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The Norwegian in-year monitoring fishery for sandeel in the North Sea using satellite-based VMS data and landings information

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Due to the critically poor status of the sandeel stock in the North Sea, the Norwegian Ministry of Fisheries and Coastal Affairs decided to conduct a monitoring fishery in April/May 2006 with a limited number of Norwegian commercial vessels. An eventual re-opening of the sandeel fishery (in the Norwegian Economic Zone) was to be based on the results from the monitoring fishery. It was later decided that the monitoring fishery should take place in week 16-18. One of the main goals with the monitoring fishery is to obtain an estimate of the strength of the 2005 year class (since age 1 is the most important age group in the fishery). This requires estimation of a relationship between Catch Per Unit Effort (CPUE) and abundance. Logbooks from the Norwegian sandeel fleet are not recorded electronically and it is therefore difficult to perform traditional CPUE calculations. However, data from the Norwegian satellite-based vessel monitoring system (VMS) can be used to measure effort, and CPUE can then be estimated by combining VMS and landings data (which exist electronically on trip level). In this work, some of the preliminary analyses conducted in advance of the monitoring fishery are presented. The correlation between estimated CPUE of age 1 (based on VMS data) and estimated abundance of age 1 (from the latest ICES assessment) was positive and significant ($p < 0.05$) for the years 2001-2005.

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Introduction

ICES classifies the sandeel (*Ammodytes spp.*) stock in the North Sea as having reduced reproductive capacity; the estimated spawning stock biomass were far below B_{lim} both in 2004 and 2005 (ICES 2005a). Prior to 2004 the sandeel fishery in the North Sea was in practise unregulated, but in 2004 onwards EU implemented fishing effort regulation based on an in-year monitoring fishery (STECF 2005; STECF 2006; ICES 2005b). Norway and Denmark (EU) are the dominating nations in the fishery and have taken respectively 19 % and 78 % of the landings during the last 20 years (ICES 2005b). EU and Norway have not yet agreed on any joint management or management plan for sandeel in the North Sea.

The sandeel fishery is conducted with small meshed (< 16 mm) bottom trawl in shallow waters (< 100 m) on sandy bottom. The main season is from April to June since one year and older sandeel mostly are burrowed in the sand the rest of the year. Some years a significant 0-group fishery takes place in July-October. Landings in the main season are totally dominated by 1-group. Consequently, poor recruitment a given year leads to a poor fishery the following year. Due to the exceptionally weak 2002 year class the fishery collapsed in 2003. This led EU to implement the in-year monitoring based effort regulation in 2004 mentioned above. The principle in EU's sandeel management is to obtain an estimate of 1-group abundance early in the season based on (commercial) Catch Per Unit Effort (CPUE) from the monitoring fishery, and implement management actions for the rest of the season according to a harvest-control rule constructed in advance (STECF 2005).

In late autumn 2005 the Norwegian Ministry of Fisheries and Coastal Affairs decided a monitoring fishery for sandeel led by the Institute of Marine Research (IMR) to be conducted in April/May 2006. An eventual re-opening of the sandeel fishery (in the Norwegian Economic Zone) for the remaining 2006-season was to be based on the results from this monitoring fishery. It was later decided that the monitoring fishery should take place in week 16-18 with a limited number of participating commercial vessels (< 10). IMR was responsible of finding an appropriate methodology and suggestions for re-opening criteria.

Evaluation of stock status and stock abundance from a monitoring fishery will mainly have to be based on CPUE. A major problem in Norway is that logbooks from industrial trawlers (which include sandeel vessels) are not recorded electronically, and it was therefore difficult to construct historic CPUE time series of sandeel based on logbooks. (A time consuming logbook collection and recording process would then have to be started, and it would have been unrealistic to collect sufficient information before April 2006). However, all sandeel vessels have been monitored with a satellite-based vessel monitoring system (VMS) since July 2000, and VMS data can be used to measure fishing effort (Murawski et al. 2005). Combined with landings data, which exist electronically on a vessel-trip level in Norway, it was possible to construct a CPUE time series for the period 2001-2005. In this work, we present the filtering and merging process of VMS and landings data. Moreover, we explore the relationship between CPUE indices and abundance estimates from the latest ICES stock assessment. The objective of the analyses was to find out whether Norwegian CPUE based on VMS and landings data in week 16-18 could be used to predict sandeel abundance, and in particular the abundance of 1-group.

Material and methods

Landings data

Sales slip data from the entire Norwegian fishing fleet exist electronically on vessel-trip level from 2001 onwards. This database is maintained by the Norwegian Directorate of Fisheries and can be accessed by IMR. The recorded information includes the landed quantity (round weight) of each species, vessel identity and landing date.

VMS data

Since 1 July 2000, all Norwegian fishing vessels longer than 24 m have been monitored with a satellite-based vessel monitoring system (ARGOS/INMARSAT-C) operated by the Norwegian Directorate of Fisheries. The information recorded from each vessel includes time (minute resolution), position, heading and speed, and the Directorate receives this information approximately every 60 minutes. IMR was given access to VMS data (only containing position and time) from all vessels with recorded sandeel landings from the period 2001-2005.

Biological samples

IMR cooperates with landings inspectors from the Norwegian Directorate of Fisheries who take samples of sandeel landings and send these to IMR. These samples, which form the basis of the estimation of Norwegian catch at age, where used to estimate the age distribution in landings in week 16-18. More specifically, the number of individuals of each age per landed weight was estimated for each year.

Stock estimates

Estimates of the number of North Sea sandeel per age group in the first half of the year were taken from Table 13.1.4.8 in ICES (2005b).

Defining sandeel fishing effort

VMS data were used to estimate each vessel’s time spent at the fishing grounds. The sandeel fishing grounds were defined as a geographic area (Fig. 1), hereafter referred to as “the sandeel area”. Since VMS data contain one observation for each hour the number of VMS records from the sandeel area were used as a proxy for the number of hours spent there (if more than one observation was recorded within the same clock hour, only one of these were kept). In order to select sandeel effort, VMS data were merged with landings data by time for each vessel. In this way VMS data could be classified into fishing trips (separated by landing dates). The landings were classified into two categories: *sandeel* and *other* (fortunately, the trawlers only have sandeel as target species during sandeel trips). Consequently, sandeel effort could then be defined as: *the number of (VMS) hours spent in the sandeel area with a following sandeel landing*. Table 1 illustrates the structure of merged VMS and landings data. The “other”landings are dominated by blue whiting and herring.

Selection of sandeel landings and effort from week 16-18

The purpose in this work as to explore CPUE from week 16-18 each year. Since the data now have a trip-by-trip resolution, and many trips had duration of more than one week, only selecting trips beginning after April 17 and ending before May 8 would lead to a very low number of relevant trips. It was therefore decided to include trips that started before Aril 17 or ended after May 8 if more than 50 % of the effort was recorded within the period (Aril 17 – May 8). Table 1 illustrates the selection of relevant trips. The number of vessels with relevant sandeel trips in week 16-18 during 2001-2005 were 26, 51, 31, 26 and 15, respectively. Only 5 vessels had relevant trips in week 16-18 all years (during 2001-2005), and these are hereafter referred to as the 5-fleet.

CPUE indices

Total CPUE (CPUE_tot) was calculated for each year as

$$CPUE\_tot = \frac{\sum_{i=1}^{n} landing_i}{\sum_{i=1}^{n} VMS-hours_i} \qquad (1)$$

where n is the number of relevant trips in week 16-18 the given year, $landing_i$ is the landed weight of sandeel from trip i (measured in kilograms) and $VMS\text{-}hours_i$ is the recorded number of VMS-hours (or VMS-observations) in the sandeel area during trip i.

CPUE of age 1 (CPUE_N1) was calculated as

$$CPUE\_N1 = \frac{\sum_{i=1}^{n} landing_i \times N1_{kg}}{\sum_{i=1}^{n} VMS-hours_i} \qquad (2)$$

where $N1_{kg}$ is the estimated number of age 1 sandeel per kilogram in catches the given year (only week 16-18).

CPUE of two years and older sandeel (CPUE_2+) was calculated as

$$CPUE\_N2+ = \frac{\sum_{i=1}^{n} landing_i \times N2+_{kg}}{\sum_{i=1}^{n} VMS-hours_i} \qquad (3)$$

where $N2+_{kg}$ is the estimated number of age 2+ sandeel per kilogram in catches the given year (only week 16-18).

CPUE was calculated both from all relevant trips and from relevant trips conducted by the 5-fleet (i.e. the 5 vessels that had relevant trips in all 5 years during week 16-

18). The CPUE time series were regressed against the corresponding stock estimates, and the uncertainty in total CPUE was briefly explored.

Results

The CPUE time series from the entire fleet and the 5-fleet are quite similar, but CPUE from the 5-fleet is generally higher in 2001 and 2002 (Fig 2a-c). Total CPUE decrease to a low level in 2003-2005 relative to 2001-2002 (Fig. 2a), and CPUE of age2+ shows a decreasing trend from 2001 onwards (Fig. 2c). CPUE of age 1 is very low in 2003-2003 but shows an increase in 2005 (Fig. 2b).

The linear relationships between total CPUE and estimated total stock biomass are positive and significant (at the 5 % level) both for the entire fleet (Fig. 3a) and the 5-fleet (Fig. 3b). This also applies for log-transformed values (Fig. 3c-d).

CPUE of age 1 is positively linearly related to the estimated number of age 1 in the stock, and the relationships are significant (at the 5 % level) both for the entire fleet (Fig. 4a) and the 5-fleet (Fig. 4b). When the values are log-transformed the fits become poorer (Fig. 4c-d), but the models are still significant at the 10 % level. Removal of 2005 has little effect, but removing 2004-2005 results in a more significant change in the line fitted to the logged values. The reason for checking the effect of removing the last two years is that the stock estimates from these years are uncertain since they probably not have converged yet. Parameter estimates for the fitted models in Figure 4 are given in Table 2.

There are no relationships between CPUE of age 2+ and the estimated number of age 2+ in the stock (Fig 5a-d).

Figure 6 shows the fitted models from Figure 4 in the same plot: the log-models give more steep lines than the linear models. Figure 7 shows a simple assessment of the uncertainty given that 6 vessels are used each year to calculate total CPUE.

Discussion

It seems as Norwegian CPUE from week 16-18 based on VMS and landings data can be used to predict the number of age 1 sandeel in the North Sea. It is therefore likely that the Norwegian monitoring fishery for sandeel in 2006 will provide usable information about the sandeel stock status. This conclusion presupposes that the stock assessment estimates are fairly accurate; especially for the years 2001-2003 since the model fit mainly is driven by these years. The strong relationship between total CPUE and total stock biomass is probably driven by the 1-group since this age group is dominating both the landings and stock. The results for age 2+ are hopeless, and this may be due to the fact that the proportion of 2+ in the catches is so small that the estimates of this proportion become very uncertain.

Our definition of effort as the number of VMS-observations (assumed to represent the number of hours) in the sandeel area is quite simple, and more sophisticated definitions are possible. Time spent in the sandeel area could have been estimated more accurately by summarising the actual time differences between following VMS-observations. Moreover, it is also possible to estimate a vessel's average speed between consecutive VMS-observations using distance and time difference, and then only use time observations below a certain speed limit (assuming that trawling and searching occur below this). In addition, sandeel searching and trawling do not occur at night so the hours of darkness should also have been removed. However, we have not looked into whether this potentially improved effort definition leads to a different effort trend during the analysed time period.

It is difficult to evaluate which model type (linear or log-log) that is most appropriate with only 5 years of data. If the residuals are log-normally distributed, this is an argument for using a log-log model. However, for 1-group the fits with log-transformed values were poorer and more sensitive to removal of 2004-2005 compared to the fits with non-transformed values. In addition, the slopes in the log-log regressions where not significantly different from 1 meaning that the observed relationship basically is linear. It should be mentioned that non-linear relationships between CPUE and stock size have been found for many other stocks (Harley, et al. 2001), and that EU uses a log-log model in their sandeel in-year monitoring program (STECF 2005). It is a well-known fact that assuming proportionality between CPUE and stock abundance (i.e. constant catchability), as we now do, may be dangerous (Gulland 1983; Hilborn and Walters 1992; Harley et al. 2001). The most important factors that may lead to trends in catchability are (a) so-called hyperstability; CPUE remaining high while abundance drops since the vessels are able to locate fish concentrations even at low stock levels and (b) gradual increases in the fleets catching efficiency. Signs of hyper-stability can be discovered by exploring the spatial fleet distribution (Salthaug and Aanes 2003); a more concentrated fleet with a small spatial extent compared to earlier may be such a sign. Increasing catching efficiency of the fleet can be adjusted for (to a certain degree) by standardizing effort, e.g. using vessel parameters assumed to co-vary with efficiency like vessel or engine size. Another alternative is to use data from the same vessels each year, as we do with the 5-fleet. However, our observed trend in CPUE for the entire fleet and the 5-fleet is quite similar, considering the large changes in the vessel composition that have taken place during 2001-2005 in the Norwegian sandeel fleet. This indicates that standardization is not critical in this case.

The present study lacks some important aspects of uncertainty, e.g.: (i) how many vessels must be used in the CPUE calculation each year before the CV stabilizes, (ii) do other CPUE-estimators than total catch divided by total effort lead do different results? and (iii) what are the effects of introducing uncertainty in catch at age?.

Recommendations for the Norwegian monitoring fishery in 2006 based on this study were to use vessels that have been active all years in 2001-2005, to use a linear model to predict 1-group abundance and to do the analyses again when vessels have been selected (only using data from these vessels).

What happended?

It was decided that 6 vessels should be allowed to participate in the Norwegian monitoring fishery. The (12) applying vessel was sorted accorded to the recorded number of sandeel landings in 2001-2005, and the 6 first vessels were selected (3 of these were from the above mentioned 5-fleet). The data from the 6 selected vessels still gave a significant ($p < 0.05$) relationship between CPUE of age 1 and the estimated number of 1-group in the stock. CPUE from the monitoring fishery predicted that the abundance of age 1 in 2006 was about 60 % of the average (over 1983-2005). This was below the pre-determined minimum limit (average year class strength) that IMR decided to use in their recommendations, and IMR recommended to not opening the sandeel fishery in 2006. (This recommendation was also based on additional arguments, e.g. results from a Norwegian research cruise conducted in parallel with the monitoring fishery). EU's monitoring fishery gave en estimate of the 2005 year class which was around the average (over 1983-2005), and recommended, based on their predetermined harvest control rule, to allow a TAC at 600 000 tons in the EU zone.

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Table 1. Illustration of how VMS and landings data were merged and how trips from (approximately) week 16-18 (April 17 – May 8) were selected. The table is a calendar with month and day in the two first columns and otherwise one column for each vessel. The number in each cell within the vessel columns is the number of hours (i.e. VMS observations) recorded within the sandeel area the given day. Landings are indicated by “sandeel” (i.e. a sandeel landing) or “other”. If VMS activity from the sandeel area was recorded on the landing date, the number of hours is written after the landing type. In this way sandeel trips can easily be identified. Trips (landings and VMS effort) that were regarded relevant for week 16-18 (the monitoring fishing period, days marked with blue/italic in the day/month columns) are emboldened.

month	day	Vessel A	Vessel B	Vessel C	Vessel D	Vessel E	Vessel F
4	7	22					
4	8		other .				
4	9						
4	10			other .			
4	11						
4	12	other .	other .				
4	13						
4	14				other .	other .	
4	15						
4	16	**21**		other .			
4	*17*	**17**		**20**			**18**
4	*18*	**15**		**20**			**14**
4	*19*	**15**		**20**			**18**
4	*20*	**sandeel .**		**18**			**15**
4	*21*	**12**		**21**			
4	*22*		**16**	**25**			**sandeel .**
4	*23*	**16**	**24**	**22**			**23**
4	*24*	**16**	**23**	**17**			**14**
4	*25*	**13**	**20**	**23**			**16**
4	*26*	**15**	**20**	**22**	other .	other .	**15**
4	*27*	**9**	**19**	**25**	other .		**13**
4	*28*	**sandeel 2**	**22**	**sandeel 6**			**16**
4	*29*	**21**	**24**	**21**			**sandeel .**
4	*30*	**21**	**15**	**18**			
5	*1*	**22**	**sandeel .**	**21**			**20**
5	*2*	**18**	**20**	**21**			**15**
5	*3*	**15**	**22**	**19**			**17**
5	*4*	**18**	**24**	**24**			**15**
5	*5*	**18**	**24**	**sandeel22**	other .	other .	**8**
5	*6*	**19**	**16**				**sandeel16**
5	*7*	**18**	**sandeel .**	17		21	15
5	8	**sandeel .**	10	20		20	16
5	9	16	22	19	other .	17	13
5	10	24	23	18		20	18
5	11	20	24	21	20	24	15
5	12	19	24	22	19	22	sandeel .
5	13	15	23	18	18	18	
5	14	20	22	25	18	21	21
5	15	23	24	sandeel 4	15	sandeel .	21
5	16	23	24	19	16		19
5	17	18	sandeel 6	21	20	16	18

Table 2. Parameter estimates (par.) with 95 % confidence intervals (conf. int.) for the fitted models* in Figure 4 (only for the solid lines, i.e. all years are used). In the model fits, CPUE is measured as number of 1-group per VMS-hour and estimated stock number of 1-group are measured in millions.

Modell	slope		intercept	
	par.	conf. int.	par.	conf. int.
Fig. 4a (linear)	0.58	0.11-1.05	16555.15	-126640.7-159751
Fig. 4b (linear)	0.49	0.09-0.89	27549.8	-109007.3-164106.9
Fig. 4c (log-log)	1.06	-0.11-2.24	-1.27	-15.79-13.25
Fig. 4d (log-log)	0.90	-0.19-1.99	0.64	-12.88-14.16

*The linear model (without the error component):

$$N1 = \beta * CPUE\_N1 + \alpha \qquad \text{(I)}$$

where α is the intercept and β the slope.

The log-log model:

$$\ln(N1) = \beta * \ln(CPUE\_N1) + \ln(\alpha) \qquad \text{(II)}$$

where $\ln(\alpha)$ is the intercept and β the slope. On the original scale the model is

$$N1 = \alpha' * CPUE\_N1^{\beta} \qquad \text{(III)}$$

where

$$\alpha' = \exp(\ln(\alpha) + MSE/2)$$

where MSE is the “mean square error” from the linear regression.

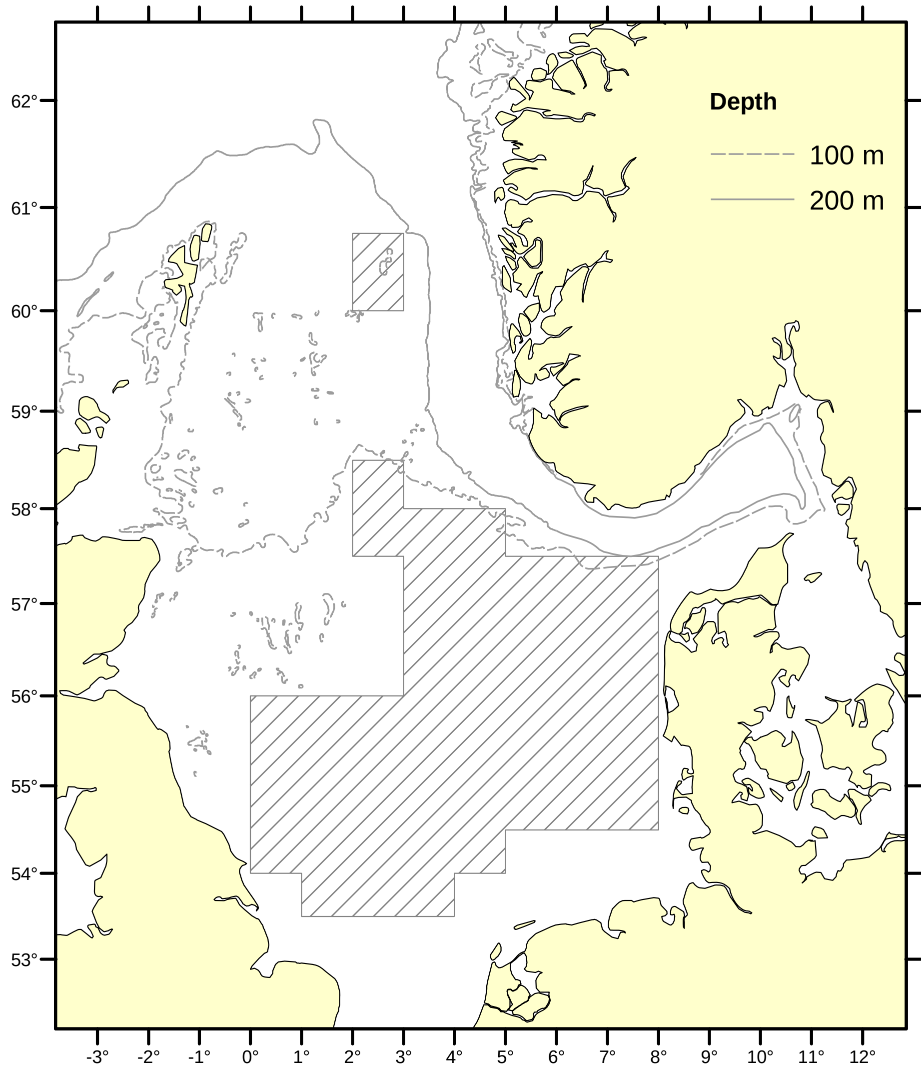

Figure 1. The sandeel area. Sandeel effort is defined as the number of VMS observations (≈hours) recorded within the shaded area with a following sandeel landing. The area includes all the sandeel fishing grounds used by the Norwegian fleet in 2001-2005.

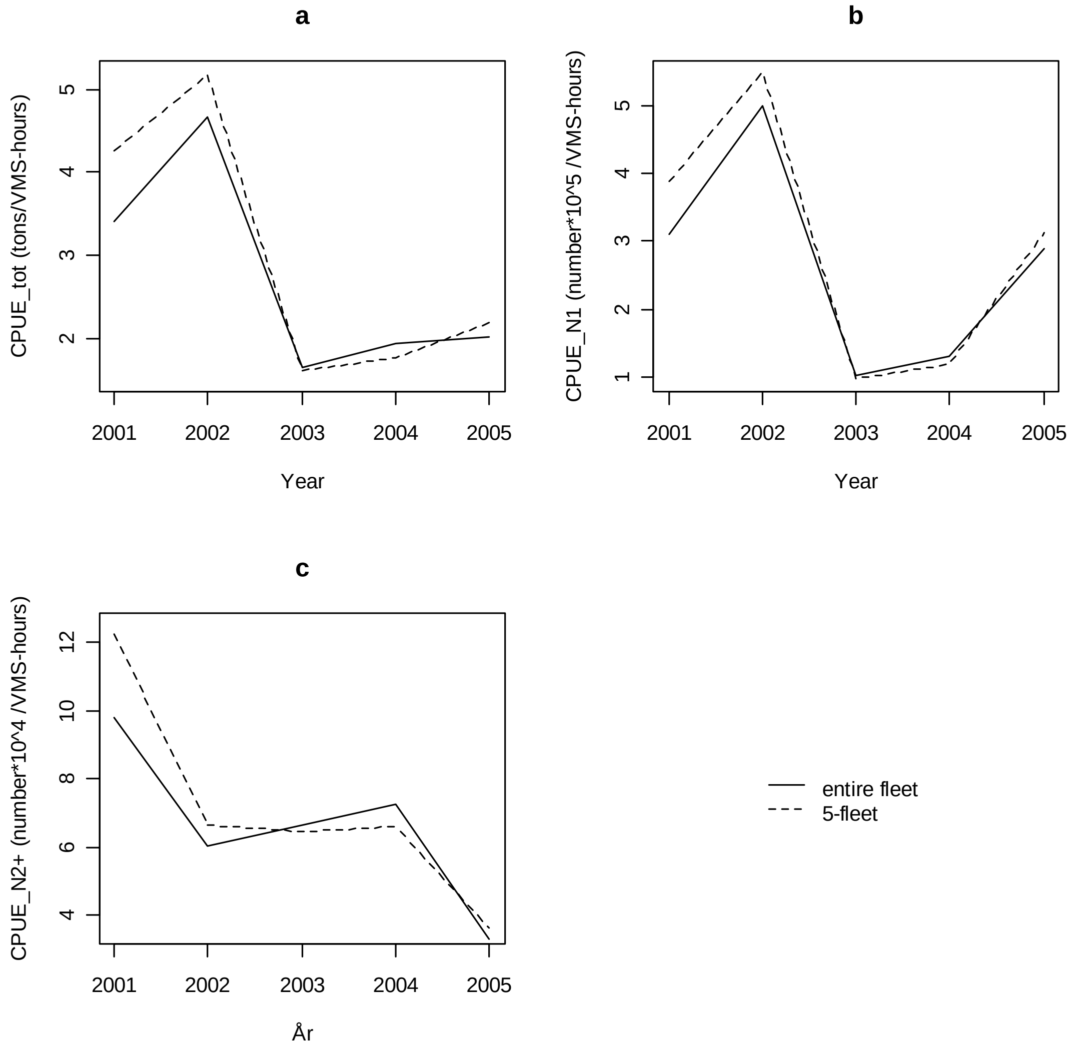

Figure 2. CPUE in week 16-18 from the entire fleet and from the 5-fleet (i.e. the 5 vessels that had relevant trips in all 5 years during week 16-18). (a) total CPUE, (b) CPUE of 1-group and (c) CPUE of 2 years and alder fish (age 2+).

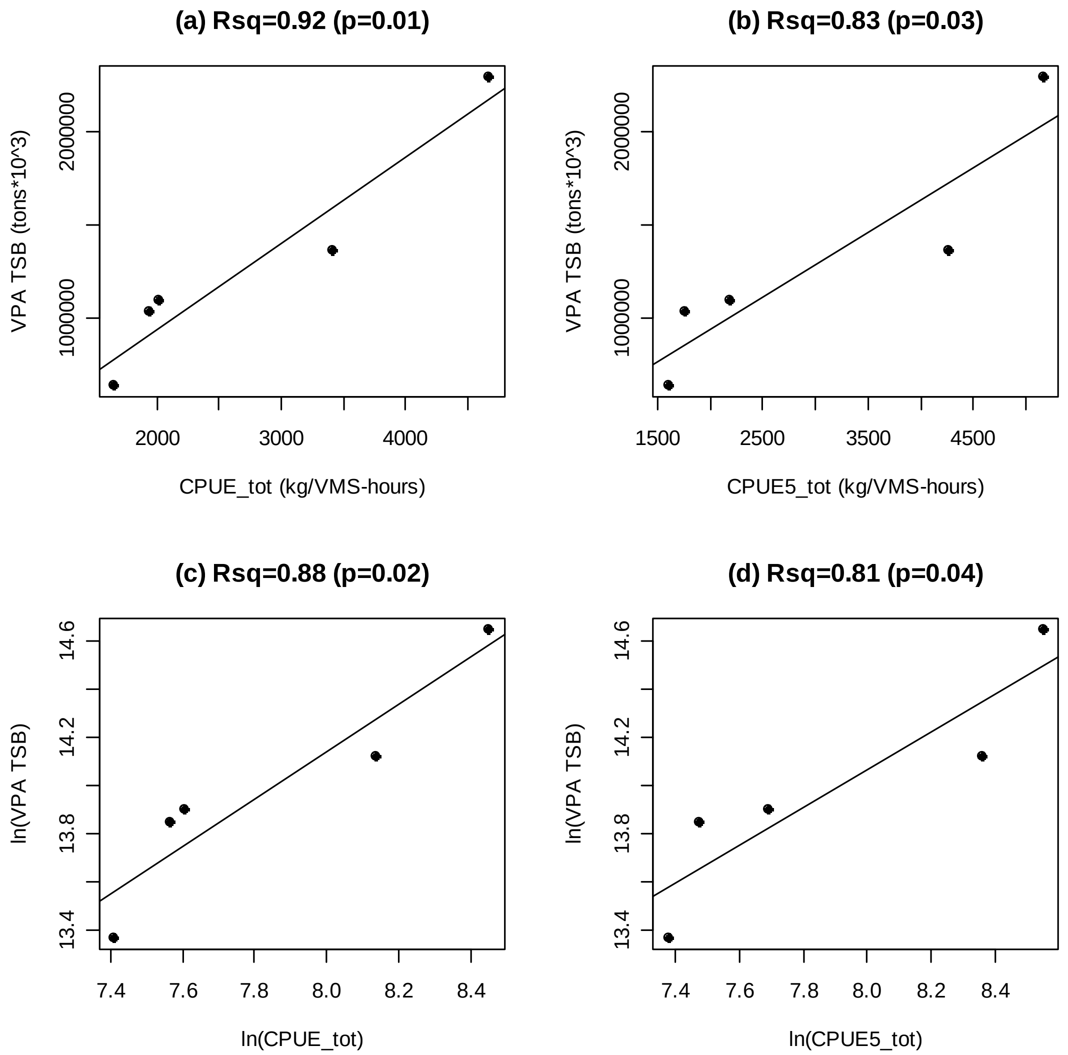

Figure 3. Total CPUE in week 16-18 and corresponding total stock biomass estimates (VPA TSB). (a) from the entire fleet (CPUE) and (b) from the 5-fleet (CPUE5). In (c) and (d) the values are log-transformed. The fitted regression lines are shown and the coefficient of determination (Rsq = r^2) and p-value are written above each plot.

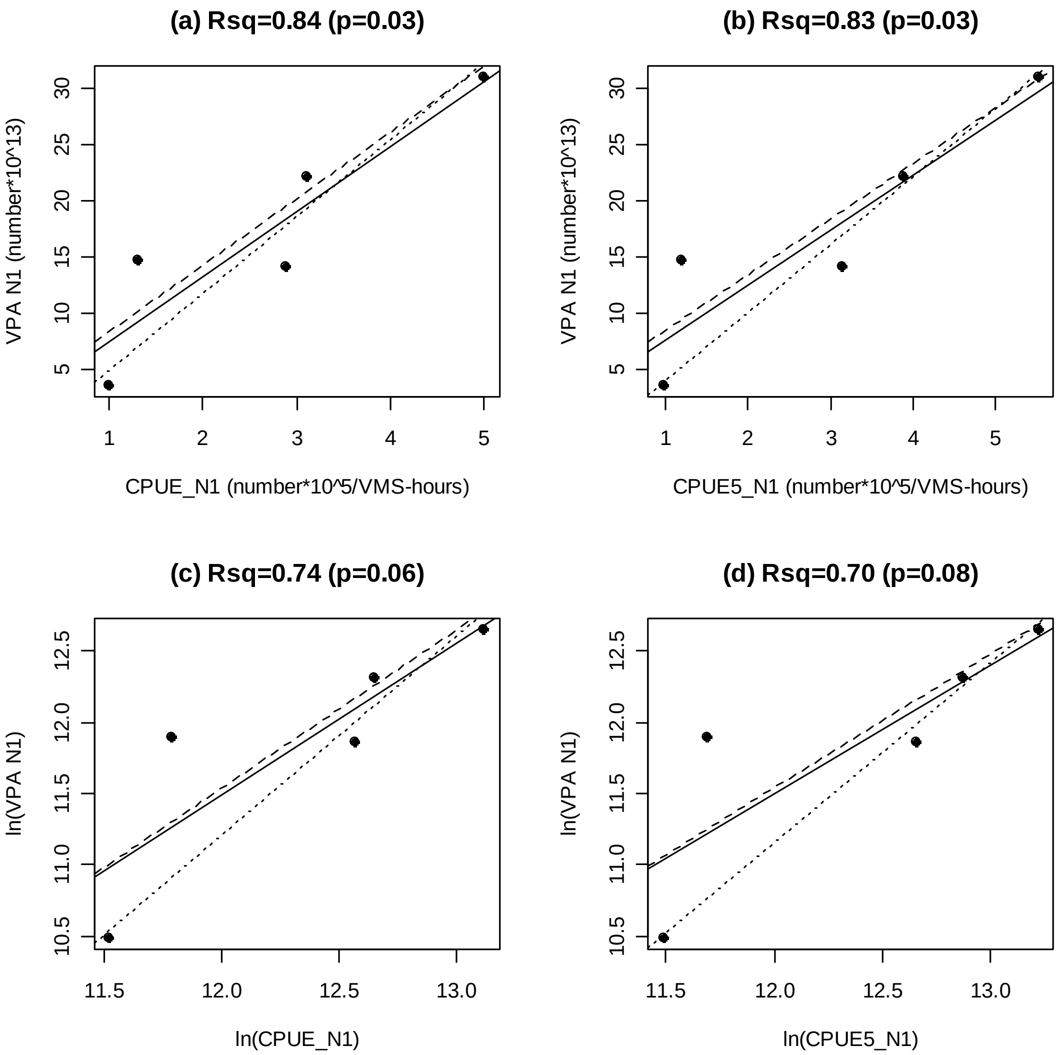

Figure 4. CPUE of age 1 in week 16-18 and corresponding stock estimates of age 1. (a) from the entire fleet (CPUE) and (b) from the 5-fleet (CPUE5). In (c) and (d) the values are log-transformed. Fitted regression lines: the solid lines are fitted to all years while the dashed lines (---) are fitted to 2001-2004 and the dotted lines (····) to 2001-2003. The Rsq and p-values belong to the solid lines. Parameter estimates and confidence intervals for the solid lines are given in Table 2.

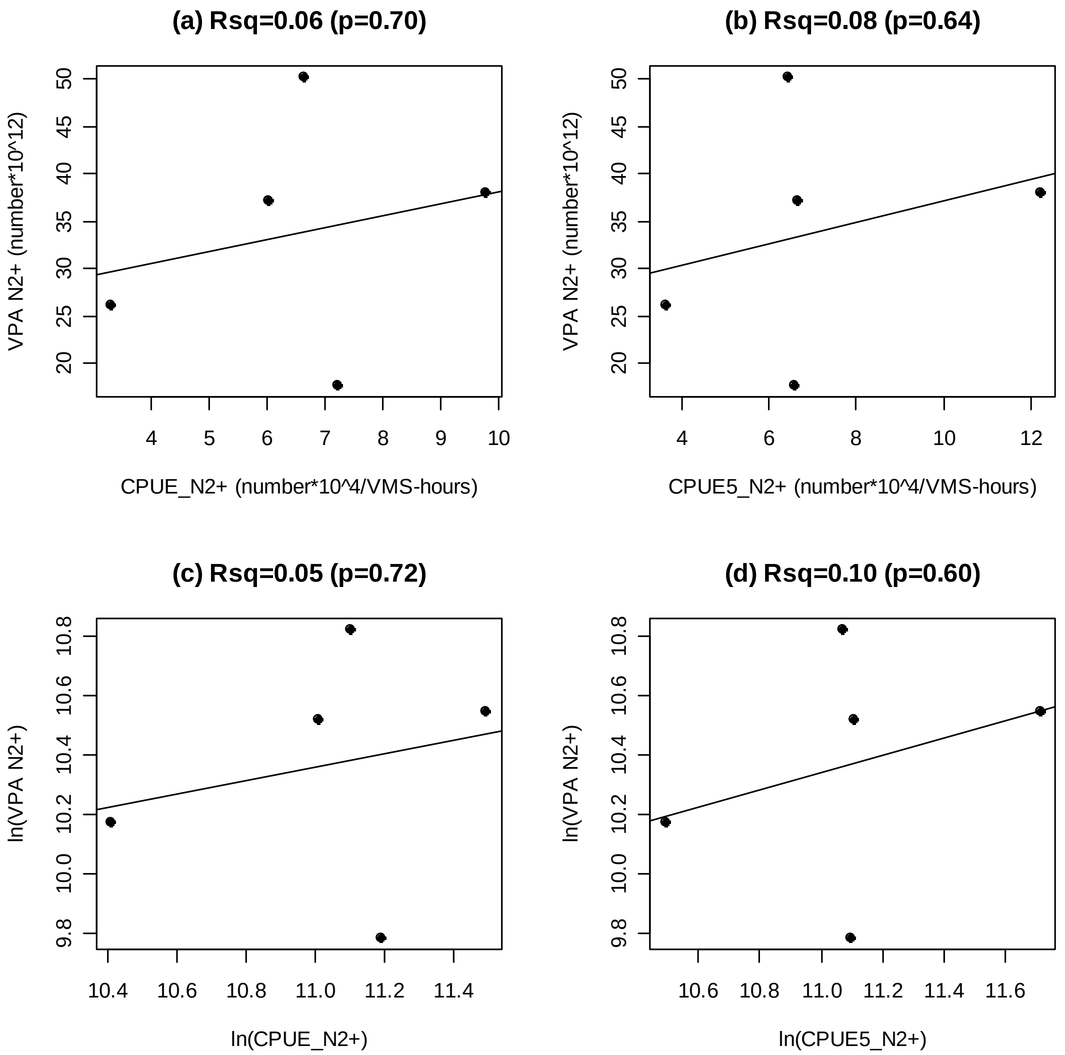

Figure 5. CPUE of age 2+ and corresponding stock estimates of age 2+. (a) from the entire fleet (CPUE) and (b) from the 5-fleet (CPUE5). In (c) and (d) the values are log-transformed. The fitted regression lines are shown and the coefficient of determination (Rsq = r^2) and p-value are written above each plot.

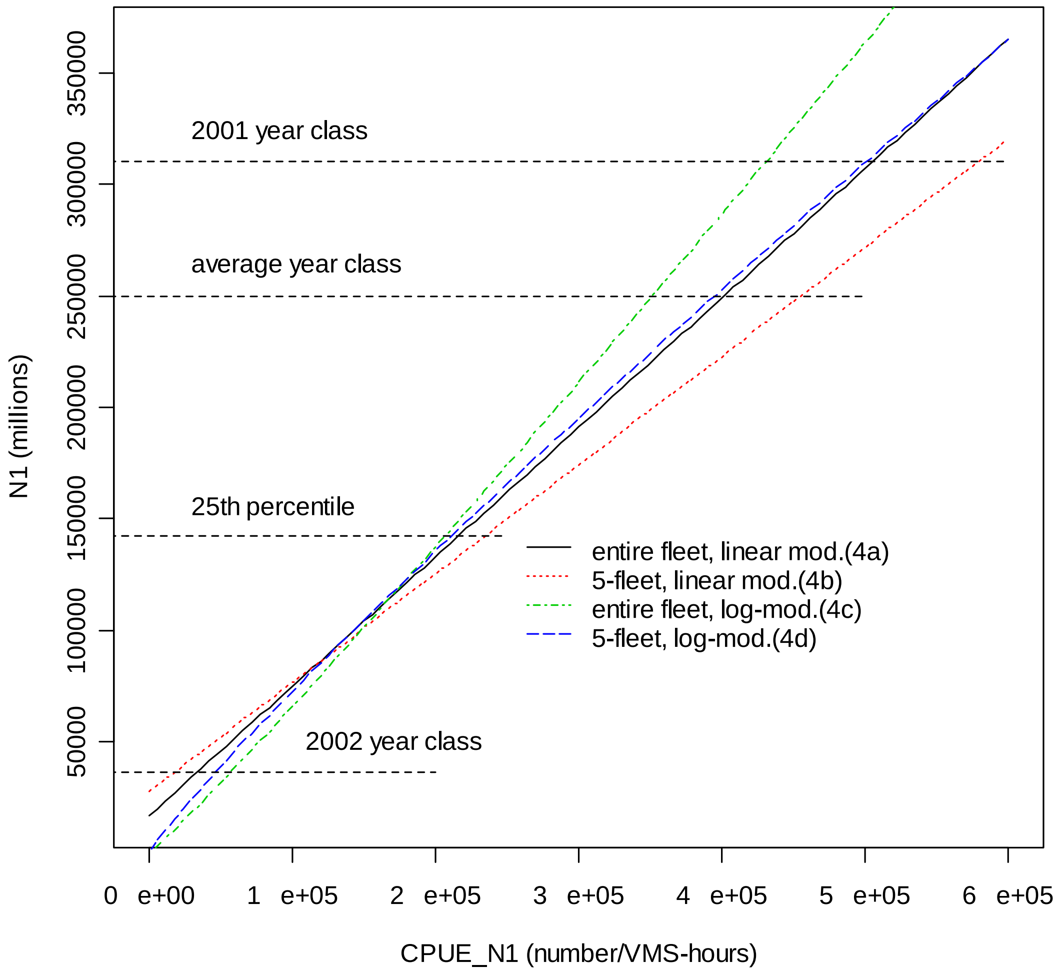

Figure 6. The fitted models from Figure 4 predicting the relationship between CPUE of age 1 in week 16-18 and the number of 1-group in the sandeel stock. Some year class strength levels are shown.

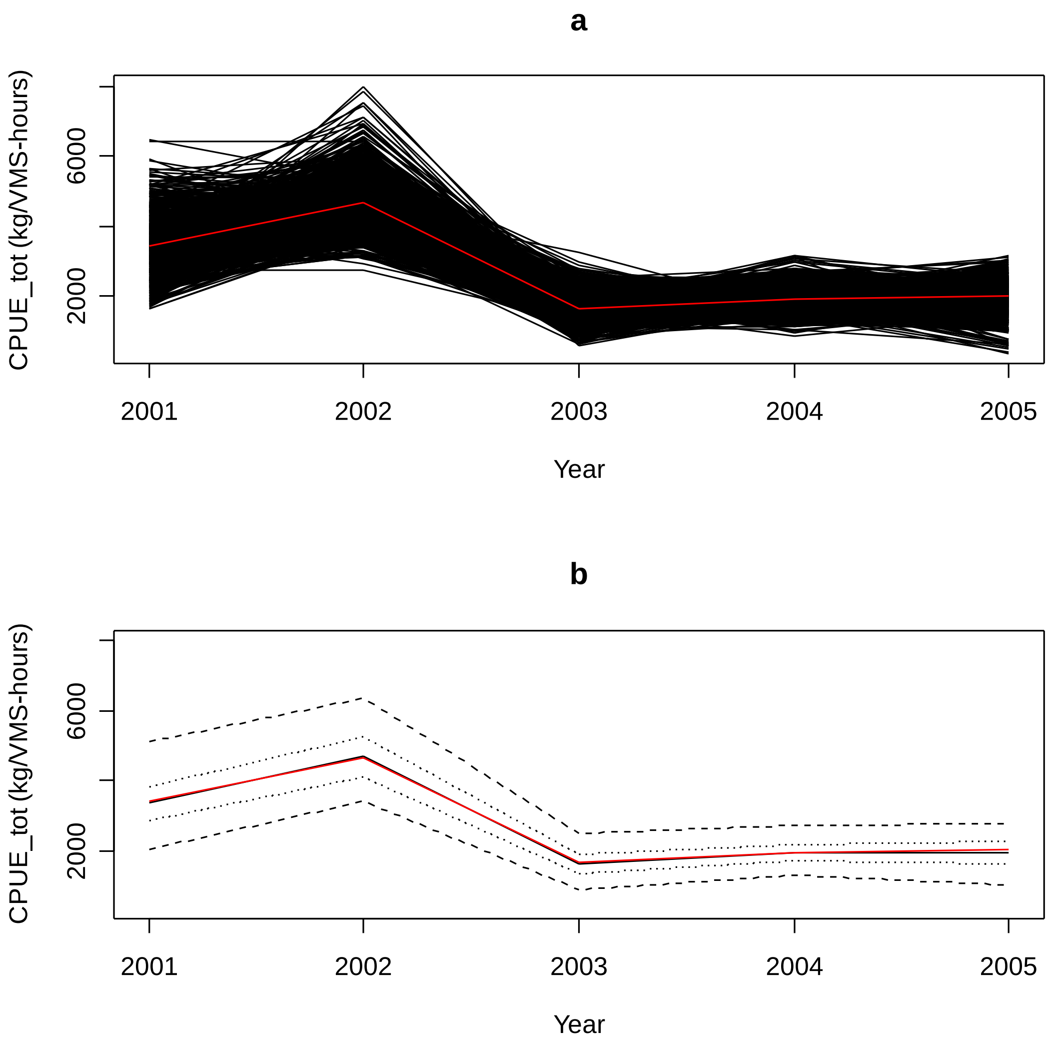

Figure 7. Uncertainty in total CPUE in week 16-18 if only 6 vessels are used each year. The uncertainty is assessed by non-parametric bootstrapping with 1000 replicates (i.e. each year 6 vessels are randomly selected from the data with replacement and total CPUE are calculated for each replicate (using Eq. 1). (a) all 1000 CPUE time series and (b) the solid black line in the middle is the average of the replicates each year while the dotted/dashed lines are respectively the 25th and 75th percentiles (····) and the 2.5th and 97.5th percentiles (---) in the distributions. The red line is total CPUE from the entire fleet, and this is nearly identical to the mean of the replicates. The coefficient of variation within each year is around 20 %.