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When acoustics is not enough – towards a measurement of sandeel availability

Espen Johnsen and Alf Harbitz

Abstract

Experimental surveys in the peak feeding season of sandeel (April-May) show that the abundance and geographical distribution of schooling lesser sandeels (*Ammodytes marinus*) can be acoustically measured, but the density measures are affected by the proportion of sandeel burrowed in the sand. An adequate sampling tool of individuals in the sand is needed to quantify the acoustic availability and understand the dynamic of the sandeel behavioural. The grab has high catch efficiency, but the operation is time consuming and even small stones may prevent the mouth to close properly. Therefore, a modified scallop dredge is preferred in Norwegian and Danish sandeel surveys, but little is known about the catching properties and catch efficiency of the dredge. In this study, the efficiency of the dredge was estimated by comparing it with the catch rates of a Van Veen grab. Moreover, the precision of the dredge was examined in a parallel towing experiment. Grab and dredge samples carried out at the same positions showed no difference in size distributions of sandeels in the catches, but the average catch of individuals per m^2 was considerably higher in the grab. Assuming a 100% catch efficiency of the grab, the catch efficiency in the dredge was estimated to be 5.7% (SD = 6.3%). The low efficiency may question the sampling reliability of the dredge, but the catch rates of the parallel dredge hauls were strongly correlated (r^2=0.90) and suggest that the dredge provides a relatively precise measure of the density of sandeel at a location. Thus, as

all lesser sandeels probably are in the seabed at night, the difference in catch rates at night and the subsequent day at a given location will presumably reflect the acoustic availability. However, the low catch efficiency calls for the development of a more efficient sampling dredge.

Keywords: *acoustics, lesser sandeel, dredge, catch efficiency, availability, North Sea*

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Introduction

A severe reduction in the recruitment and spawning stock size of lesser sandeel (*Ammodytes marinus*) has been documented in the North Sea since 2001 (ICES 2008a). Such a decline affects top predators such as birds, seals, and predatory fish (Furness, 2002), along with the fishing industry. In the late 1990's the sandeel in the North Sea supported annual landings exceeding one million tonnes (ICES, 2008a). In 2003 and 2004, the landings were reduced to about 300 thousand tonnes, and dropped to about 170 thousand tonnes in 2005 (ICES, 2008a). From 2006, the TAC advice has been based on an in-year monitoring programme using commercial CPUE to estimate the abundance of 1-year-old sandeel (ICES, 2008b). In 2009, the sandeel fishery was closed in the Norwegian Exclusive Economical Zone (EEZ), and the method applied only in the EU EEZ. There are several concerns related to use of CPUE to measure the abundance of fish (Rose and Kulka, 1999) in general and in particular for schooling species (Ulltang, 1980).

With the objective of developing a robust fishery independent routine survey to map the distribution and abundance of sandeel, the Institute of Marine Research, Norway has carried out experimental acoustic sandeel surveys in the peak feeding season (April-May) in the North Sea since 2005. During the feeding season the sandeels are burrowed in the substrate at night and emerge from the substrate at dawn (Winslade, 1974a) and form schools which can be size and species identified with echo sounders (Johnsen *et al.*, 2009). It is reasonable and common to assume that all sandeels stay in sand at night and the daytime pelagical proportion is one minus the day/night proportion of sandeels in the sand. Theoretically, the proportion can be estimated by comparing day and night catch rates of burrowed sandeels.

Both grab and dredge are commonly used to sample sandeel individuals in the sand, but the grab has a long operation time and even small stones in the substrate may prevent the mouth to close properly. In contrast, the modified scallop dredge that is used in Danish and Norwegian sandeel surveys is considerably more time operational efficient.

There are several concerns regarding the sandeel sampling due to escapement reactions and the patchy sandeel distribution (Macer, 1966; Winslade, 1974b; Wright *et al.*, 2000). These factors introduce both random and systematic errors, but whereas the random errors can be evaluated through statistical analyses and reduced by more samples, the systematic errors result from biases introduced by the sampling methodology (Everitt 1998). In this study, the effect of spatial patchiness of sandeel on the measurement errors is analysed for both the grab and dredge samples. It is hypothesized that the small sampling area of the grab in combination with high sandeel patchiness and occasionally poor sampling quality due to improperly closure of the mouth make the dredge to the preferable sampling tool. However, a previous study indicates that the catch efficiency of the dredge is low (Mackinson et al. 2005), and biases are difficult to deal with as they can only be detected by using alternatively methodology. Thus, the objective of this study was to estimate the catch efficiency of the dredge by comparing the catch rates of sandeel in the dredge and the grab. In addition, the precision in the density estimates is examined by comparing catch differences in two identical dredges trawled in parallel. The results will be discussed in relation to a future standard survey strategy to estimate the pelagical proportion of sandeel in the water column.

Materials and methods

The data used in this study were collected during sandeel surveys in the North Sea April-May 2008, and May 2009 with R/V "Johan Hjort" and R/V G.O. Sars, respectively.

A Van Veen grab with a light opening of 42 cm x 54 cm (Figure 1a), and modified scallop dredge with a hood were used (Figure 1b). Three replicates were done per grab station. The width of the dredge is 1 m, the mesh size in the net is 5 mm. The dredge towing duration and speed were 10 min and 2 knots, respectively. Wire length was three times bottom depth plus 50 m, and the wire dimension was 10 mm. The catches were sorted by species and weighed according to standard procedures (Mjanger *et al*., 2000). For small catches, total length (L_T) of each sandeel was measured to the nearest 0.5 cm. For large catches, L_T were measured from 100 sandeel in a random sub-sample.

Parallel trawling experiments

During the period 8 – 23 May 2009 two identical dredges (Fig 2) were towed in parallel using the trawl winches on starboard and port side. Thus, the distance between the dredges was approximately 10 m and the start and stop towing time were identical for both dredges. For the first few parallel hauls the walls of the net of the of the port side dredge were tied to the coat to see if the catch efficiency changed with this type of rigging. However, it was quite evident that the rigging did not affect the efficiency and after 12 hauls the port side dredge was rigged identical to the starboard dredge.

Spatial variation model

Two questions can be answered by analysing the catch rates of the parallel hauls. First, any systematic catch efficiency difference between two identical dredges reflects an unwanted and unpredictable sensitivity of the sampling tool. Secondly, large non-systematic catch rates differences in the two dredges indicate a high spatial patchiness of sandeels which give an imprecise measure of fish density at a given site and time. Such differences can be defined as the residual source of random variation and can be quantified (Hjellvik et al. 2002).

If an additive individual dredge effect is allowed α_j, j=1, 2, to permit for efficiency differences, the difference (z_i) can be defined as:

$$z_i = y_{i,1} - y_{i,2} = \alpha_1 - \alpha_2 + \varepsilon_1 - \varepsilon_2$$

Where the residuals ($\varepsilon_{i,j}$, i=1,..., n; j=1,2) are assumed independent zero-mean identically distribution random variables and $\sigma_\varepsilon = sd\ (\varepsilon_{i,j})$ is here defined as the residual variation. The expected difference is:

$$E(z_i) = \alpha_1 - \alpha_2$$

Because of the independence of $\varepsilon_{i;1}$ and $\varepsilon_{i;2}$,

$$\sigma_z^2 = \mathrm{var}(z_i) = \mathrm{var}(\varepsilon_{i;1} - \varepsilon_{i;2}) = 2\sigma_\varepsilon^2$$

Further, the standard error can be estimated as:

$$\hat{\sigma}_{\varepsilon} = \frac{1}{\sqrt{2}} \left\{ \frac{1}{n-1} \sum_{i=1}^{n} (z_i - \bar{z})^2 \right\}^{\frac{1}{2}}$$

whereas $\delta = a_1 - a_2$ is estimated by $\hat{\delta} = \bar{z}$.

Here, the $y_{i;j}$ represents the log-transformed number of sandeels in the catch. The transformation reduces the heterogeneity of the variance.

The efficiency difference of the dredges can be examined by a t-test if the observations are normal distributed. The normality was tested by using the method present by Hjellvik et al. (2002):

$$x_i = \frac{z_i - \bar{z}_k}{s_k}$$

Where the *k* denotes dredge 1 and 2 for haul *i*, and $\bar{z}_k$ and s_k are the average and estimated standard deviation of the of the *z*-values. The normality was examined with histograms and Shapiro-Wilk normality tests (Royston, 1982).

Grab-dredge comparisons

In 2008, six days of the survey (design A) were dedicated to a dredge-grab comparison experiment, whereas the main focus was on other objectives during the rest of the survey in 2008 and in 2009. Nevertheless, time allowed several dredge-grab comparisons in this period. Hence, the data were sampled with two different experimental designs:

Design A: Six comparison sites were systematically allocated within small areas where high acoustic densities of sandeel had been observed at daytime, and originally three grab stations were located along each dredge towing path. The grabbing turned out to be time consuming and as a high fraction of the samples contained zero sandeel, it was decided to change the sampling procedure; if the dredge catch contained less than 20 sandeels, no grabbing was carried out. If the catch contained between 20 and 200 sandeels one grab station was located in the centre of the dredged path, and if the number of sandeels in the catch exceeded 200 three grab stations were allocated as original planned. The comparison (*i*) for Design A included all grab and all dredge hauls within the same night at the site.

Design B: In selected areas with acoustic sandeel observations one dredge station was carried out and number and positions of appurtenant grab stations followed the procedure described above. Hence, for Design B a comparison (*i*) included one dredge haul and one or three grab stations.

All dredge and grab comparisons in the experiment were carried out at night (start time of the station when the sun is below the horizon). In a few stations the number of grab samples deviated from the planned sampling procedure (Table 1), but there is no reason to believe that the results are biased by the deviation.

Poisson and negative binomial model

The simplest statistical model corresponds to the assumption of randomly located single fish with a constant density, ρ, in terms of expected number of fish per area. This is synonymous with a Poisson distributed number of fish in the dredge as well as in the grab, with parameter λ equal to the expected number in the distribution, but with a far smaller λ-value for the grab than for the dredge. As observations reveal, however, the realistic spatial distribution of sandeel is far patchier than the Poisson-model predicts. Therefore a negative binomial model for the number of fish in the dredge and the grab are applied as well, probably providing more reliable (and larger) uncertainty estimates.

Let N_s and N_g denote the number of fish in the dredge and grab, respectively, and let A_s and A_g be the corresponding areas covered by these tools. Assume the two tools cover the same fish density. Assuming 100% grab efficiency, the efficiency, *eff*, of the sledge is then given by

$$(1) \qquad eff = \frac{\lambda_s / A_s}{\lambda_g / A_g}.$$

We focus on the natural estimator

$$(2) \qquad eff^* = \frac{\sum_{j=1}^{n} N_{sj} / \sum_{j=1}^{n} A_{sj}}{\sum_{j=1}^{n} N_{gj} / \sum_{j=1}^{n} A_{gj}}$$

where the number of fish and the corresponding areas are cumulated separately over the *n* stations. Our two statistical models are now reflected in the distribution of N_{sj} and N_{gj}.

Simulations

Because no grab samples are taken if less than 20 fish are caught in the sledge, these data cannot be included in the estimator eff*. This will give a larger expected value for eff* than if grab samples for all sledge samples were available. How large this effect is quantitatively, along with the standard deviation and other statistical features of eff*, can be simulated by simulation as described below.

Simulation procedure to examine features of eff*

1. Calculate eff* from data.

2. Set $\lambda_{sj} = N_{sj}$ and $\lambda_{gj} = \frac{\lambda_{sj} A_{gj}}{eff^* A_{sj}}$, j = 1,2,...,*n*.

3. Simulate a random value $N_{sj,sim}$ and $N_{sj,sim}$ for N_{sj} and N_{gj}, respectively, j = 1,2,...,*n*.

4. Calculate eff^*_{sim} from eq.(xxx) with $N_{sj} = N_{sj,sim}$ and $N_{gj} = N_{gj,sim}$.

5. Repeat steps 2-5, and skip the trials where $N_{sj,sim} < 20$, untill nsim N_{sj} eff^*_{sim} values are obtained.

Based on the nsim eff^*_{sim} values we can now estimate the bias and stdandard deviation of eff* as follows:

(3) bias*(eff*) = mean(eff^*_{sim})

(4) std*(eff*) = std(eff^*_{sim})

Point 3 above is straight forward for the Poisson model, which only contains one parameter, lambda. The negative binomial model contains two parameters, *x* and *p*, where x is an integer and *p* is a Bernoulli probability between 0 and 1. To estimate these parameters, at least two observations are needed for the grab as well as for the sledge. The moment estimators for the parameters are then as follows:

(5)
$$\hat{p} = mean(N)/\text{var}(N)$$
$$\hat{x} = \hat{p} \cdot mean(N)/(1-\hat{p})$$

and will change between dredge and grab as well as between stations.

Results

Parallel trawling

The Shapiro-Wilk normality test (p = 0.21) does not reject the null hypothesis of normality at a 10% level for the standardized observations (x_i), and the histogram show a normal distribution (Figure 2). No systematic difference in the efficiency between the two dredges was found ($p = 0.91$) with a large overlap in their 95 % confidence intervals; [1.90, 4.05] and [1.85, 3.92]. These intervals show as expected a large variability in the catch rates between dredge stations, but the catch rates of the starboard and port side dredge were strongly correlated (r^2=0.90) (Fig 3). A high small scale spatial variation should have been reflected in a large residual variation (σ_ε), but compared to var(y_1)=8.58 and var(y_2)=7.97 the residual variation was only $\sigma_\varepsilon = 0.64$.

Grab-dredge comparisons

In accordance to the assumption that all lesser sandeels are burrowed in the sand at night, only samples carried out when the sun was below 0^o of the horizon were included in the analyses, and 37 and 11 comparisons were carried out in 2008 and 2009, respectively. As Welch two sample t-test revealed no significant annual difference in the grab-dredge catch rates relationship (Eq. 1) ($p = 0.22$) all samples were combined in the analyses. One comparison (Pair no. 1 in Table 1) in 2008 consisted of zero catches in both the grab and the dredge and was excluded in the analyses. Pair no. 35 was also excluded in the analyses as the sandeel in dredge catch were limp and hardly moved, and a following video shoot showed many fish laying half dead on the sea-bed (a thorough investigation could not find the reason for the peculiar behaviour). Nevertheless, catch rate relationship (= 80.6) was the highest of all grab-dredge comparisons at this station (Table 1).

The rest of the dredge tows had catch rates ranging from 0.0065 to 12.7 (mean = 0.88, SD = 2.41) individuals per m^2. The mean catch of sandeels [n/m^2] in the grab was 15.8 (SD = 37.2) were considerably larger than for the dredge stations, but in spite of a significant higher catch efficiency in the grab the low sampling area resulted in many zero catches (47% of total samples). Excluding all zero catch observations in the grab the mean grab-dredge-catch-ratio relationship was 0.057 (SD = 0.063).

The statistical handling of the zero values in the grab samples is clearly a challenge. In the run depicted in Figure 4a, all zero grab samples are excluded in the binominal model simulation. It is a clear peak around 0.05, but some of the sampled data indicate a relatively large uncertainty.

The size distributions of the sandeels were similar for the grab and dredge catches (Figure 5), and a paired Wilcox test revealed no difference in the weighted length average (p = 0.40) for the grab and dredge comparisons. In this test, all comparisons with less than 3 sandeels in the grab samples were excluded.

Discussion

The catch efficiency of sandeels in the grab was in average 11 times higher than in the dredge, but due to the considerably larger sampling area for a standard dredge tow the total number of sandeels caught dredge samples were about 20 times higher than the total numbers of sandeels in the grab samples. Nevertheless, the positive catch ratio correlation and the correspondence in the length distribution of sandeels in the grab and dredge comparisons suggest that both sampling procedures reflect the underlying density and size distribution of sandeel buried in the sand. These findings show as expected considerable higher catch efficiency in the grab and present a more accurate estimate of number of sandeel buried in the sand. In a previous study it was indicated that the catch efficiency of the grab may be less than one due escapement underneath the jaws of the grab (Høines and Bergstad, 2001). In one sample in the 2008 survey the mouth of the grab had cut a sandeel in two and only the tail end was caught. If many sandeels manage to escape downwards it seems likely that this phenomenon had occurred more frequently, particularly in samples with high catches of sandeels. Based on our observations and on available information it is not possible to conclude that the catch efficiency is less than one in the grab. However, important factors make the reliability of the grab as a sampling tool questionable. First, a successful closure of the grab mouth is sensitive to the substrate as even small stones may prevent the grab to close completely. A few times during the surveys the grab was not properly closed and little sand was still left when the grab was taken on board. No sandeels were caught in these incidents and such samples were classified as invalid and not considered in the results presented. Still, the observations indicate that the efficiency is affected by the substrate, which is an unwanted quality for a sampling tool. Further, the ratio between area coverage and operation time is small for the grab. Typically, three grab replicates took about 15 min from start to stop and in addition a few minutes are used to manoeuvre the vessel into position, which means that at least 20 minutes were spent to grab sample 0.68 m^2. In comparison the area coverage - operation time ratio for a standard dredge haul was more than 700 times higher. Although grab sampling was restricted to locations with more than 20 sandeels caught by the dredge many of the grab samples contained no sandeels. Despite of high catch efficiency the combination of sediment sensitivity, a long operation time and a relative low probability of catching any sandeel seems to makes the grab unsuitable for estimating sandeel density over extensive areas. Still, the grab seems appropriate to correlate substrate type with density of sandeel.

In a previous study the catch efficiency of sandeel in a 1.2 m wide dredge was estimated be in the range from 1.4 % to 8.6 % (Mackinson et al. 2005) by comparing night catch ratios in the dredge with acoustic biomass estimates of sandeel at daytime. Clearly, the estimate is affected by the target strength (Mackinson et al. 2005), but the accuracy of the acoustic estimates is also affected factors such as vessel avoidance, correct allocation of the nautical area scattering coefficient (s_A) to species and proportion of sandeel burrowed in the sand at daytime. The proportion of sandeel in the sand may vary with time of the day and between days (Freeman *et al*., 2004) and will thereby affect the acoustic sandeel density measures. Despite the uncertainties in the acoustic estimates, it is clear that that the catch efficiency of the dredge is low, which was also confirmed by our study. Still, the results of the parallel towing show that the dredge catches provide a relatively precise measure of the density of sandeel at a location. Preliminary studies (pers. comm: egil.ona@imr.no) suggest that the sandeels stay in the same location, thus, if the sandeel as all sandeels probably are in the seabed at night, the difference in catch rates at night and the subsequent day at a given location will presumably reflect the acoustic availability. However, both the grab and dredge samples show a high patchiness in the geographical distribution of sandeel. Therefore, a reliable availability estimate is dependent of a precise navigation of the vessel to be able to sample the same location at night and day. If such a navigation is possible, it seems realistic to establish a ruinously procedure to measure the acoustic availability. However, the low catch efficiency calls for the development of a more efficient sampling dredge.

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Tables

Table XXX. Sandeel catch in number and sampling area (m^2) of the grab and dredge by pair.

	Grab		Dredge			Grab		Dredge			Grab		Dredge	
Pair	Catch	Area	Catch	Area	Pair	Catch	Area	Catch	Area	Pair	Catch	Area	Catch	Area
*1	0	2.04	0	617	17	0	0.68	174	617	33	0	0.68	69	679
2	1	2.04	5	617	18	1	0.68	52	679	34	2	0.68	24	679
3	0	2.04	4	617	19	0	0.68	85	617	*35	1	0.68	731	617
4	0	0.68	40	617	20	3	0.68	41	556	36	1	0.68	76	741
5	1	0.68	177	679	21	1	0.68	28	617	37	0	0.68	65	679
6	0	0.68	37	741	22	0	0.68	32	617	38	211	2.04	1726	617
7	0	0.68	21	679	23	2	0.68	45	617	39	267	2.04	3543	617
8	5	2.04	441	617	24	9	0.68	600	679	40	11	0.68	170	617
9	6	2.04	133	679	25	4	0.68	37	617	41	0	0.68	28	617
10	0	0.68	68	1296	26	0	0.68	55	617	42	0	2.04	1074	679
11	3	0.68	178	556	27	2	0.68	103	617	43	0	0.68	58	617
12	0	0.68	56	617	28	0	0.68	55	679	44	194	2.04	1617	617
13	0	0.68	32	617	29	3	0.68	200	679	45	43	0.68	79	679
14	0	0.68	84	617	30	0	0.68	29	679	46	190	2.04	5645	617
15	0	0.68	53	617	31	5	0.68	91	617	47	278	1.81	7853	617
16	0	0.68	85	617	32	7	0.68	65	617	48	0	0.68	118	679

* Excluded in the analyses

Figures

Figure 1a A Van Veen grab, 42 x 54 cm.

Figure 1b The sandeel dredge, width 1 m.

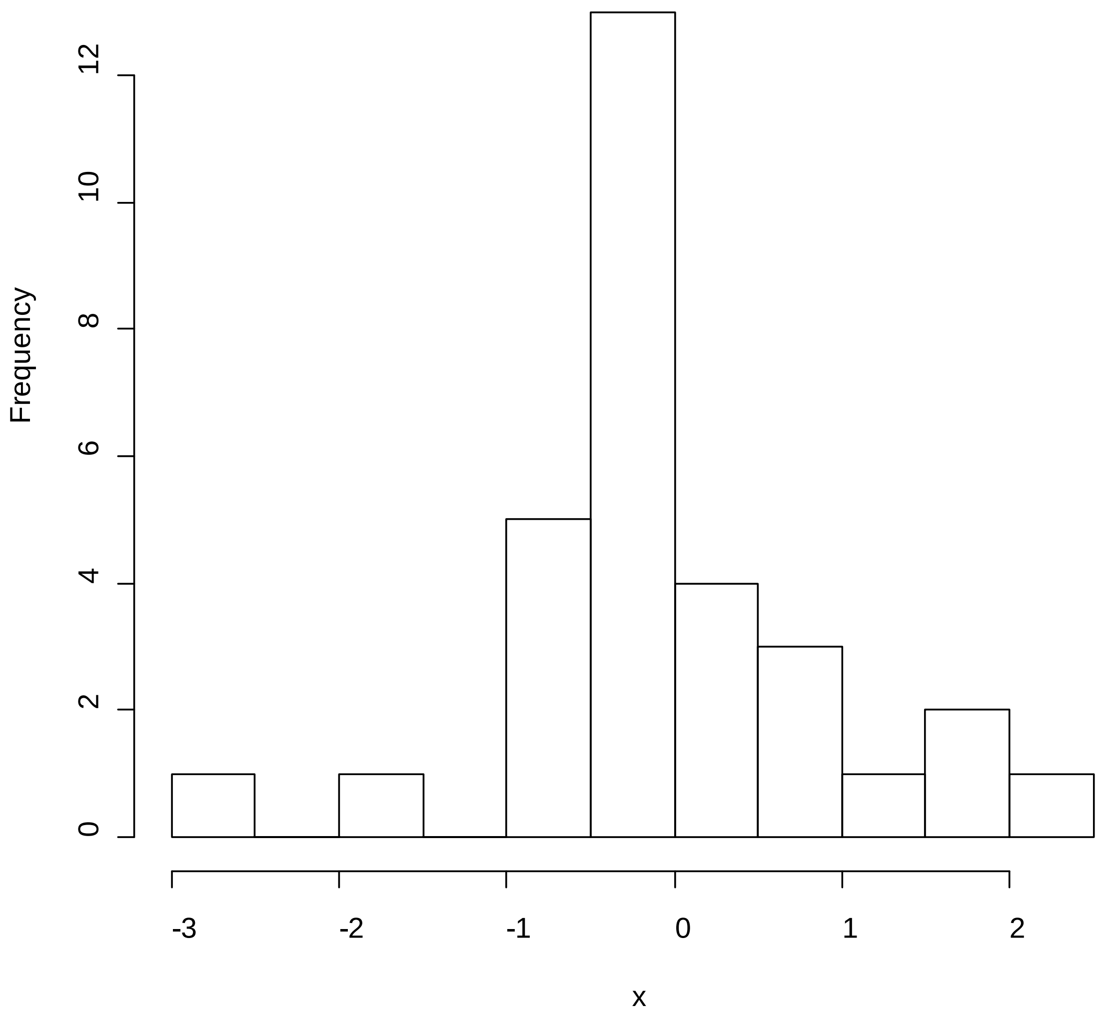

Figure 2 Histogram of the $x_i = (z_i - z_k)/s_k$ distribution

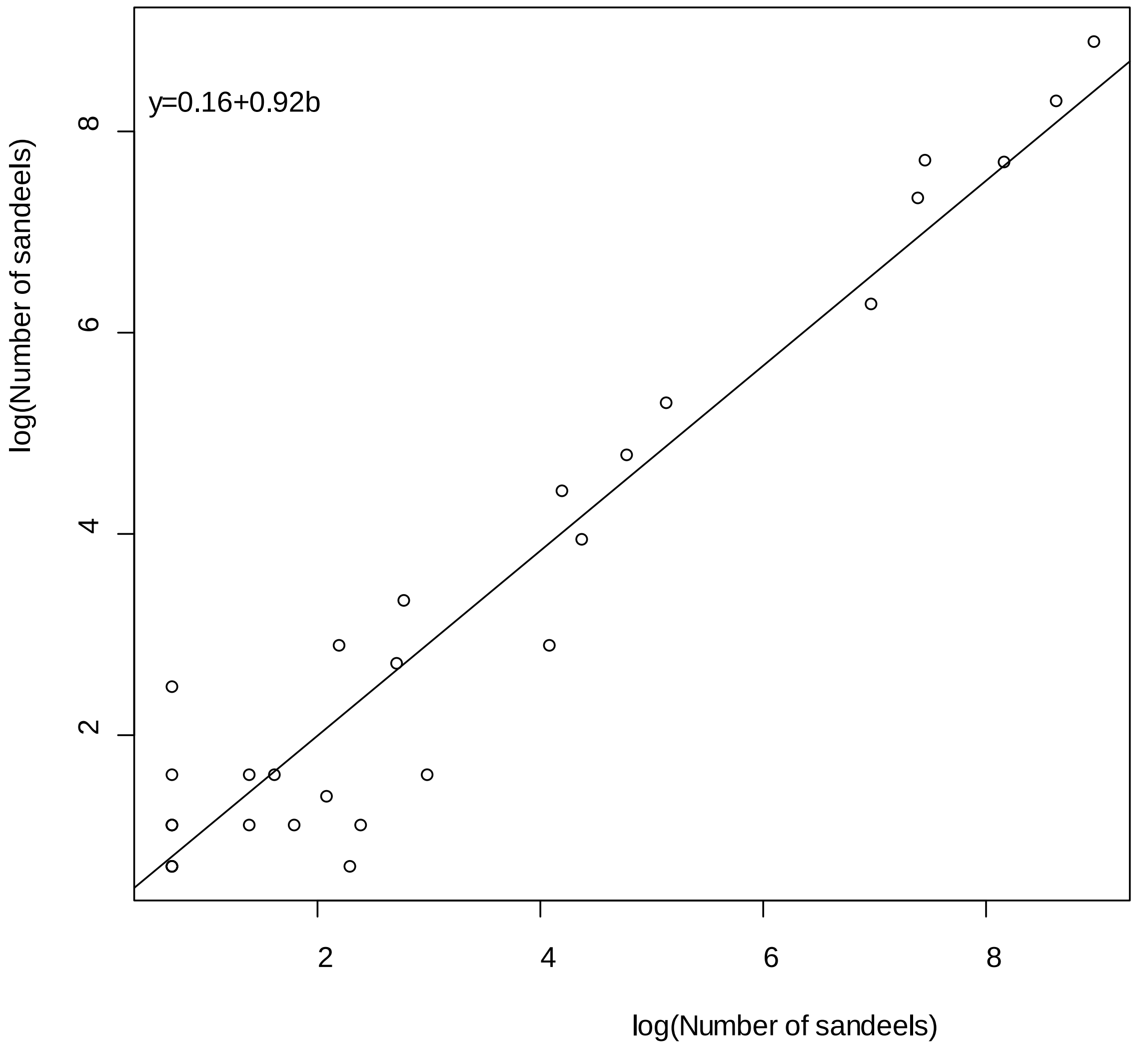

Figure 3 Catches of lesser sandeel in numbers of the starboard (x-axis) and port side (y-axis) dredge.

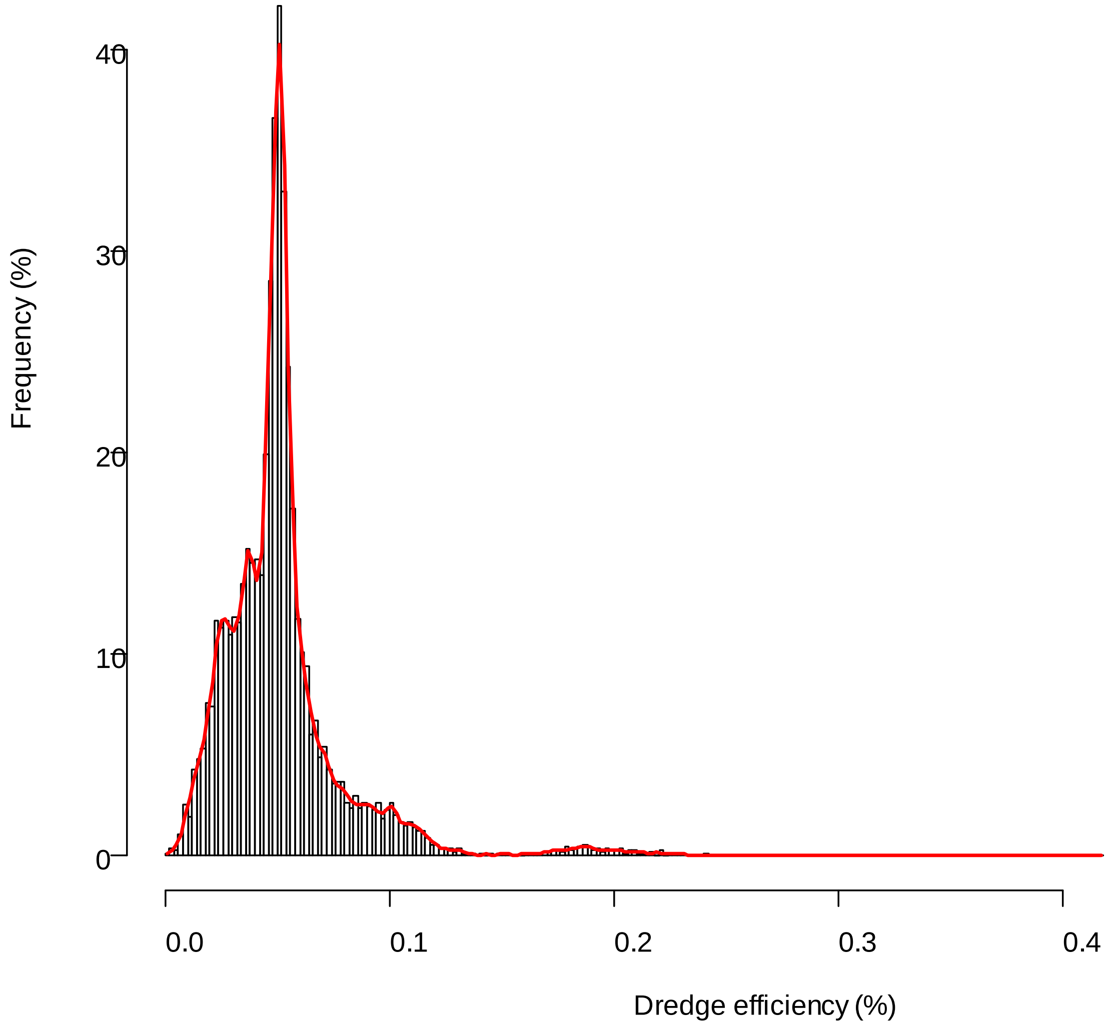

Figure 4. Output distribution of simulation for the dredge efficiency from 1000 simulations.

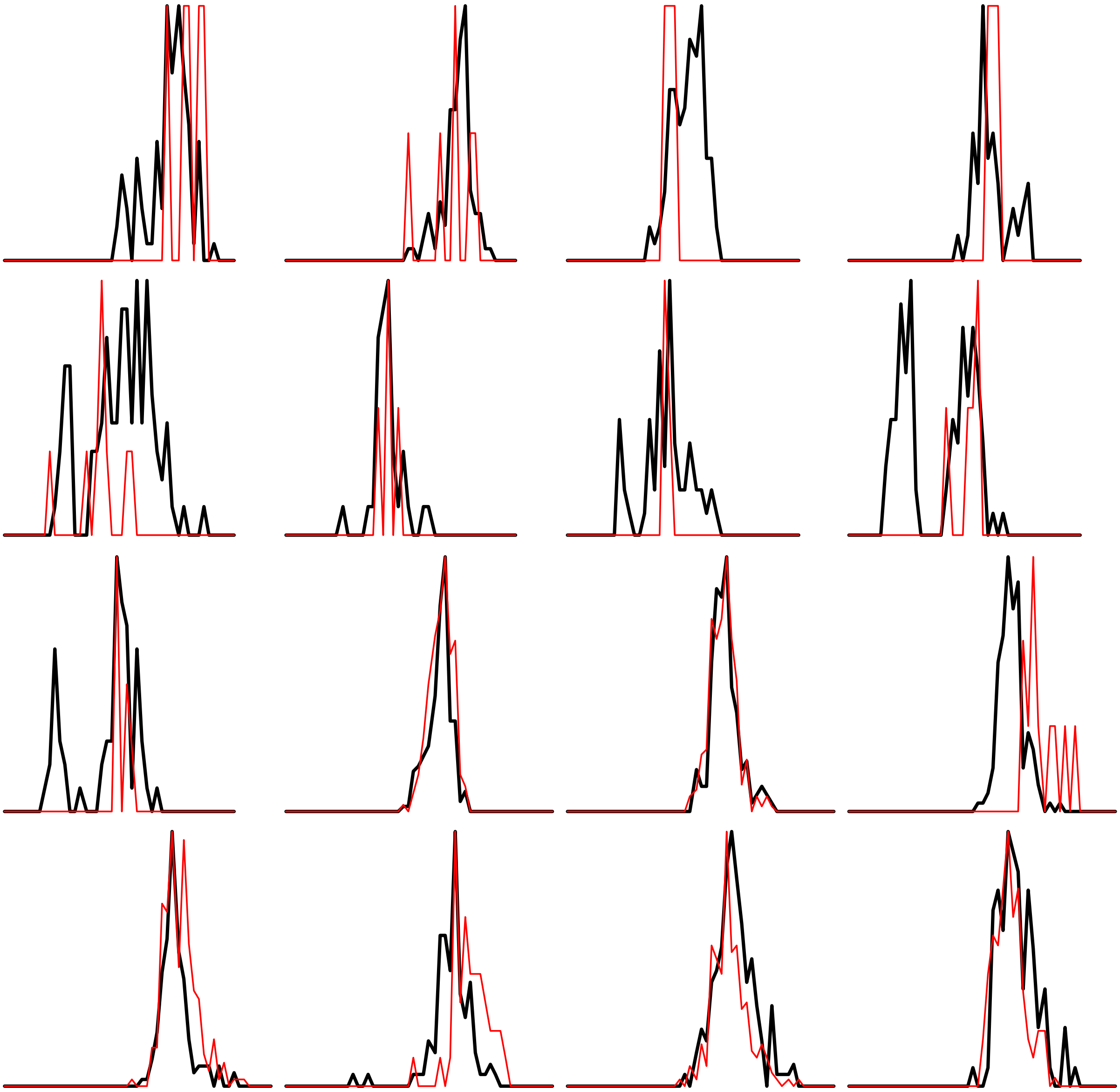

Figure 5 Normalized length distributions of sandeel caught in the grab (red) and dredge (black). Only comparisons with more than three lesser in the grab are depicted.