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QUANTIFYING THE AMOUNT OF FISH UNAVAILABLE TO A BOTTOM TRAWL BY USE OF AN UPWARD LOOKING TRANSDUCER

by

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ABSTRACT

When surveying demersal fish with a wide and variable vertical distribution, it is desirable to combine information from a bottom trawl survey with the information from a hydroacoustic survey into an absolute abundance estimate. To do this requires an estimate of either the amount of fish lost in the bottom acoustic deadzone or the amount of fish unavailable to the bottom trawl. In the latter case, this quantity is not easily estimated using an hull-mounted transducer due to vertical movement between the moment a fish passes the acoustic beam and the moment it reaches the trawl. For such situations, we have examined an alternative procedure based on an upward-looking, trawl-mounted acoustics system designed to directly measure the amount of fish passing above a trawl. This paper describes a pilot experiment for such measurements. To avoid disturbances of both fish behaviour and trawl geometry due to a cable connection between the vessel and the trawl, the echo sounder, the data logging system (a portable PC) and the power supply were put in an underwater housing and mounted on the trawl together with the transducer. An underwater camera showed that the attached equipment did not have any influence on the trawl geometry. The equipment is described and some preliminary results are shown.

INTRODUCTION

Since bottom trawl surveys and hydroacoustic surveys census different components of a semi-pelagic fish stock it has been argued that a combination of the two density estimates would improve the reliability of the survey results (Godø and Wespestad, 1993; Godø *et al.*, 1998; Aglen *et al.* 1999). Both indices are assumed to reflect total stock abundance, but neither of the two survey methods samples the complete water column (Figure 1). Fish close to the bottom are best assessed by use of a bottom trawl while pelagic fish are best assessed by use of acoustic methods. Thus, temporal and spatial variation in the vertical distribution of fish may produce differing and likely correlated affects on the two types of density estimates.

Vertical herding is highly dependent on fish size and vertical distribution. One possible way of reducing the bias generated by vertical herding would be to combine the acoustic and swept area estimates using a hydroacoustic system towed near the bottom to estimate the density of fish in the acoustic deadzone (Dalen and Bodholt, 1991). However, towed systems do not completely eliminate the bottom deadzone and, in addition, a towing cable can generate noise that potentially affects fish behaviour. As an alternative, we investigated the feasibility of measuring fish density above the trawl, and quantifying fish diving, by attaching an upward-looking transducer at the trawl headline. To avoid possible affects of a towing cable on fish behaviour, the acoustics system was designed to be completely contained within an underwater housing. Here we describe this new method and show some preliminary results.

MATERIAL AND METHODS

The experiment was conducted 1-6 March, 1999, off the Norwegian coast, near 70°N latitude and 28°E longitude, at a bottom depth of 250 m. A standard Norwegian sampling trawl, Campelen 1800, with rockhopper groundgear (Engås and Godø, 1989) and a pelagic trawl («Åkra trawl») with a circumference of 486 m (152 meshes x 3200 mm) (Valdemarsen and

Misund, 1994) were used. Both the pelagic trawl and the bottom trawl were equipped with a cod end of 22 mm, and Vaco doors of 6 m^2 (1600 kg). Towing speed of the bottom trawl was 3 knots; towing duration was usually 20 minutes, but was occasionally reduced to 15 minutes in high densities of fish. The bottom trawl hauls were conducted during daylight and at night but not during twilight. Twenty bottom trawl hauls were taken, 6 during daylight hours and 14 at night. A Scanmar height sensor was used to measure the headline height. Towing speed of the pelagic trawl varied between 3.5 and 4.5 knots. Three pelagic trawl hauls were taken. A schematic view of the measurement set-up is shown in Figure 1.

A hull mounted transducer (Simrad EK500 38 kHz echo sounder) was used for acoustic measurements and the Bergen Echo Integrator (BEI) was used for post-processing (Knudsen, 1995). A pulse length of 1 ms was used and the maximum depth for echo integration was set at 0.5 m above the acoustic bottom for both transducers. A minimum bottom-scattering strength of -45 dB was chosen for the bottom detection algorithm. With these settings there was no indication that fish concentrations close to the bottom were detected as bottom. Acoustic measurements were logged continuously.

An upward looking transducer (Simrad EY 500 38 kHz echo sounder), the data logging system (a portable PC) and the power supply were put in an underwater housing and mounted on the trawl headline, together with the transducer. The acoustic values were scrutinised from paper records. Some noise and interference from the Scanmar sensors were removed by subjective judgements. The remaining values were allocated to demersal fish (haddock+cod+redfish) and capelin according to their appearance on the echogrammes. All results presented relate to the s_A values allocated to "demersal fish". Out of the twenty stations undertaken, only fourteen (5 at day and 9 at night) stations are available for comparisons between the hull mounted and the trawl mounted echo sounders because of data inadequacies on occasional hauls of the trawl-mounted system. In some cases, the pulse repetition rate that was chosen caused severe interference with bottom echoes from a previous transmission («ghost bottom»). In other cases, the depth range for logging that was chosen did not cover the entire water column. The distance separating the hull-mounted and the trawl-mounted transducers was 0.4 nautical mile, except for the four last stations where, due to greater bottom depth, it was increased to 0.5 nautical mile. For both echo sounders the average area backscattering coefficients per unit sea surface (s_A; square meters per square nautical mile, Knudsen, 1995) were stored with a resolution of 0.1 nautical mile horizontal and 10 m vertical. A towed vehicle (Focus 400, see Øvredal and Huse, 1999) equipped with an underwater camera was used to check if the trawl-mounted equipment had any influence on the trawl geometry. Rigging of all the equipment used is shown in Figure 1.

A theoretical s_A was calculated from the trawl catches as described by Aglen (1996). First the swept area fish densities (ρ_{sl}) by species (s) and length (l) were estimated for each bottom trawl haul by the equation;

$$\rho_{sl} = c_{sl} / (d * w_{sl}),$$

where d is the towed distance, w_{sl} is the effective fishing width and c_{sl} is the catch of species s and length group l. As described for the standard surveys in the Barents Sea (Jakobsen *et al.* 1997), a length-dependent fishing width was then applied. The following functions were used:

$w_{sl} = 2.08 \times l^{0.75}$ for haddock

$w_{sl} = 5.91 \times l^{0.43}$ for cod and redfish,

where l is the fish length in cm. These equations are derived from Dickson (1993) and they are considered to be valid for lengths from 15 cm up to 62 cm for cod and 48 cm for haddock. Outside this range fishing widths are assumed constant. To make the swept area densities comparable to the acoustic observations, the density estimates were converted to a theoretical s_A value (s_{Acatch}) using the backscattering cross-section (σ_{sl}) for species and length group,

$$s_{Acatch} = \sum_{sl} \rho_{sl} \times \sigma_{sl}$$

Only cod, haddock and redfish were included in the calculations. For these species target strength (TS) was assumed to vary with fish length according to:

$TS = 20 * \log l - 68$ (Foote, 1987).

This leads to the following backscattering cross-section function:

$\sigma_{sl}= 1{,}99*10^{-6}*l^2$.

RESULTS

Acoustic observations

The correlation between the s_A values from the hull-mounted transducer (integrated from 10 m above bottom to the surface) and those from the trawl-mounted transducer (Figure 2a) was rather weak (r=0.66). In general, the trawl-mounted transducer recorded fish densities approximately one half as large as those recorded by the hull-mounted transducer. After the catches were converted to acoustic densities ($s_{A\ catch}$) and added to the trawl-mounted densities, the correlation with the densities from the hull-mounted transducer (from bottom to the surface, $s_{A\ total}$) increased (r=0.81) (Figure 2b). For s_A values less than 300 m^2 nautical $mile^{-2}$, the correlation was nearly 1.0, but as the densities increased the correlation became less.

The vertical s_A distributions for both echo sounder systems (Figure 3) show considerable variability in the movement of fish from the time a fish was recorded by the hull-mounted transducer until it was recorded by the trawl-mounted transducer. For 5 of 14 stations (stations 134, 135, 142, 156, 157) a downward shift in the vertical distribution could be observed. In these cases, fish were primarily distributed more than 100 m above bottom. For 9 of 14 stations (stations 136, 137, 138, 143, 147, 148, 150, 151, 152), there was a upwards shift in distribution. In these cases, fish were primarily distributed less than 100 m above bottom. In addition, a combination of these two pattern can be seen in some of the stations (stations 134, 142), where fish distributed more than 50 m above bottom showed an upward shift in the vertical distribution, while fish closer to bottom seemed to dive further down toward the bottom.

Figure 4 compares the total observed values of "demersal fish" for the entire water column above certain height. This total value was in nearly all cases lower for the trawl mounted-compared to the hull mounted echo sounder. Above the lower observation limit for the trawl mounted echo sounder (10 m height) only station 152 showed highest value on the trawl mounted echo sounder. For heights above 30 m, two stations (152 and 148) showed highest values on the trawl mounted echo sounder. At these two stations most of the fish were recorded at heights above 30 m. This is also the depth at which most of the fish was recorded.

Bottom and pelagic trawl catches

The bottom trawl catches consisted of haddock (*Melanogrammus aeglefinus* L.), cod (*Gadus morhua* L.) and redfish (*Sebastes marinus* L.), with haddock as the most numerous species at 15 of the 20 trawl stations (Figure 5a). Throughout the sampling period, the catches varied considerably in weight (Figure 5b), but no long-term trend over the experimental period was found in catch weight or numbers. However, catches by 5 cm length groups showed day/night differences for all groups between 25 and 50 cm for haddock, between 10 to 55 cm for cod and between 25 to 50 cm for redfish (Figure 6). For all three species the variances in catches were higher during the day than at night. This variation was mainly caused by a high variation in the catches of fish in length groups 35-39 cm for haddock, 30-34 for cod and redfish 15-19 cm for redfish. The ratios of day to night catch rates (Table 1) were greater than one for all except some of the least abundant length groups. Small (10-34 cm) and medium sized (34-49 cm) fish dominated the bottom trawl catches during day, but the variances in catches were significantly higher during the day than at night only for one group, cod from 30 -34 cm.

The catch composition from the pelagic trawl stations (Table 3), shows a dominance of medium sized (35-54 cm) haddock, with a element of large cod (above 55 cm) during day and night. During night a larger proportion of small haddock was caught pelagically.

Discussion

The most appropriate way of combining the bottom trawl and acoustic density estimates is not known. There are at least four approaches to the problem: 1) change the construction of the trawl so that it will catch all the fish in the water column; 2) improve the bottom detection of the echo sounder so that the deadzone problem can be eliminated; 3) use the bottom trawl catches to estimate the amount of fish in the deadzone or; 4) use the acoustic fish density profile to estimate the amount of fish that are not available for the bottom trawl. In all these approaches the vertical distribution of different species and length groups and the variation in the behaviour of the fish in response to an approaching vessel is essential for the reliability of the combined survey data. In the two last and most realistic approaches, it is important to obtain an estimate of the thickness of the acoustic deadzone and the effective fishing height of the trawl.

The purpose of this study was to estimate fish density above the bottom trawl and to quantify the diving reaction of the fish. The hull-mounted transducer recorded twice as much fish as the trawl-mounted transducer. This difference could easily have been explained if the reflective properties of the swimbladder were known to be higher from the dorsal aspect than from the ventral one, but it has been shown that the difference between the two is minor (Love, 1977; Ona, 1982). A more likely explanation concerns two consequences of fish diving between the passage of the vessel and the arrival of the bottom trawl. First, if fish dive below the depth of the headline they would not be recorded by the upward looking transducer. Such diving is supported by the strong correlation between the combined trawl and acoustic estimates (s_{Acatch} + s_A from the upward looking transducer) and the acoustic estimates from the whole water column (s_A from the hull-mounted transducer). In addition, the slope of the regression of the combined estimate on the acoustic estimate was greater than 1, which could indicate that the amount of fish in the deadzone increased with increasing fish density.

Second, since diving substantially changes the tilt angle of a fish and a change in tilt angle of only a few degrees has a marked effect on target strength (Nakken and Olsen, 1977; Rose and Porter, 1996), diving would cause a dramatic apparent reduction in fish density. Qualitative evaluation of the potential affects of changes in tilt angle could be obtained by comparing the mean target strength of the targets identified by the trawl-mounted system to that of the targets identified by the hull-mounted system, provided that the fish were sufficiently dispersed for target identification. Changes in tilt angle in response to the vessel and gear can also be assessed with target data collected with an hydroacoustic buoy using a analytical procedure know as target tracking (Godø *et al.*, 1999).

This study shows that the diving pattern of fish is variable. In some cases no reaction could be observed, in others extensive diving reactions occurred. In response to vessel noise, fish in the pelagic zone is likely to swim towards the bottom (Olsen *et al.*, 1983; Ona and Godø, 1990). However, in this study it was observed an upward shift in the vertical distribution from the time the fish was recorded by the hull-mounted transducer until the trawl-mounted transducer recorded the same fish. This indicates that some of the fish actually did rise up in the water column instead of getting herded down to the bottom. Based on these observations we hypothesise that fish react to the noise generated from both the vessel and the gear (warps), generating areas with low fish densities in the upper water column as well as above the bottom trawl (Figure 7). This hypothesis is further supported by earlier observations by using echo sounder on a towed vehicle (focus 400), showing that the area within a 20 m diameter of the warps was completely devoid fish.

The factors influencing the behaviour of fish are several and they might vary between areas, with time (year, seasons and a 24 hour cycle) as well as for different species and length groups (see Michalsen, 1999). Correction factors accounting for all of this variability are not easily established. The challenges is to efficiently and adequately incorporate information about the vertical distribution of the fish into a model that predicts the vessel-affected behaviour and suggest the optimal way of combining density estimates of bottom trawl and acoustics. For this purpose the upward looking transducer will provide important information about vertical herding and the effective catching height of the bottom trawl.

In the application of the trawl mounted hydroacoustics system considered here our objective is to estimate a correction factor that can be applied to a hydroacoustic estimate of biomass from a survey so that the hydroacoustic estimate can be combined with the bottom trawl estimate to obtain a total water column estimate. Another application now being considered by the Alaska Fisheries Science Center is to use the system in situations where semi-pelagic species are surveyed using charter vessels that are unsuitable for routine hydroacoustic work. In such cases, the trawl-mounted system could be used to obtain water-column estimates of abundance within individual trawl tow paths. Thus the type of survey envisioned would be less like a combined hydroacoustic bottom trawl survey, typified by the Norwegian Barents Sea survey, and more like a traditional bottom trawl survey with discrete sampling.

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Table 1. The day/night ratio (mean number) of fish caught per 5 cm length group. * indicates length groups with significant difference between day and night, at 5% significance level.

Length (cm)	Day/night ratio: Haddock	Cod	Redfish
5- 9			
10-14		2,60	
15-19	1,84	2,47	2,14
20-24	1,27	2,03	1,55
25-29	2,23	1,78	1,76
30-34	4,38	3,42*	1,51
35-39	6,53	2,63	1,16
40-44	5,48	1,87	0,92
45-49	3,41	1,56	1,26
50-54	1,44	1,35	
55-59	1,23	1,18	
60-64	2,83	0,83	
65-69	0,86	0,69	
70-74		0,62	
75-79		1,31	
80-84			
85-89		0,79	
90-94		0,47	
95-99		2,89	

Table 3. Composition (%) of species and size groups, as well as total catch in numbers in pelagic hauls. The daytime station is marked with *.

	Haddock				Cod				Total
st.no	0-19	20-34	35-54	55+	0-19	20-34	35-54	55+	catch
144*			70	28				2	98
146*			71	22				7	303
149	8	26	60	2				5	62

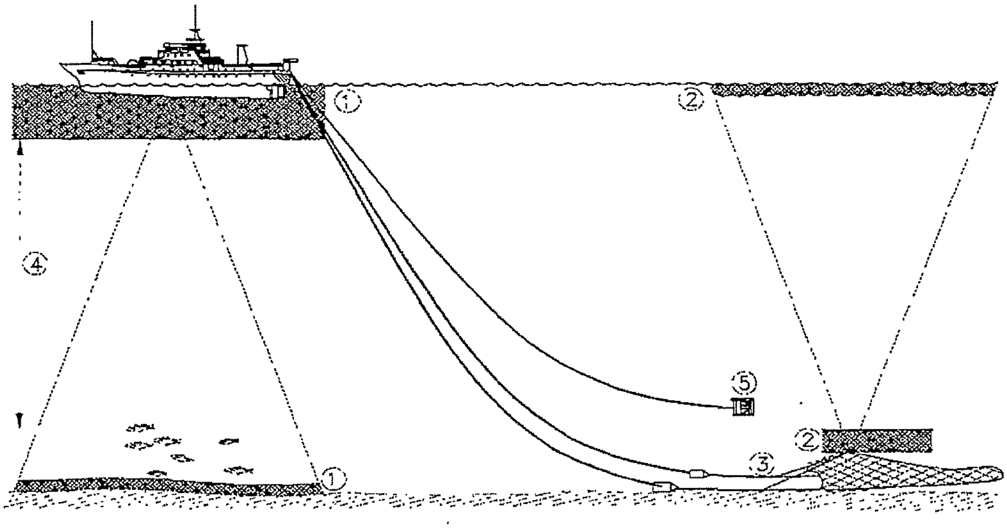
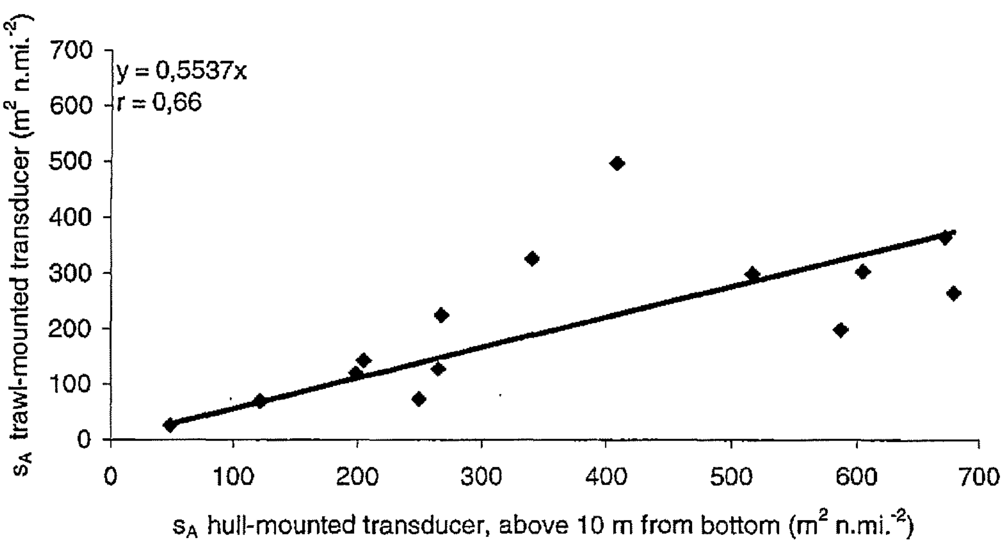


Figure 1. The equipment used and the water column covered. 1) shows the upper (10m) and lower (0.5m) acoustic deadzone for the hull-mounted echosounder, 2) shows the upper (0.5m) and lower (6m) acoustic deadzone for the trawl mounted echosounder, 3) indicate the vertical opening of the bottom trawl (4m). Effective acoustic sampling is conducted in the area between the deadzones and 4) is the area from which the fish densities measured by the two echo sounders was compared. 5) Shows the arrangement of the towed vehicle (Focus 400).

a)



b)

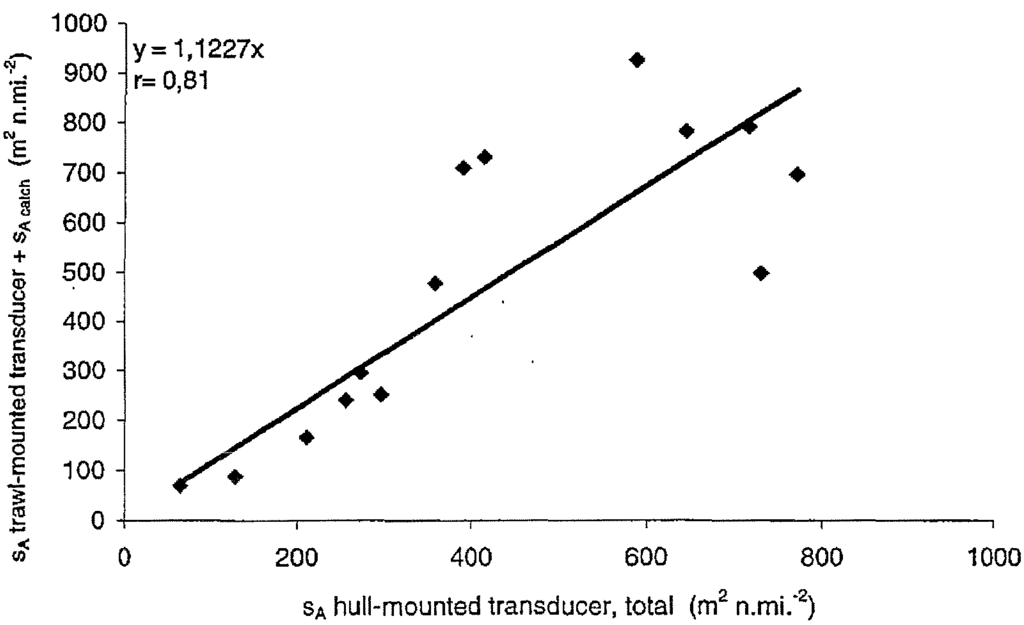


Figure 2. Correlation between the s_A values from the hull- and trawl-mounted transducer. a) values integrated from 10 m above bottom to the surface, b) a combination of the acoustic densities from the trawl -mounted transducer and the trawl catches, related to total fish densities from from bottom to the surface, recorded by the the hull-mounted transducer.

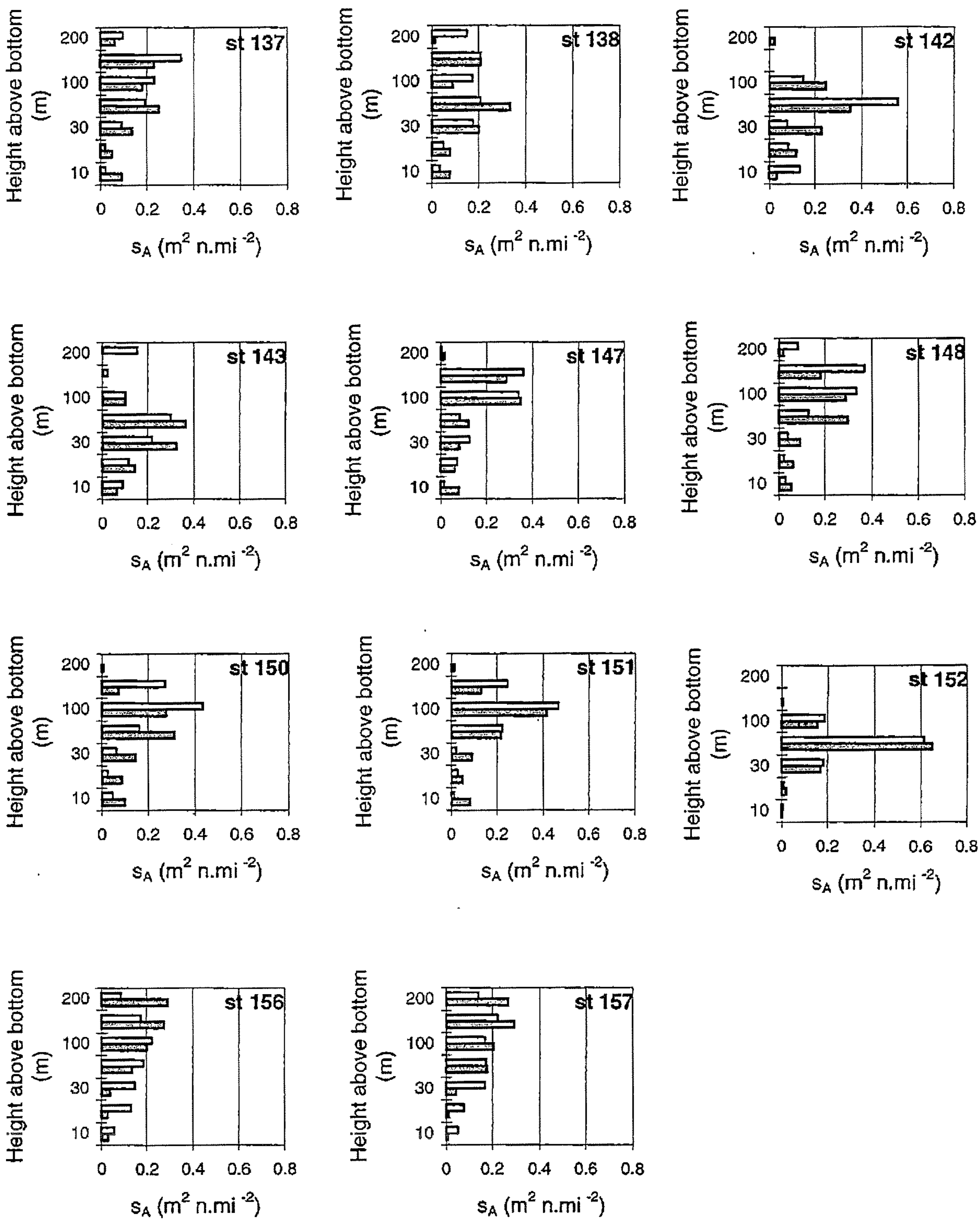


Figure 3. The fraction of s_A values within height intervals (relative to total fish density above 10 m height) from the different trawl stations. Open bars represents the trawl-mounted transducer, the filled bars represents the hull-mounted transducer. The height interval is given by the lower limits.

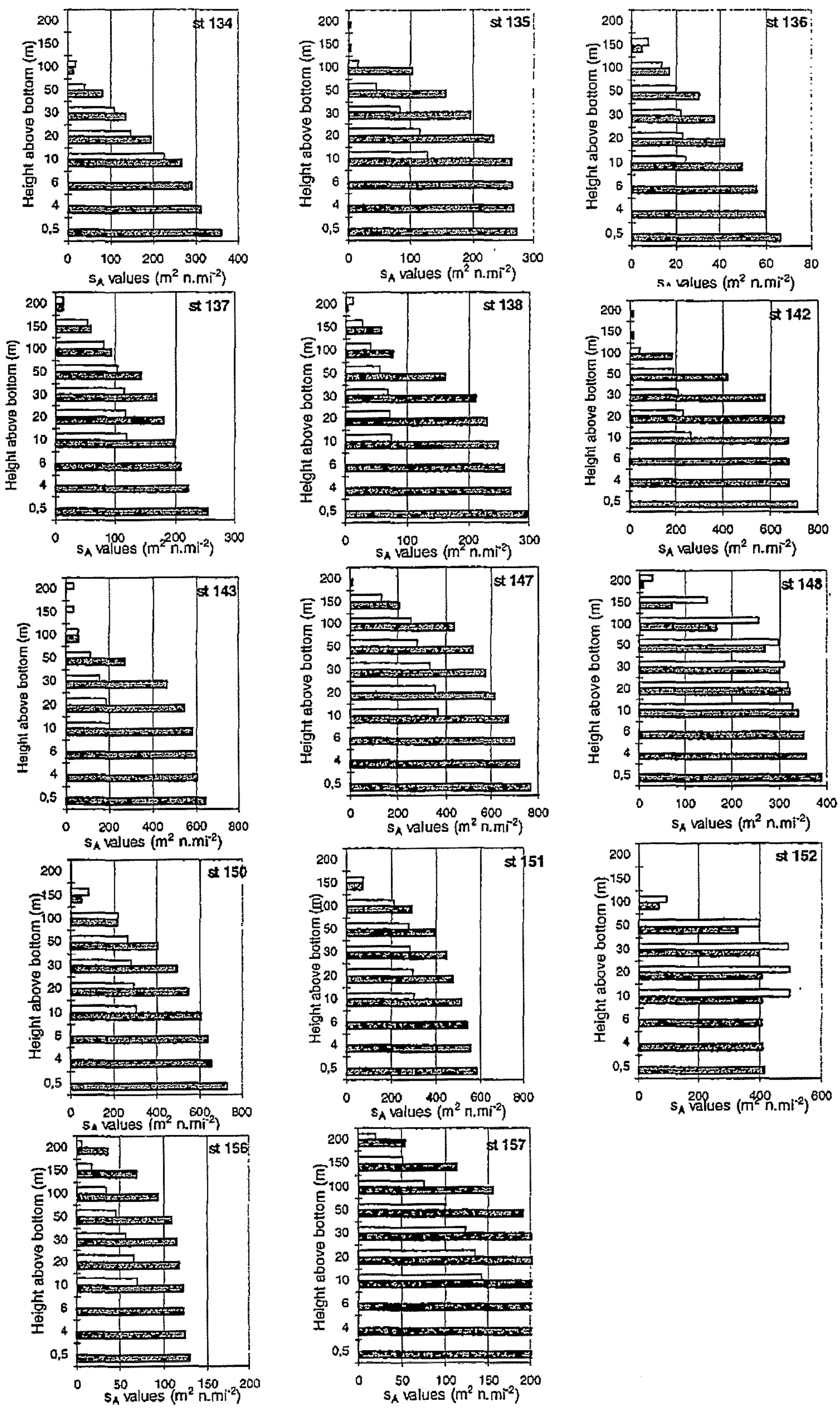
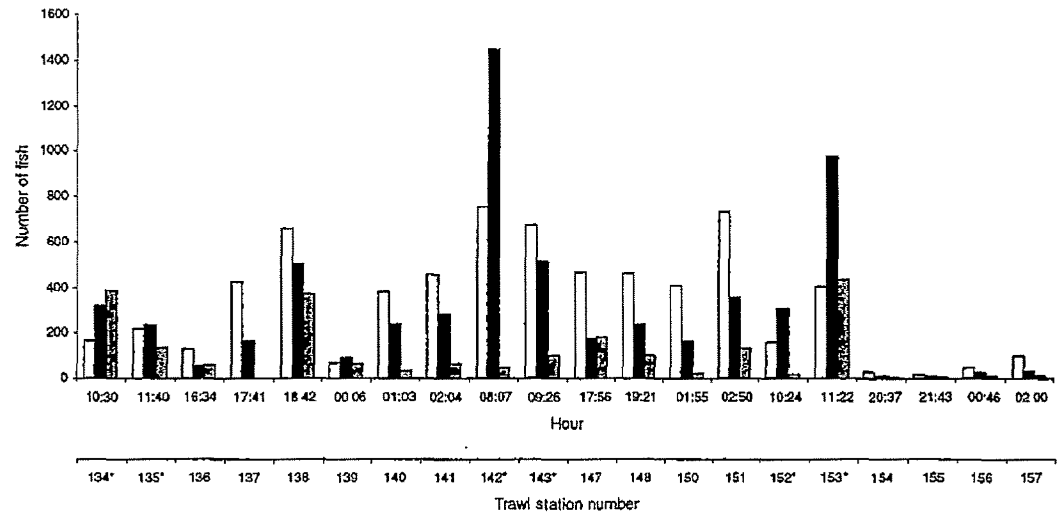


Figure 4. Total s_A values, above certain heights, from the different trawl stations.

a)



b)

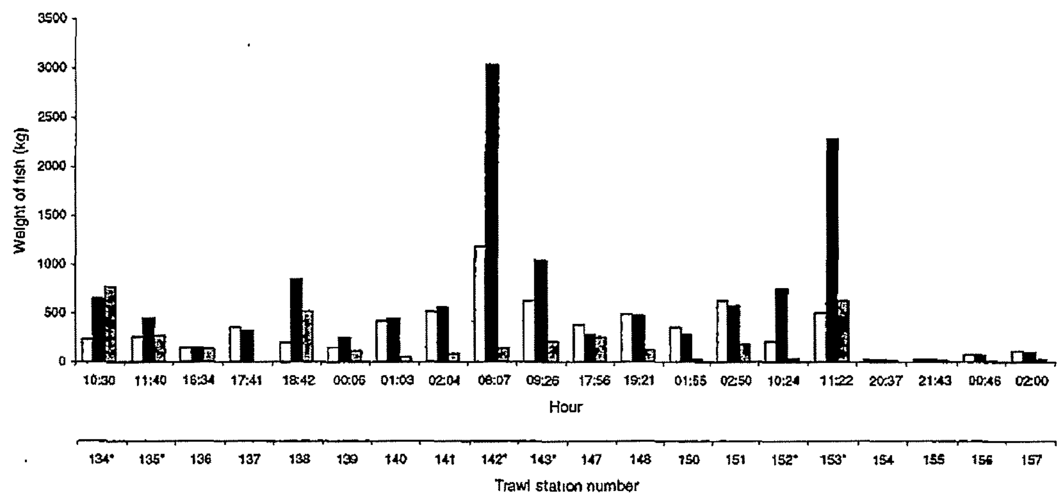


Figure 5. Bottom trawl catch rate (numbers per nautical mile) by species. a) Catch in numbers, b) catch in weight. Trawl stations taken during daytime are marked with a star. Open columns represent haddock, black columns cod and shaded column represents redfish.

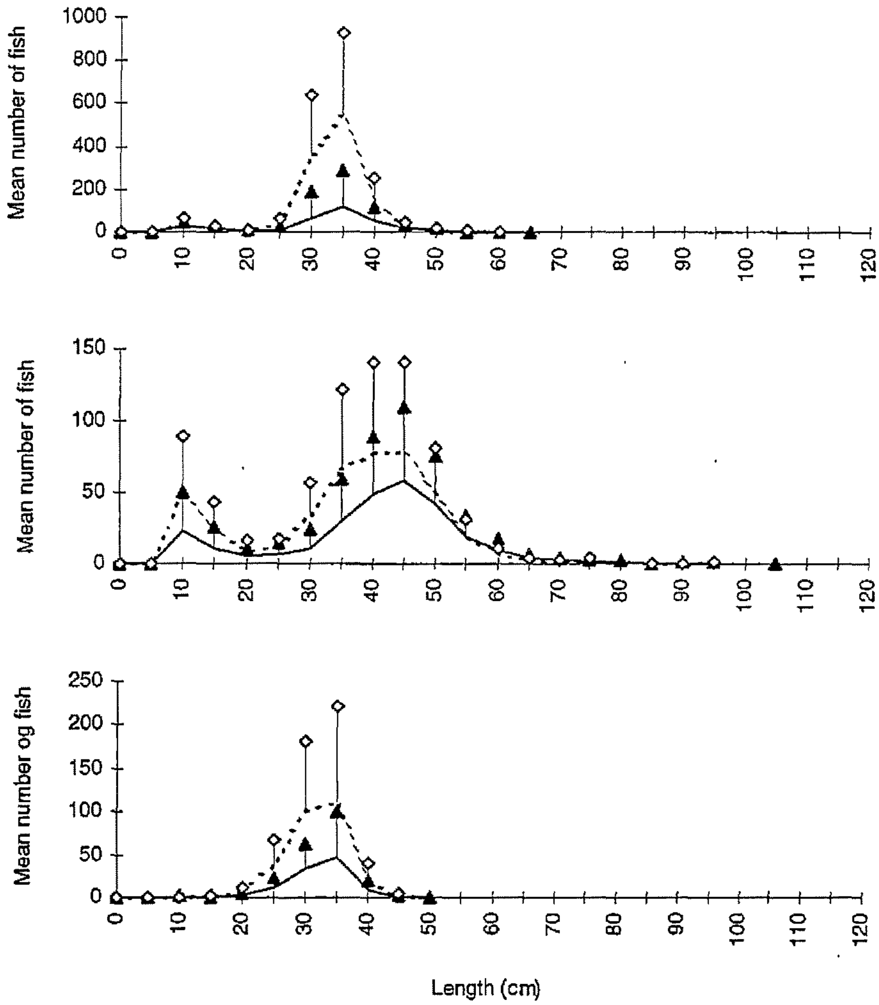


Figure 6. Mean numbers of fish per 5 cm length group day (dotted line) and night (full line) for a) haddock, b) cod and c) redfish. Vertical lines with an open diamond indicate the standard deviation during the day and vertical lines with a black triangle indicate standard deviation at night.

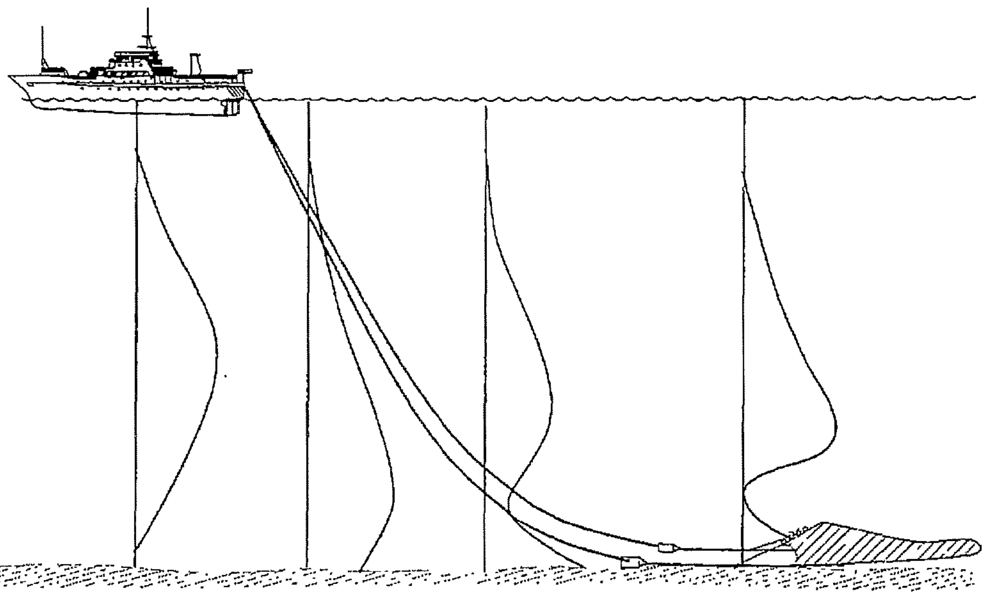


Figure 7. Fish reaction during different stage of the trawling process. The curved lines illustrate vertical fish distribution.