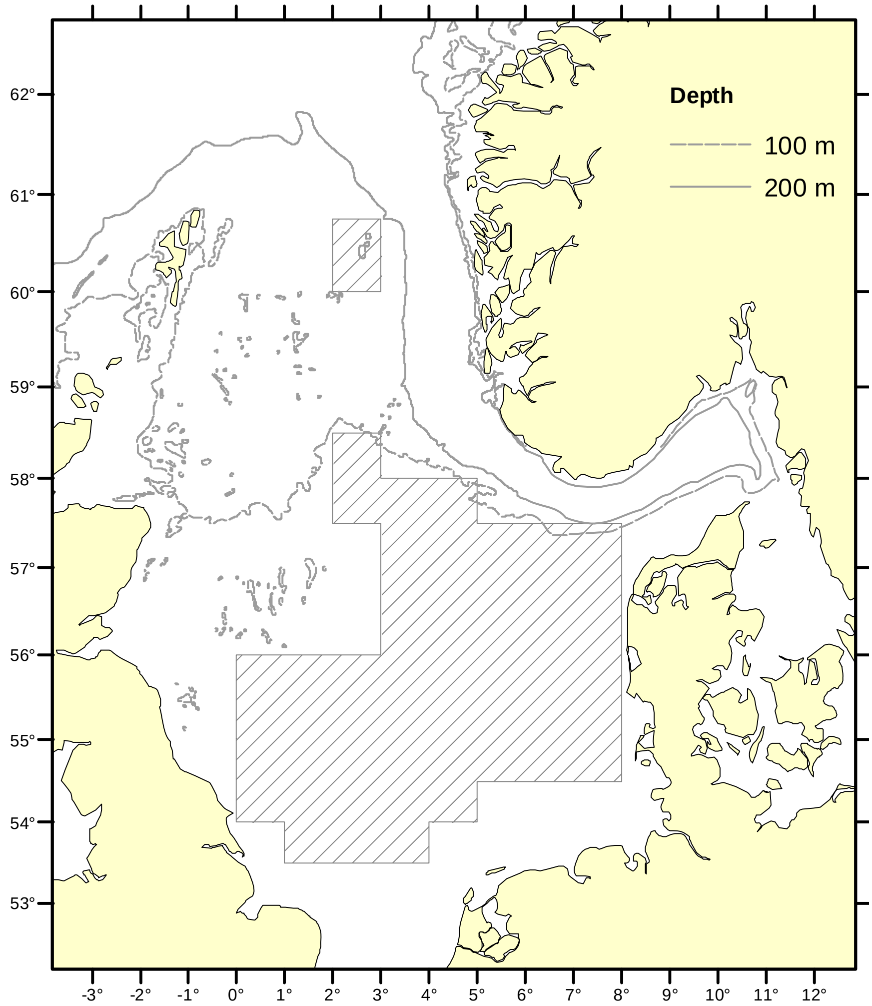

Figure 1. "The sandeel area" which was used to define days at sea for fishing trips. Includes all the sandeel fishing grounds used by the Norwegian fleet in 2001–2006.

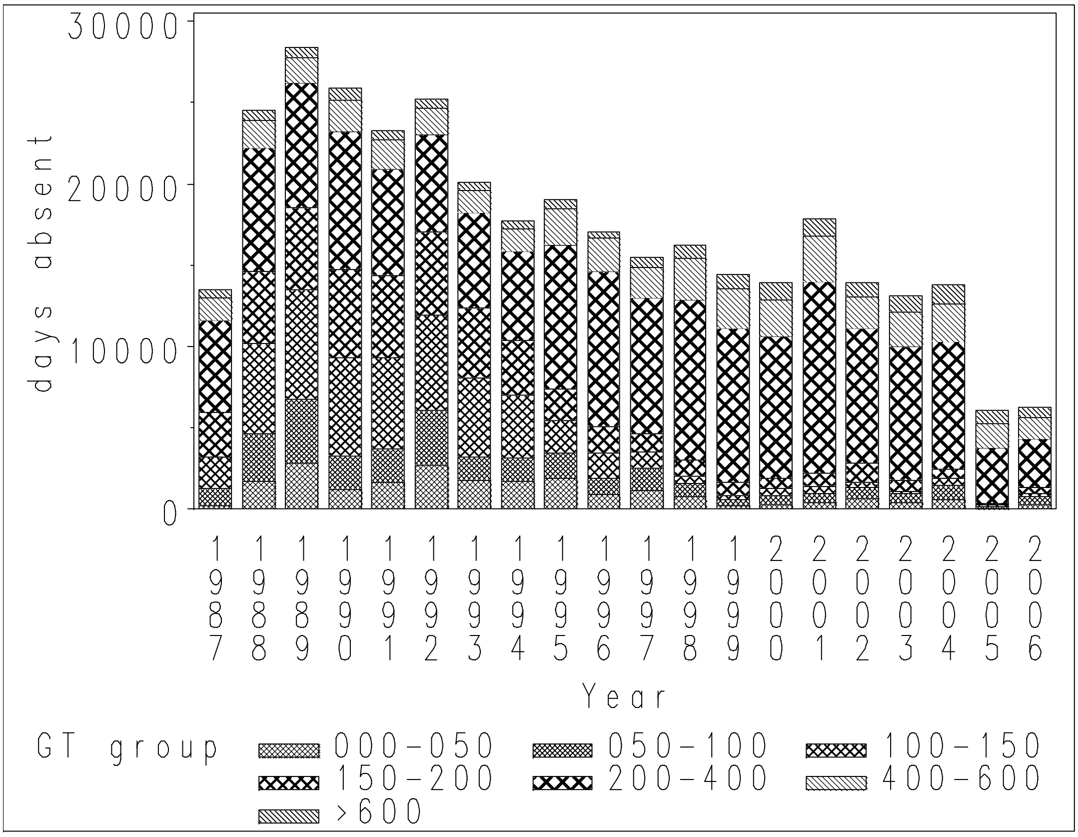

Figure 2. Effort (days absent) by GT class and year for the years 1987–2006.

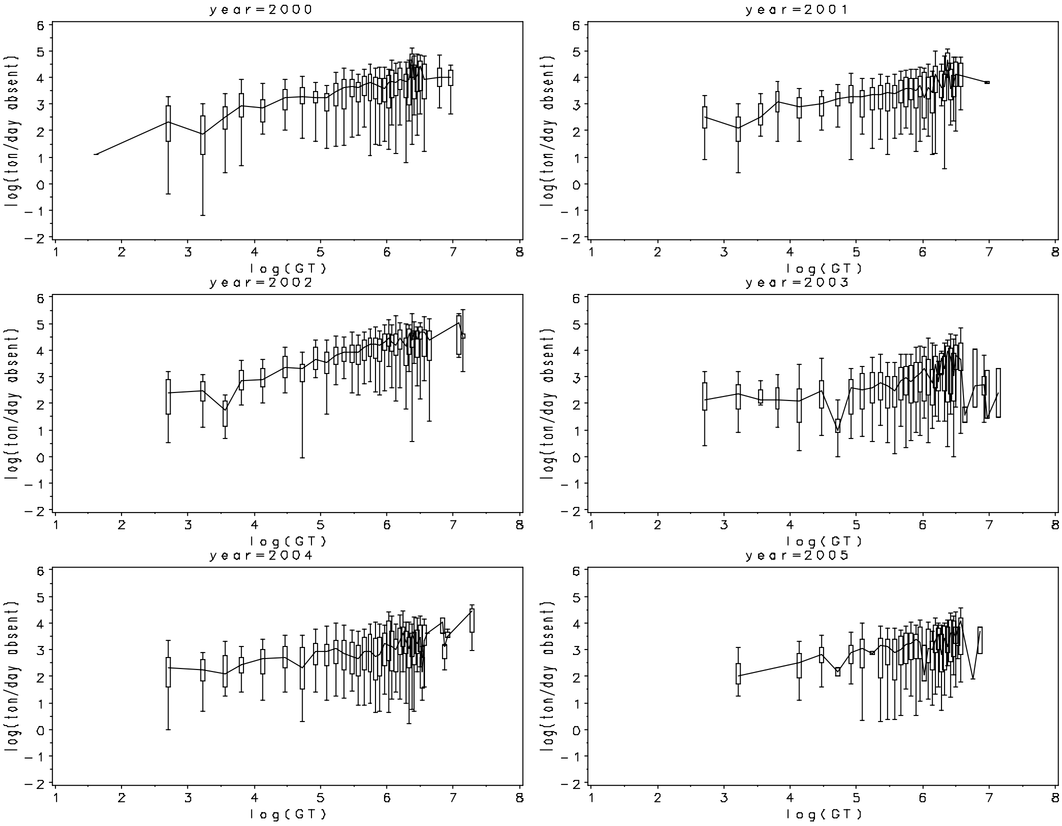

Figure 3. Boxplot (5,25,50,75 and 95th percentiles) of CPUE by GT group.

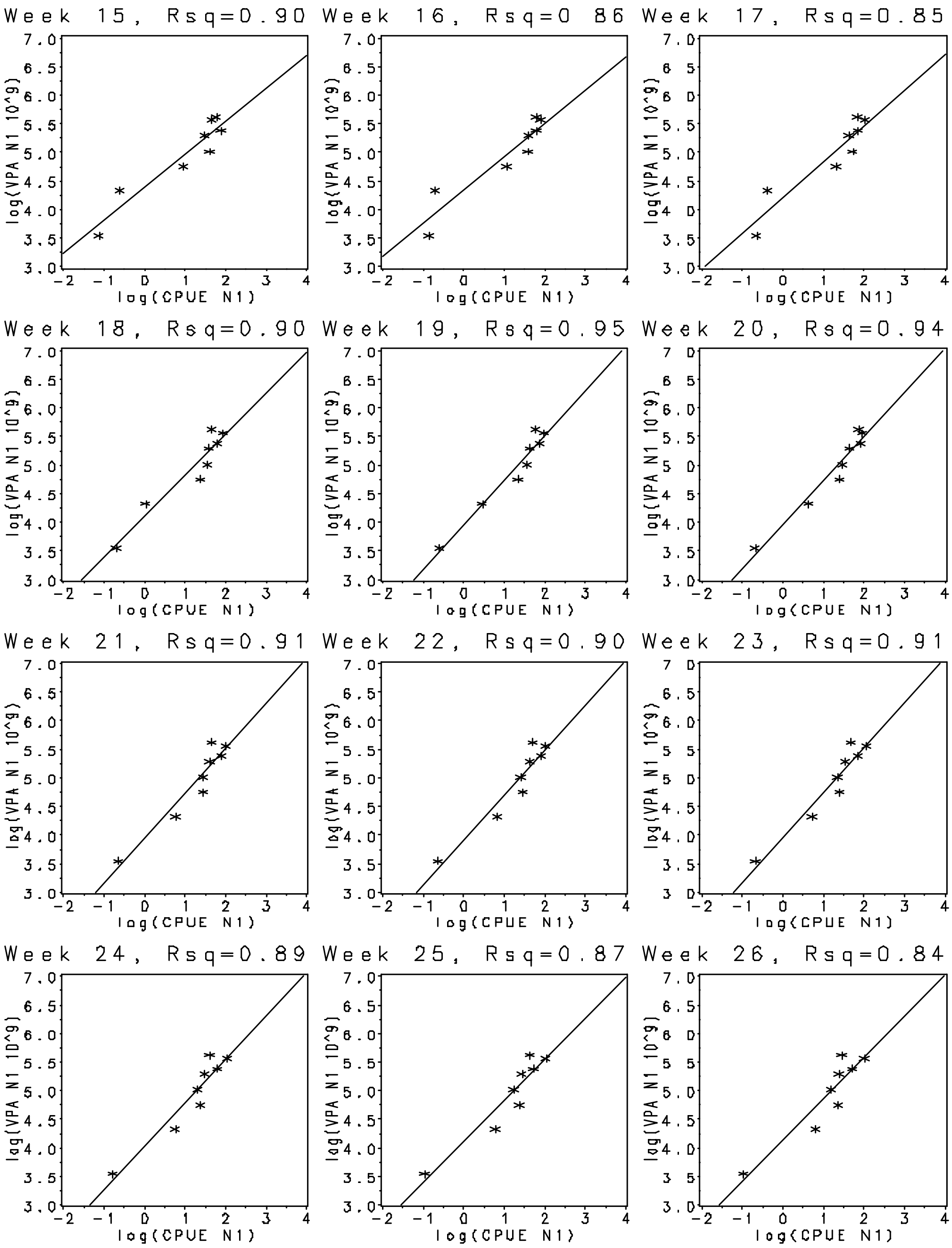

Figure 4. Weekly regression analysis of log(VPA-1-group, billions) on cumulative log(CPUE 1-group, millions).

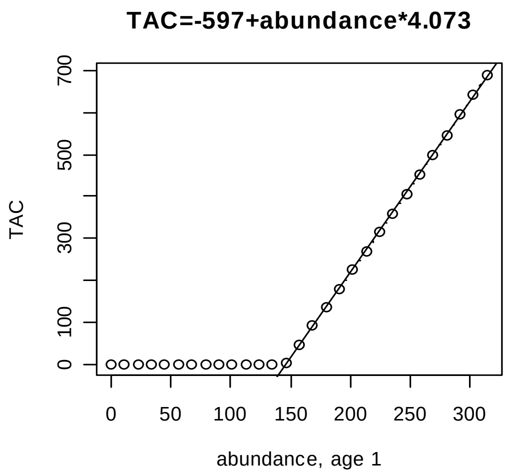

Figure 5. Relation between N1 abundance and TAC.

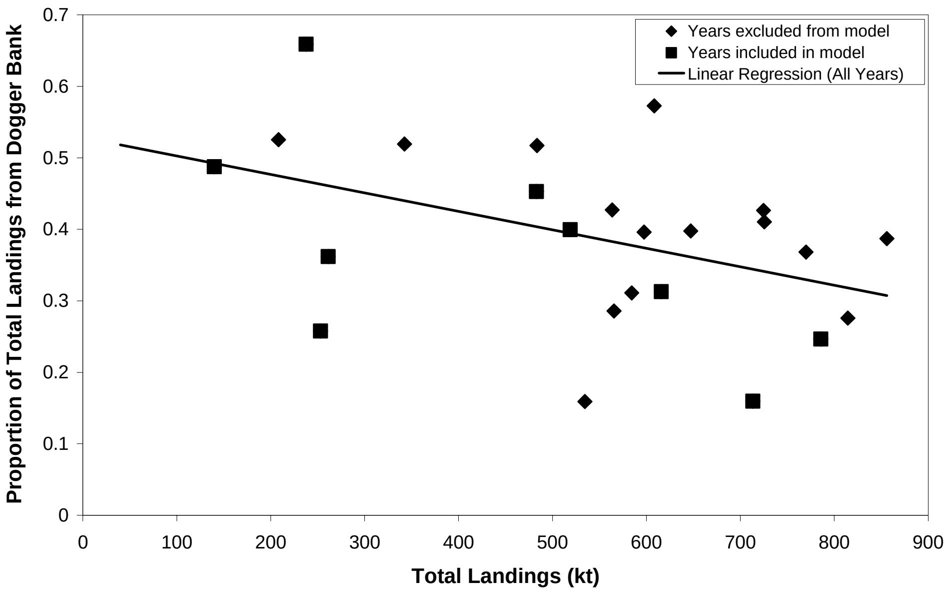

Figure 6. The proportion of total landings caught in the Dogger Bank region as a function of total Sandeel landings. The figure differentiates between years which were included in the CPUE regression model (1991, 1994, 1999, 2000, 2001, 2003, 2004, and 2005, denoted by ■) and those excluded from the model (♦). A linear regression line shows the significant negative correlation (r^2=0.185, t=2.23, df=22, p=0.036) between the parameters.

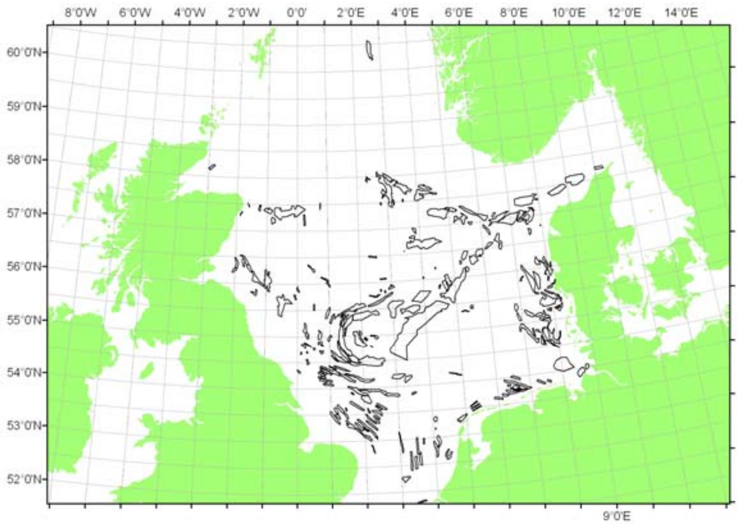

Figure 7. Distribution of sandeel fishing grounds.

Annex 1: Participants

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Annex 2: Development of a sandeel population model

Modelling of the sandeel life cycle in the North Sea ecosystem progress along different lines and supported by EU and national research projects e.g PROTECT, BECAUSE and the Danish sandeel fishery forecast model. The major components are:

A 3D-hydrographically coupled Sandeel Larval Advection Model including temperature driven growth provides a year by year transport matrix between all known sandeel banks in the North Sea (SLAM).

A spatially resolved Sandeel Population Analysis Model (SPAM) (see Annex 1).

A number of supporting activities supply basic information and sub-models as input for SLAM and SPAM. Details of these models are given below:

SLAM

A flexible, coupled hydrodynamic and individual based model (IBM) framework has been developed from previous work (Schrum *et al.*, 2003, Alekseeva *et al.*, 2004). It features a 3D coupled hydrodynamic ECOSMO (Alekseeva *et al., 2004*) with an individual-based model (IBM) for the early life-stages (egg/larvae) of the lesser sandeel, based on the underlying physical-biological processes. The setup is sketched in Figure 1, left.

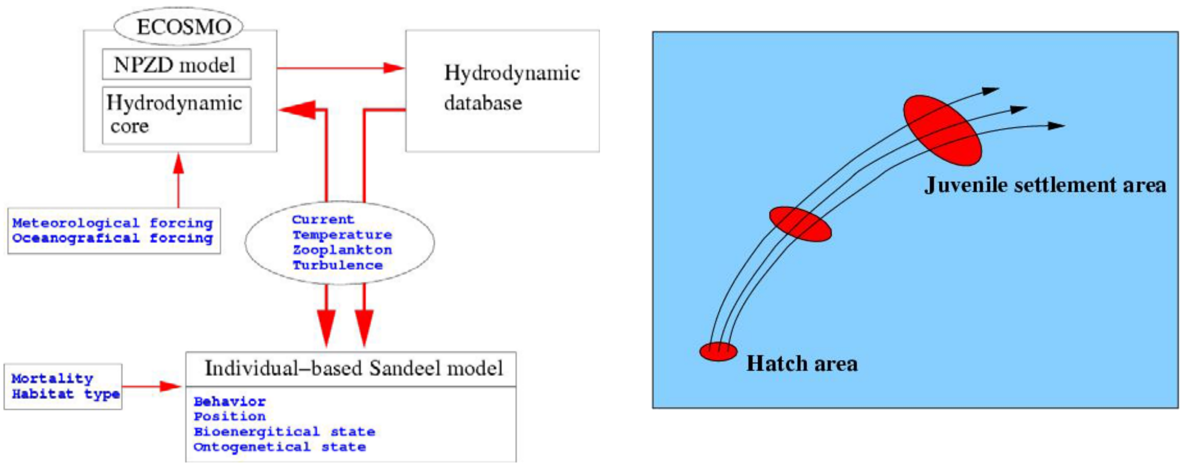

Figure 1. Sketch of coupled hydrodynamic/IBM model

Hydrodynamic model

The hydrodynamic model (Schrum and Backhaus, 1999) is based on a staggered Arakawa C-grid with a 5 nm horizontal resolution, open surface and 5 m layers down to a depth of 40 m (and 8 m layers below 40 m depth). The physical fields from the ECOSMO model (currents, temperature, salinity, turbulence) are applied to the IBM as daily averaged fields (for data compression purposes).

Particle tracking

Horizontally, the larvae are described as passive floaters, with no explicit active vertical/horizontal migratory behaviour. Vertically, the dominant dispersal mechanism in the North Sea is turbulent diffusion, due to subgrid processes, coupled to current layer shear. The larvae move vertically in the water column according to a random walk process with local jump amplitudes reproducing local Eulerian field dispersal rates, which are proportional to the square root of the local diffusivity *K(x,y,z)*. Since the description of the motion of an ensemble of non-infinitesimal tracers in a turbulent field still contains open questions, we compare two random walk schemes (Visser, 1997): simple random walk (SRW), and canonical random walk (CRW) to access the possible influence of this question. The difference indicates the influence of patchiness in the vertical larvae distribution on horizontal larvae transport. Alternatively, one may put forward that the difference between the SRW and CRW accesses the influence of active vertical behaviour in a very crude level, because tracers in SRW tend to aggregate in low-turbulence areas, which in the North Sea, to a large extend, coincides with areas of high secondary production.

Only vertical turbulent dispersal is taken into account, since this is normally believed to be the dominant horizontal dispersal mechanism, along with residual current transport (by transporting material between layers with different horizontal currents speeds). As larvae are hatched and advected, they disperse relative to each other; this is sketched in Figure 1, right. The physically released larvae population are mathematically sampled by a representative tracers (a meta population) which each represents a fixed number of individuals (the ratio need not be stipulated, since density effects are not addressed explicitly, only relative numbers matter).

Individual-based biological model

The biological part of the IBM contains an egg and a larvae submodel. The biological states are updated daily, based on the physical environment. We model the hatch process stochastically, because the extended hatch period is probably an important part in the sandeel life strategy, because larval recruitment success are believed to be strongly dependent on proper timing with secondary marine production. Strictly deterministic modelling of the hatch process will give a time-peaked hatch process, if eggs are releases on a specific time. This would not be in correspondence with field observations.

Stochastic egg development model

The eggs are developed according to a hatch probability function, as parameterized from the egg develop experiment of Smigielski *et al.*, 1984. These fits are mapped to an adiabatic hatch probability function, depending parametrically on temperature. When eggs are developed according to the stochastic egg model, each egg is automatically promoted to a larvae individual starting at the bottom, when the egg development according to the model above is complete.

Larval growth model

The larval growth model accounts for the length growth of larvae as a deterministic, daily increment, according to

$$\frac{dL}{dt} = L^{\gamma}\lambda(T)(1-\frac{L}{L_{\infty}})$$

This growth model is parameterized to North Sea MIK trawl data from 1995 and 1996 (Jensen, 2001). Larval ages were obtained by otolith analysis. The model parameterization was performed by back-tracing larval samples individually from catch time and location, thereby recreating the expected hydrodynamical history of larval sampled at various places in the North Sea.

Initialization of larval/egg populations

In our setup, tracers may be initialized in an arbitrary egg or larval state (or a mixed set). Eggs are immobile and demersal, whereas larvae are pelagic (but released at the bottom). Eggs/larvae are released on the suitable habitats in the North Sea, as described below. For later use, we will distinguish simulations according to how tracers are released by the following notation

Sandeel Habitats

The suitable sandeel habitats in the North Sea have recently been mapped by H. Jensen from fishery data (Jensen 2005 to (see Figure 7)). These sandeel habitats has been projected onto hydrodynamic cells (5x5 nm), in which sandeel hatch and settle. To analyze patterns in population variability, these 596 high resolution habitat cells are also clustered into 5 larger regional bank systems. Other more detailed regional divisions are conceivable and well-justifiable, but this generally places higher demands on our biological submodels and assumptions and further large volumes of data tend to obscure the patterns present in the results. Especially, a much more fine-grained bank division may require a more detailed settlement model than the simple one used in our work. It is likely that habitat choice happens gradually around the length of metamorphosis $L=L_m$. This uncertainty is absorbed by choosing a coarse-grained bank system definition, because it is only boundary cases that are affected by this uncertainity: the transport matrices T_{ij} are unaffected of exact settlement positions, as long as they are in the correct bank system. The lateral extend of our bank systems are typically larger than 100 km.

Larval transport

We wish to quantify transport between banks and retention on banks, as sketched on Figure 2.

Often the concept of transport is used casually and to clarify the our meaning of transport, the dependence of simulation parameters we give a rather formal definition of transport indices, in the sense we use it.

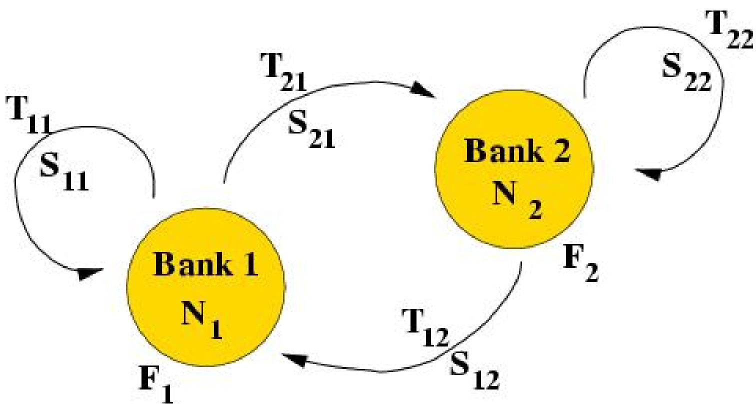

Figure 2. Notation for inter and intra bank transport.

Hydrographic transport is a linear process, meaning that it is transported matter is proportional to the released amount of matter and that transport from one point to another is independent of initial distribution of larvae. In other words, the net transport is a weighted superposition of point-to-point transport, where the weighting is the initial distribution of larvae. The function describing the point-to-point transport is the socalled Greens function (or transport kernel) G(x,t,x',t'), which describes the probability of being transported from (x',t') to (x,t). The function G(x,t,x',t') is given by the hydrodynamic model. Normally, hydrodynamical model output the current fields, along with turbulent diffusivity, but this is equivalent to the function G(x,t,x',t'). When using mapped habitats as hatch areas, and a settlement model is specified, the transport matrix T_{ij} (t_0) between habitats is uniquely defined, corresponding to hatch time t_0. As settlement model, we have assumed that larvae settle at the point of metamorphosis, at L_m=40 mm, but results are qualitatively insensitive to a finite time window settlement.

To compute the net recruitment, the conditional survival S (0 < S < 1) has to be specified, along with the bank specific fecundity F. The spatial explicit recruitment R^y_i in year y to bank i given by

$$R_i^y = \sum_j (T_{ij}^y S_{ij}^y F_j^y) N_j^y$$

where N_j^y is the bank specific sandeel abundance.

Technically, a transport matrix for a given year is obtained by releasing 600 000 tracers distributed homogemeously over all 596 hydrograhic cells covering habitats and forward tracking each of them by the approriate biological submodel(s), as described above, until the juvenile stage; then the final positions are reprojected onto the 596 hydrograhic cells covering habitats and the raw 596x596 transport matrix is aggregated into the 5x5 regional transport matrix for further analysis. With the raw, high resolution transport matrices T_R (i.e. the 596x596 transport matrix), it is always possible to calculate the transport for any alternative aggregate bank system.

SPAM

The spatial life cycle model for North Sea sandeel populations, SPAM, integrates the state of sandeel sub-populations one year forward in time, given input of transport, fishery, growth indices etc. for that year. Different options exists for developing predictions of per sandbank age structured population numbers and derived from that total catches with age and length distributions. These predictions may be formally expressed in formulation of objective functions for estimating a number of the basic parameters in the model.

The major state variables of the model are the population cohort abundances N_{ia}, which is the number of individuals on bank i and age a. They have the average length distribution L_{ia} which is the average length of individuals on bank i and age a. The matrices N,L refers to just after January 1 (where the eggs have been spawned). All other state variables and properties of the sandeel populations are derived from N,L matrices. The dynamical equations updating the population distributions are

$$N_{i,a+1} = N_{i,a} e^{-Z_{ia}} + \delta_{a,0} R_i$$

Where the total mortality Z_{ia} is

$$Z_{ia} = Z_{ia}^{harvest} + Z_{ia}^{predation} + Z_{ia}^{background}$$

$Z^{predation}$ and $Z^{background}$ are currently imported from operational VPA models and neglecting spatial variability, but may be estimated in the total objective function. The recruitment R_i (in the update year, age=1 next year) is calculated explicitly as

$$R_i = e^{-Z_{i0}} \sum_{ja} T_{ij} S(\rho_{ij}) F(L_{ja}) N_{ja}$$

T_{ij} is the interbank transport (from 3D hydrodynamic simulations in SLAM). S(ρ) is the density dependent larval drift survival probability. In the model all density effects are modelled by a bank-specific density effect index of the total biomass in relation to a bank

$$B_i = \sum_a (cL_{ia}^b) N_{ia}$$

resolved carrying capacity, where the bank-resolved biomass is

The response on population density ρ may be age –specific. The argumentation for using the same density index for all age-classes is that all compete for the same resources; also, but to a lesser extend, faces the same predators (risk sharing density effect). For drifting larvae, migrating from habitat j to i, we use an average effect between banks i and j, but for non-linear density responses and different residence times in habitat (i,j), a more advanced parameterization may be needed.

The fecundity relation is a power function of length where density effects enters indirectly via growth. The fecundity is assigned to an area explicit length - age related maturity ogive.

The larval/adult growth is also modelled explicitly and density dependent scaling to the growth function.

Since the density index ρ is year-wise constant, the length growth from age classes within a season from $L_0 = L(t_0)$ to $L=L(t_1)$ may be determined analytically. The fit corresponding to ρ = 1 is shown below, along with measured data for sandeel larvae/juveniles.

Improvement of this model formulation tries to include intra year dynamics (for short time scale interactions, like fishery/growth, fishery/density) and growth variability (in addition to average growth), more advanced density effect representations and bioenergetic refinements (condition/fecundity couplings, non-linear survival effects like starvation limit crossing).

Model interface specification

The model is not specific to a particular choice of bank definitions. Biological submodels/parameters are easily modified

1) Input data:
   - $Z^{harvest}$: fishing mortality (bank/age resolved)
   - $Z^{predation}$: predation mortality (bank/age resolved)
   - $Z^{background}$: other natural mortality (bank/age resolved)
   - T: interbank larval transport
   - C: bank biomass caring capacity
   - Initial guesses on N,L (for model spin-up)
   - Biological parameters

2) Output data:
   - N: sandeel population (bank/age resolved)
   - L: average lengths (bank/age resolved)
   - H: catch in biomass (bank/age resolved)
   - B: sandeel biomass (bank/age resolved)
   - R: recruitment (resolved on target/destination bank)
   - SSB: spawning stock biomass (age and length based, bank resolved)

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Annex 3: Reviews of the Report of the *Ad hoc* Group on North Sea Sandeel

Review by Andre Forest

The report is clear, and the ToR have been addressed even if for some of them (options for future management arrangements) it is stated that there is a need for more data and research development. Therefore in my opinion ACFM could adopt conclusions and proposals made by the working group in order to formulate its advice; there are quite large uncertainties about biology of sandeel, fisheries and stock assessment but the report give the “state of the art”.

Some points for clarification:

- Effort data:

Fishing for Danish and Norwegian fleets are estimated using different data and different methods and are then combined (simply added?) to derive a total Danish and Norwegian fishing effort, before standardization of effort. Such a methodology is questionable (are the two effort series comparable?); according to the report, the effect of including Norwegian data in the procedure of estimating the stock is negligible, due to the low effort and landings of the Norwegian fleet; but one could remark that Norwegian fleet represent 20% of total effort and landings, which is not totally negligible; furthermore, if it is actually negligible, why to include this data in effort estimates?

- Biological data
- Catches estimates by species and age composition of total landings seem to be derived only from Danish samples; is it a cause of concern?
- WG report stipulates that records of *H. lanceolatus* have been discarded for the construction of age compositions of landings; however, there is no indication on the magnitude of the contribution of this species to the total landings of sandeel; SSB estimates and catches projection are performed for *A. marinus* alone (in reality *A. marinus* + *G. semisquamatus)*, but all species are mixed in landings and TAC are for all species combined (as far as I understand!); does it means that TAC estimates are conservative referring to *A. marinus* ?

Review by Franz van Beek

Most relevant is to have a procedure to arrive at a TAC for 2007 and future years. Such a procedure is given for 2007, but there are a number of problems with them so the proposed procedure is not obvious for future years. I am pleased to see that the SG has been critical to its own work and I fully share these critics. The most important conclusion is that the performance of the proposed in-year monitoring management regime is highly sensitive to assumptions that have to be made at several steps in the deriving of a TAC.

Although there is no information on the quality of the basic data in the report, the massage applied to these data is considerable and suggest a large variability in the basic data. A number of 'outliers' in the basic data have been removed on a posteriori reasons which I think can be questioned. I am pointing to selection gates like minimum percentage in catch, maximum trip length, exclusion of years. I suspect that the massage would lead to or increase bias in the signals coming from the remaining data.

There are several factors contributing to the variability of the data such as distribution of the stock and the fishery, which makes it difficult to interpret a cpue from an experimental fishery early 2007 in the polished relationship.

I understand that the critical estimate is the year class 2006 which matures in 2008. This year class should provide a fishery in 2007 and a remaining minimum stock at the start of 2008. The year class is estimated from an early season limited fishery cpue and a 'polished' relationship between cpue and stock number. The proposed method will lead to an estimate of the year class and a TAC decision. However, given the sensitivity to all assumptions I think there is no or little guarantee that the decision will lead to the expected effect.

May be it is possible to test the estimation of the year class size using hind casting. For each year (also the excluded ones) there are fishery data from which a 'limited fishery cpue' can be sampled to estimate the year class. This would give an indication how well this part of the procedure works.

With regard to complying to the terms of reference on setting up a monitoring system there are some suggestions of what is done (surveys and cpue monitoring) or could be done but it seems to early to give a recommendation what to do. The group is clear that the procedure for 2007 is a temporary solution.

Further, I note that the SG considers the sandeel in the North Sea as a set of substocks with only limited exchange. It this is true, the recent failures of recruitment, appear to affect all substocks simultaneously. This makes it unlikely that the fishery for sandeel or side effects of other fisheries are responsible for the recruitment failure.

I also note that the participants of the group with the exception of the chair were all Danish or Norwegian. A solution to the problem has been sought by exploring variable (or poor) data, may be pretending that we do better than we actually can. The group would benefit from a few outsiders bringing in alternative idea's.

Review by Martin Pastoors

P 7.

- Bias correction of the assessment: what is the value that is used. Is it a fixed value over time? Is the bias plotted somewhere?
- What is the basis for the TAC equation: TAC=-597 + 4.073 * N1. I can see the figure for this relationship, but that is not very interesting. It would be more interesting to know the basis of it.
- Third paragraph: it is not enough to say that these arguments have been carefully considered in a long process. That is not going to convince anyone. What ARE the arguments!

P 11

- Are there time series of CPUE by area available?
- **FUNDAMENTAL ISSUE:** bias in CPUE could occur due to spatial distribution of the fleet! How does that affect the previous results and the TAC formula?

P 16

- "Commercial CPUE is a poor predictor of year-class strength"? On the one hand we are building on commercial CPUE in predictor of N1 and on the other hand we say it is a bad predictor?

Review by Alberto Murta

The Ad Hoc Group on Sandeel had the difficult tasks of standardising CPUE data from commercial vessels, use the available biological samples to obtain standardised CPUE in number at age 1, and finaly to produce a meaningful relationship between the series of CPUE data and the latest assessment estimates of the series of numbers at age 1. As stated in the report, the reliability of the abundance indices and of the assessment estimates is expected to be higher in the future, once fisheries independent information becomes available, a better knowledge of the sandeel population dynamics is achieved, and its spatial and sub-population structure is taken into account.

Regarding the preparation of the biological and effort data used, it is clear that there was a great deal of work to make the avaliable data as reliable as possible. The procedures described to filter possible errors from the biological data seem very adequate. As it is said that the Norwegian catch and effort data will start, in 2007, to be based on real logbook data, instead of VMS data, it seems advisable that both systems would be kept in parallel for some time, in order to check the differences between the two sources of data.

For the two principal tasks, standardising CPUE and building a relationship between CPUE and abundance of age 1 sandeel, the Group relied exclusively on regression techniques, making in both cases similar options that are in some way questionable. When standardising CPUE, it was assumed that the CPUE was related to Gross Tonnage as: CPUEy = ay×GTb. However, to estimate parameters ay (in fact log ay, expression 2 in page 4 is wrong) and b, it is stated that “a log transformation was required to stabilise the variance in CPUE”. An adequate procedure to deal with heterogeneous variance would be, for example, using weighted least-squares instead of ordinary least-squares. However the Group decided to linearize a non-linear model, taking the risk of obtaining different estimates of the parameters than those that would have been obtained by a non-linear fitting procedure. That option also changed the relative weight of vessels with different GT, giving a higher importance to vessels with low GT, as acknowledged in the text. Nevertheless, having decided to transform the data to linearize the model, the option to just use observations with GT between 50 and 600, in order to keep a linear relationship, seems adequate.

Another option that seems questionable is to use a different b parameter estimate for each week, when standardising effort. As can be seen in Table 3.1, the b estimates are all close to 0.4, except for the 1st week (week 12). It would be expected that the relationship between CPUE and GT would not change throughout the fishing season, except for the initial weeks, probably due to the exploratory behaviour of the fleet. Therefore, to use a different b for each week could be just introducing needless noise in the data.

The relationship between CPUE and estimated abundance at age 1 was defined in a similar way to the model used to standardise CPUE. A model with log-transformed data, logN1 = a + b × log CPUE1, was used in order to “give a more uniform distribution of the residuals”. However, it is said that, even after the log-transformation of the data, the relationship between N1 and CPUE1 was still not linear. This could indicate that, not just linearizing was a bad option, but also that the implicit model, N1 = exp(a)×CPUEb 1, was probably not the most appropriate to describe the relationship between N1 and CPUE1. Instead of exploring other possible models (if that exploration was done, it is not described in the report), such as N1 being exponentially related to CPUE1, the Group decided for a censoring of the data, not by truncating the range of values in the x axis, as done for CPUE standardisation, but by removing the observations in the y axis that did not conform with a linear relationship. Those observations indicated that CPUE values in a very close range could correspond to very different abundances. By removing the high abundance observations, the model will probably give biased predictions, not being able to predict strong year-classes.

While removing data points corresponding to years with high SSB seems an adequate option, because in those years the CPUE for age 1 could have been unreliable, to remove observations with reliable CPUE values, just because the corresponding abundance estimates do not fall in a straight line, seems an procedure difficult to justify. I would prefer to explore different alternatives to model the relationship between abundance and CPUE, instead of discarding data points. It is stated by the Group that “smaller year classes are the important ones in the present context”, hence expecting that the CPUE1 and corresponding N1 for 2007 would be low. If that will be the case, then the current procedure to predict N1 may provide a sensible figure for practical purposes, although not following the practice that is advised in regression analysis textbooks. I would also calculate and plot the prediction interval for the chosen model (even if it is non-linear), which is more informative regarding the power to predict a new N1 than the CV calculated in the end of page 6 of the report.

In the future, in case there are difficulties in formulating a satisfactory model to relate abundance with CPUE, or there is the need to incorporate other sources of information (e.g. spatial distribution, etc), other non-parametric approaches to predict N1 could be explored. Neural networks, in particular, are an example of non-parametric methods that have revealed great predictive power in non-linear situations.