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Vertical distribution of cod, haddock and redfish; Impact on bottom trawl and acoustic surveys in the Barents Sea.

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Abstract

At a selected location in the Barents Sea acoustic observations, bottom- and pelagic trawl catch data were collected over a 10 day period. A large proportion of the fish were in the acoustic dead zone during the sampling period. Only during a few hours in the daytime high acoustic values were obtained. According to the pelagic trawl hauls these recordings consisted of large haddock ascending from the bottom, while small haddock and small redfish dominated the acoustic recordings at night. The bottom trawl catches showed higher variability and higher average catch rates during the day than at night, but the diurnal variations were relatively less than those of the acoustic recordings. The largest reduction in catch rates from day to night was observed for small haddock and redfish. This is consistent with the observation that these were found pelagicly during night. The acoustic observations and the bottom trawl catch rates were found to be correlated with diurnal cycles in observed light level and semidiurnal cycles in current speed. The results are interpreted in terms of variable catchability of the bottom trawl and variable availability for the echo sounder.

Keywords:, Acoustic observations, bottom trawl catches and pelagic trawl catches, diurnal and semidiurnal cycles, catchability, availability.

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INTRODUCTION

Bottom trawl and acoustic surveys have been carried out in the Barents Sea and Svalbard area since 1981. These two sets of indices of abundance have bee used independently in tuning of the VPA and recruitment predictions in the annual stock assessment at ICES (Anon., 1996). Since fisheries-dependent data have become less reliable for use in these methods due to changes in fishing strategy and efficiency the last decades, results from the standardised scientific surveys have increased in importance (Hylen *et al.* 1986). In spite of the high influence in the assessment procedures, neither of the two survey methods sample the complete stock. Fish distributed near the bottom are best assessed by a bottom trawl survey while acoustic measurements obviously are more applicable on pelagicly distributed fish. In addition changes in availability of the fish to the survey methods might change from year to year (Godø and Wespestad 1993) as well as within a diurnal cycle (Engås and Godø 1986, Wardle 1993, Michalsen *et al.* 1996). Diurnal differences in catch rates and length frequency have also been reported (Engås and Soldal 1992, Wardle 1993, Michalsen *et al.* 1996). In order to increase the reliability of the survey estimates, factors which influence the behaviour of the fish as well as the performance of the two methods have to be understood. One of the most important sources of errors in this case is the vertical movements undertaken by the fish.

Vertical migration is in most cases described as a trade off between predation risk and food consumption, modulated by changes in light (Neilson and Perry 1990, Helfman 1993). Water currents are also known to influence the vertical distribution, either due to the fish avoiding or utilising them (Arnold 1981, Arnold *et al.* 1994, Metcalf and Arnold, 1997).

The present study was based on acoustic observations, bottom- and pelagic trawl catches collected over a 10 day period at a selected location in the Barents Sea. Data from 10 days of trawling and acoustic sampling were analysed and related to measurements of current, light and temperature. The results were interpreted and discussed with regard to potential impact on the reliability of bottom trawl- and acoustic surveys.

MATERIAL AND METHODS

Acoustical observations, bottom- and pelagic trawl catches

Based on experience from annual surveys in February the area around the North Cape Bank was expected to be suitable for the experiment. After some searching in this area a fixed bottom trawl towing path was selected at position N72°41' E 25°30', with a towing distance of 1 nautical mil in direction 20° N. Pelagic tows covered more or less the same path but were extended by about 1 nautical mile to each end of the bottom trawl path as indicated in the first panel of Figure 3.

In order to compare differences in the distribution of fish between day and night, no hauls were made during dusk and dawn. During the first days 3-4 bottom trawl hauls were made both during daylight and at night. Then it was decided that a useful strategy for sampling the fish recorded pelagicly was to make one pelagic haul close to the bottom (footrope about 3 m from the bottom) and one haul with the footrope about 30-40 m above the bottom both day and night. Accordingly the number of bottom tows had to be reduced to 1 or 2 during day and night. This procedure was generally followed after the 3 April. During daytime, however, it became evident that when towing 40 m off bottom the fish rather effectively managed to escape below the trawl. Therefore most daytime pelagic hauls were made close to the bottom. The catches were sampled and measured following standard procedures for the purpose of calculating catch by 1 cm length groups for all species.

The bottom trawl used was the standard bottom trawl used in Norwegian surveys in the Barents Sea, equipped with a rockhopper groundgear as described by Engås and Godø (1989). The doors used were 6 m^2, 1600 kg Vacoo doors. The doorspread was restricted to about 50 m by attaching a 12 m long rope to the warps 150 m in front of the doors. The pelagic trawl ("Åkra trawl") had a circumference of 486 m (152 meshes x 3200 mm) and a 24 mm cod end (Valdemarsen and Misund 1994).

Acoustic measurements were logged continuously. Most observations were made while towing or sailing along the trawl path. In addition, to obtain some general information on the fish distribution in the surroundings, acoustic surveys of an area approximately 5 by 5 nautical miles were made, including the position of the current meters and the towing path. Due to the trawling programme, mainly dusk and dawn periods were available for these mini surveys. Table 1 lists the surveys, and the grid applied for most of the surveys is shown in Figure 3. Of the 14 surveys, 3 were made during darkness and 2 during daylight. A Simrad EK500, 38 kHz echo sounder was used for acoustic measurements and the Bergen Echo Integrator (BEI) was used for post-processing (Knudsen 1995). The processed data (s_A values) were stored with 0.1 nautical mile horizontal and 10 m vertical resolution.

Stormy weather prevented the collection of biological data in the period from the 26 March until the 1 April. The current meters continued to record data during this period.

Environmental measurements

Current and temperature data were collected with RCM4 current meters. The mooring was stationary and recorded in two depths, 5 and 50 meters above the bottom. Speed, instantaneous direction and temperature were recorded in averages of 10 minute intervals. The total speed represents the flow of water masses independent of direction, while the East-West and North-South components of the current indicate changes in the transport in the respective directions. Since this study among other things focused on variation in the relation between bottom trawl catches and acoustic recordings we concentrated on the recordings of total speed closest to the bottom.

Changes in light (µEinstein) were measured with a Li-1000 data logger at 15 minute intervals.

Statistical analyses

The trawl data were tested with Student's t-test for differences of means, and with the F-test for differences in standard deviation. Linear regression was used to test if there was a trend over time in the bottom trawl catches of cod and haddock, that means, if the slopes of the regression lines were significantly different from zero.

To study variations in catch rates with regard to diurnal or semidiurnal cycles, a correlation matrix was made. Total weight of each species per trawl station were related to mean values per trawl haul of light level, temperature, current speed, relative current direction as well as the acoustic values in the bottom - and the pelagic channels.

Time series analysis were conducted to study variations in the acoustic recordings. Due to missing values in the stormy period, only data from 1 to 8 of April was used. Since the current was measured with 10 minutes interval, we used this time axis as a standard and interpolated the acoustical recordings and light levels accordingly.

RESULTS

Light, current and temperature

Figure 1 shows the measurements of light intensity at surface as well as temperature and current speed 5 m above the bottom. The light level showed one main peak each day, and the maximum value increased continuously during the sampling period.

The current speed showed two peaks during the 24 hours cycle (Figure 1). Close to the bottom the water was transported at speeds of 0-20 cm s^{-1}, while at 50 meters higher up the current was 1.5-2 times stronger. During the period of 26-29 March, with Westerly gales, the maximum values increased only slightly while the minima increased from an average of 1 cm s^{-1} to about 10 cm s^{-1} compared to the rest of the period.

The temperature was affected by the gale with a reduction of 1-1.5 ^{0}C during the stormy period. The temperatures close to the bottom were generally lower than the ones 50 meters above the bottom.

Acoustic observations and pelagic trawl sampling

The acoustic values were highly variable. Figure 2 shows the time sequence of values (1 nautical mile averages) for the whole period in the study area. A diurnal pattern was evident. The highest values were observed at the brightest time of the day, while the lowest values tended to occur around sunrise and sunset. In addition there is another, but considerable smaller, peak in the acoustic values during night.

The peak in light intensity and the acoustic values seem to increase during the sampling period, and to cancel out this long term effect the two data sets were log transformed. Examination of cycle duration and match between cycles was conducted on these data as well as from the recordings of the current. A time series analysis confirmed a 24 hour cycle for the light, a 12 hour cycle for the current and both a 12 hour and a 24 hour cycle for the acoustical values

Table 3 shows that for all data the acoustic values, both at bottom and pelagic, have a positive correlation with the light and a negative correlation with the current. If the data observed during the day are excluded from the analysis the correlation between acoustic values and the light became negative. The tables present results when the separation between bottom values and pelagic values are made at 10 m above bottom. Similar values were obtained when splitting at 30 m height.

Most of the acoustical observations in Figure 2 are from the bottom trawl towing path. One could therefore suspect that diurnal variations in the samples could be caused by diurnal patterns in horizontal movements of fish in and out of this restricted area. The mini-surveys (Table 1 and Figure 3) did not support such a theory. They indicated that low values at the trawl path were associated with low values in the surroundings and vice versa. There was a significant correlation (r=0.7) between the values at the trawl path and the values in the remaining survey area.

The typical diurnal pattern seen on the echo-gram was scattered recordings of fairly weak single fish echoes during darkness. These records were most dense close to the bottom and decreased gradually up to about 30-40 m above bottom. During the day, loose aggregations (mainly single fish traces) of larger fish were recorded at various depths, decreasing in density up to 100m above the bottom. The catch composition in pelagic hauls is given in Table 2. It shows a strong dominance of large haddock during the day and a mixture of small haddock, small redfish and a few small cod during the night. Towing the ground rope 2-3 m above bottom and towing with the ground rope 30-40 m above the bottom generally gave the same species composition. This indicates that large haddock were the main contributors to the total acoustic values during the day, while mainly small specimen of haddock and redfish contributed at night.

Bottom trawl catches

During the sampling period the bottom trawl catches varied considerably (Figure 2), but no significant long term trend over the experimental period was found (r^2=0.001). The total weight of the day catches were higher than the total night catches, but the diurnal variation was still relatively much lower than in the acoustic recordings. Haddock dominated over cod in the catches. Both haddock and redfish catches were significantly higher during the day than at night (Figure 5 and 7). For cod, the day catches showed much higher variation than the corresponding night catches (Figure 6) and there was no significant difference in catch rate between day and night.

Bottom trawl catches of four different length groups of haddock indicate that during the night the smallest fishes decreases in the catches compared to the day catches (Figure 8). In terms of relative changes between day and night catches, the two median length groups seem to be fairly stable, while the largest fishes only are caught at day and then to a very small extent. All size groups of cod generally seemed to stay on the bottom both day and night, although some of the small cod were occasionally caught in the pelagic hauls at night (Figure 9). For redfish the same diurnal patterns as seen for haddock was observed (Figure 10).

A theoretical s_A which corresponds to the trawl catches was calculated as described by Aglen (1996). The calculated values were consistently higher than the acoustic values observed during towing. The comparison was made in the lowest 4 m echo integration interval which corresponds to the vertical opening of the bottom trawl. If the effective fishing width and TS-values applied in calculating theoretical s_A are unbiased, and if the effective fishing height of the trawl is 4 m, the difference between the theoretical s_A calculated from the catch and the s_A observed is an estimate of the acoustic value lost due to the acoustic bottom dead zone. Figure 11 shows this difference as percentage of theoretical s_A calculated from the catch. The results indicate that in all, but 3 cases, more than 50 % of the acoustic value is lost. Even if we assume that the bottom trawl catches effectively all the fish in the water column (comparing with total observed acoustic value during the tow) there were still significant losses at all the night time stations.

DISCUSSION

Along the coast of Finmark a residual current, the Norwegian Coastal current, comes from the South - West and goes eastward into the Barents Sea (Midttun 1989). In addition the tidal ellipse in this area is dominated by the East-West component of the current which undulates with a tidal flow of 0-10 cm s^{-1} (Gjevik *et al.* 1990). Current speed is a designation of the total transport of water masses per time unit, regardless of direction. During this study, the current speed showed a fairly regular cycle of about 12 hours. A strong influence of the tide should theoretically result in a 12.4 hour cycle, which means that the peak in the current should be delayed by about 10 hours over a 10 days period. However, the time series analysis did not reveal such a clear delay. This could be due to westerly gale in the beginning of the sampling period but also the fact that the period of time was very short, makes it difficult to differentiate between a 12 and a12.4 hour cycle. Anyway, in the sampling period, the peak in the current speed corresponds with the peak of light at day as well as the drop of light at night.

When combining the information from bottom- and pelagic trawl sampling with the diurnal patterns observed in the acoustical recordings, it seems evident that the integrator values observed during the day are mainly from medium sized and large haddock, while they at night are from small haddock and redfish. Most of the medium size groups, which were observed in the bottom trawl catches, seemed to be hidden in the acoustic dead zone. This is in line with the observation that when the fish lifted up from bottom and the dead zone during the day, the acoustic values increased in the bottom channel as well as in the pelagic area. Thus the main reason for the diurnal variation in the total integrator values were groups of fish which migrated up and down from the acoustic dead zone.

Comparison of observed s_A values with those calculated from bottom trawl catches also confirms that fish missing in the pelagic zone tend to be in the acoustic dead zone. In addition, the two peaks in the acoustic values during 24 hours, could indicate that small and large fish (mainly haddock) conducted separate vertical migrations, alternating in opposite cycles. During day large and medium size haddock were distributed from bottom up to 100 m above bottom, while they tend to descend towards bottom at night. Contrary, small haddock and redfish lifted up from bottom at night, while they stayed close to bottom during the day. Such migration patterns will result in fairly stable bottom trawl catches of medium sized and large fish, while the catches of small fish will show a diurnal variation.

Fish migrating vertically often are in a trade off situation where the increased predation risk of being pelagic, particularly for a small, non-schooling demersal fish, have to be balanced against the increased feeding opportunity found in the upper water masses where the primary production takes place (Clark and Levi, 1988). For larger fish the predation risk is much lower and they can concentrate on maximise the food consumption. Consequently, small haddock and redfish could have adapted a strategy where they feed pelagicly during the hours of minimum illumination when the predation risk is lowest.

One other explanation on the two peaks in the acoustic values could be that the different size groups of fish reach differently to increased current speeds. But then it should have been observed a semi-diurnal in stead of a diurnal pattern in the size groups caught by the bottom-and pelagic trawl. A diurnal variation in catch efficiency of the trawl, decreasing with decreasing light intensity (Wardle 1993), could have camouflaged a possible a semi-diurnal pattern.

The day/night variation in bottom trawl haddock catches mainly seems to originate from the vertical migration, and thereby variation in availability towards the bottom trawl, of the small fish, as discussed earlier. In addition there is a residual discrepancy between day and night catches of medium sized and large fish which might be ascribed to decreased catch efficiency at night. During day the bottom trawl catches seems to give fairly reliable estimates of total abundance as well as size and species composition, while it at night tend to underestimate the fish density of all size groups.

To increase the reliability of the bottom trawl- and acoustic surveys, this study illustrates the need for treating day and night observations separately when calculating the total abundance. In addition day time and night time effort should be allocated to geographical strata in a balanced manner and a combination of daytime acoustic observations with night time catches and visa versa, should be avoided. Most of all the results underline the importance of finding efficient methods for combining density estimates from bottom trawl and acoustics.

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Table 1. Results of the mini surveys.

survey no.	date	hour GMT	distance n. miles	mean s_A of total survey	s_A at trawl position	mean s_A outside trawl position
1	25.Mar	12-15	30	202	215	201
2	25.Mar	19-22	34	88	122	87
3	01.Apr	16-18	14	5	6	5
4	01.Apr	19-24	43	71	40	71
5	02.Apr	06-11	50	74	29	75
6	04.Apr	15-17	27	25	81	23
7	05.Apr	13-16	24	89	218	83
8	05.Apr	16-18	23	14	7	15
9	05.Apr	18-20	23	13	39	12
10	06.Apr	17-19	26	27	26	27
11	07.Apr	03-05	24	48	5	50
12	07.Apr	17-19	24	20	18	20
13	08.Apr	02-04	23	65	12	67
14	08.Apr	06-09	26	111	85	112

Table 2. Composition (%) of species and size groups as well as total catch in numbers in pelagic hauls. The percentages are sorted according to day/ night and average distance of the footrope from bottom. Values less than 0.5 are indicated with +.

Day/Night	N	N	N	N	N	N	N	D	D	D	D	D
Dist.from bottom	40	30	30	30	3	3	3	40	3	3	3	3
St.no.	230	215	223	239	216	224	240	235	220	227	233	241
Species and size gr.												
Had 0-19	54	71	15	69	79	80	36		+			
Had 20-34	4		1	14	9	2	12		3		1	
Had 35-54				1	3		3	94	88	100	93	95
Had 55+								3	4		1	5
Redf 0-9	40	25	81	11	2	10	41				1	
Redf 10-19				+								
Redf 20-34					1							
Redf 35-54		4			2				1		+	
Cod 0-19	2		3	5	3	7	3		1			
Cod 20-34					+							
Cod 35-54					+		3	2	2		4	
Cod 55+							3	2				
Total catch (N)	222	22	85	267	298	350	36	131	318	3	270	460

Table 3. Correlation matrix for light, current speed 50 m above bottom and 5 m above bottom, temperature 50 m above bottom and 5 m above bottom, acoustic values less than 10 m above bottom (Bot10) and more than 10 m above bottom (Pel10) and total acoustic values. Acoustic values and light are log transformed and normalised for trend. The analysis is based on observations within 10 min. intervals for the period 1-7 April. a: all data (N=987), b: observations at night, dusk and dawn (16-04 GMT, N=504).

a)

	Light	Speed50	Speed5	Temp50	Temp5	Bot10	Pel10	Total
Light	1.00							
Speed50	0.17	1.00						
Speed5	0.07	0.62	1.00					
Temp50	-0.04	0.03	0.11	1.00				
Temp5	-0.13	-0.02	0.16	0.81	1.00			
Bot10	0.37	-0.36	-0.28	-0.001	-0.01	1.00		
Pel10	0.19	-0.45	-0.38	0.19	0.18	0.75	1.00	
Total	0.27	-0.44	-0.36	0.04	0.04	0.92	0.94	1.00

b)

	Light	Speed50	Speed5	Temp50	Temp5	Bot10	Pel10	Total
Light	1.00							
Speed50	0.57	1.00						
Speed5	0.38	0.63	1.00					
Temp50	0.08	0.02	0.02	1.00				
Temp5	-0.11	-0.16	0.08	0.58	1.00			
Bot10	-0.19	-0.28	-0.06	0.11	0.09	1.00		
Pel10	-0.47	-0.42	-0.26	0.10	0.21	0.65	1.00	
Total	-0.37	-0.38	-0.19	0.10	0.14	0.88	0.92	1.00

Table 4. Correlation matrix for light, relative current direction (Rdir5), current speed and temperature 5 m above bottom, acoustic values less than 10 m above bottom (Bot10) and more than 10 m above bottom (Pel10) and catch weight of cod (CodW), haddock (HaddW) and total catch (TotW). The data are not transformed or normalised for trend. The analysis is based on observations within 20 min. intervals corresponding to the bottom trawl hauls (N=34).

	Light	Rdir 5	Speed5	Temp5	Bot10	Pel10
Light	1.00					
Rdir5	0.27	1.00				
Speed5	0.04	0.05	1.00			
Temp5	0.11	0.01	0.15	1.00		
Bot10	0.62	0.22	-0.12	0.18	1.00	
Pel10	0.43	0.15	-0.24	0.24	0.64	1.00
CodW	0.05	-0.44	0.07	0.14	0.09	-0.11
HaddW	-0.004	-0.31	0.06	-0.16	0.25	-0.02
TotW	0.02	-0.40	0.08	-0.08	0.23	-0.05

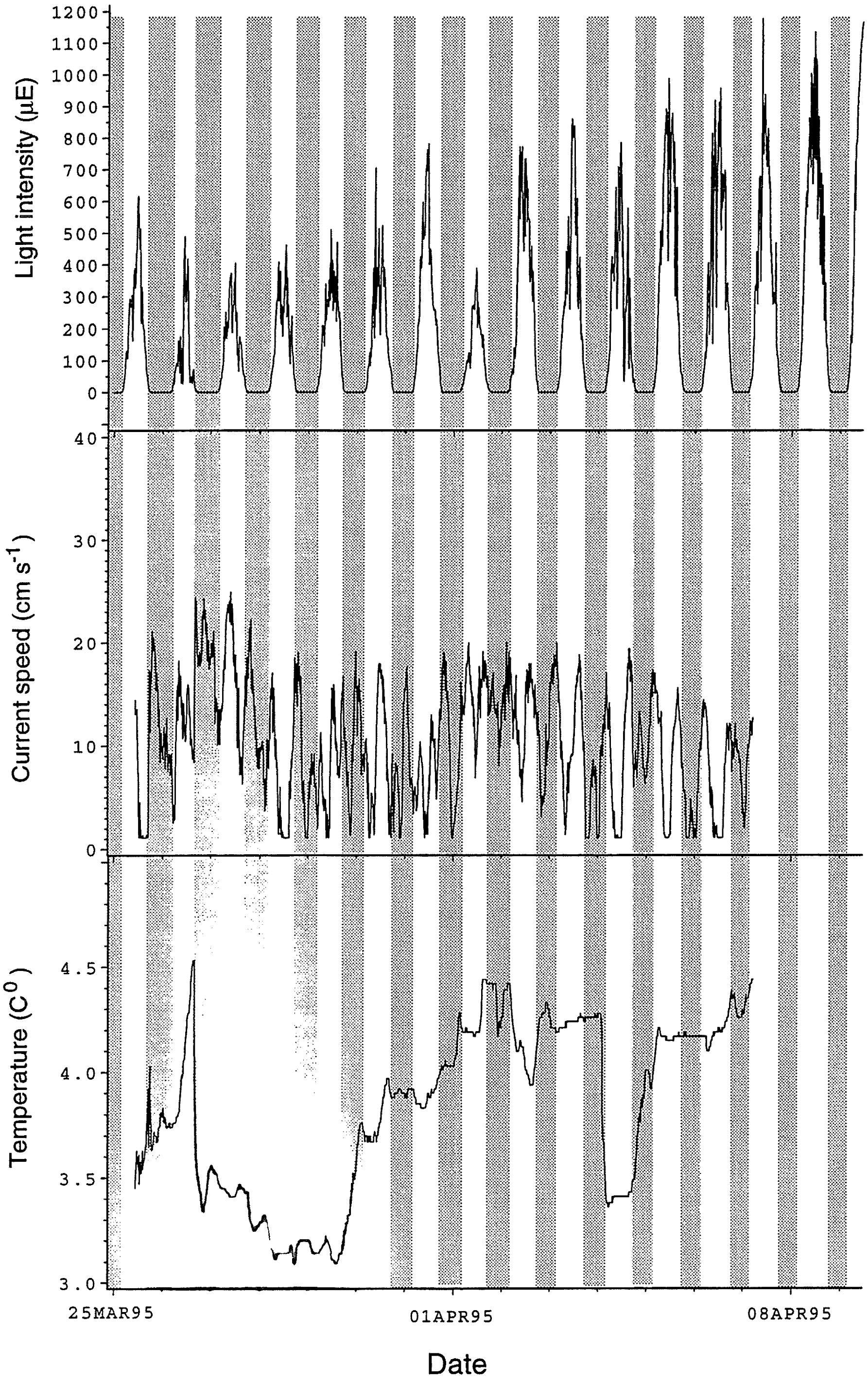

Figure 1. Measurements of light intensity (µE) at surface, current speed and temperature 5 m above bottom. Shaded areas indicate periods with less than 50 µE and is defined as night.

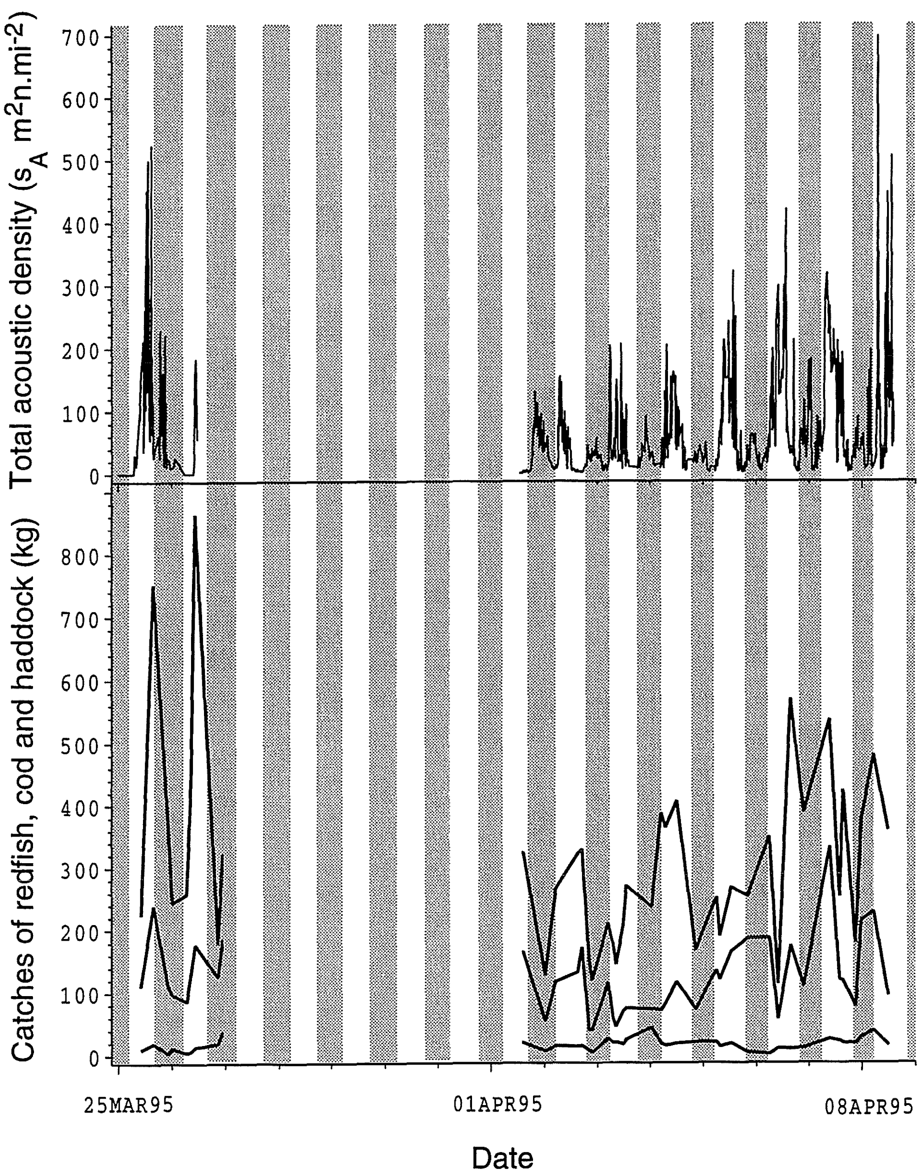

Figure 2. Total acoustic density (upper panel) and catch per nautical mile in bottom trawl hauls (lower panel). The lower graph of catches represents redfish, the middle represents redfish? cod and the upper represents redfish+cod+haddock. Shaded areas indicate periods with less than 50 μE light intensity.

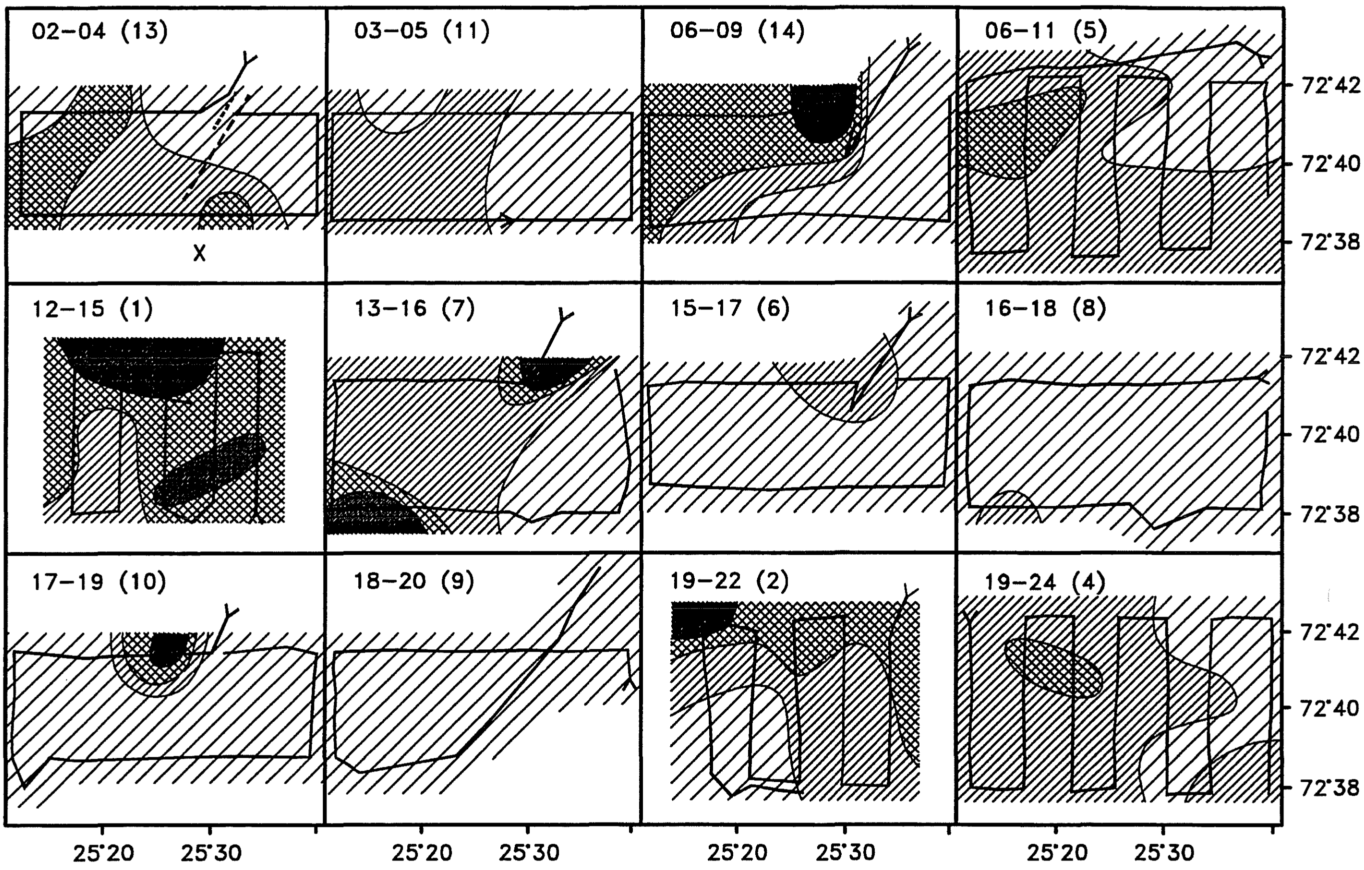

Figure 3. Distribution of acoustic values observed during mini surveys. The shading represent four groups of fish densities, increasing from light to dark: group 1: s_A values between 1 and 49, group 2: s_A values between 50 and 99, group 3: s_A values between 100 and 199, group 4: s_A values above 199. The survey grid is shown with the starting point indicated by a V. On the upper left panel the bottom trawl towing path is indicated by a short broken line and the pelagic by a parallel longer line. The x in the lower part of that panel is the position of the current meters.

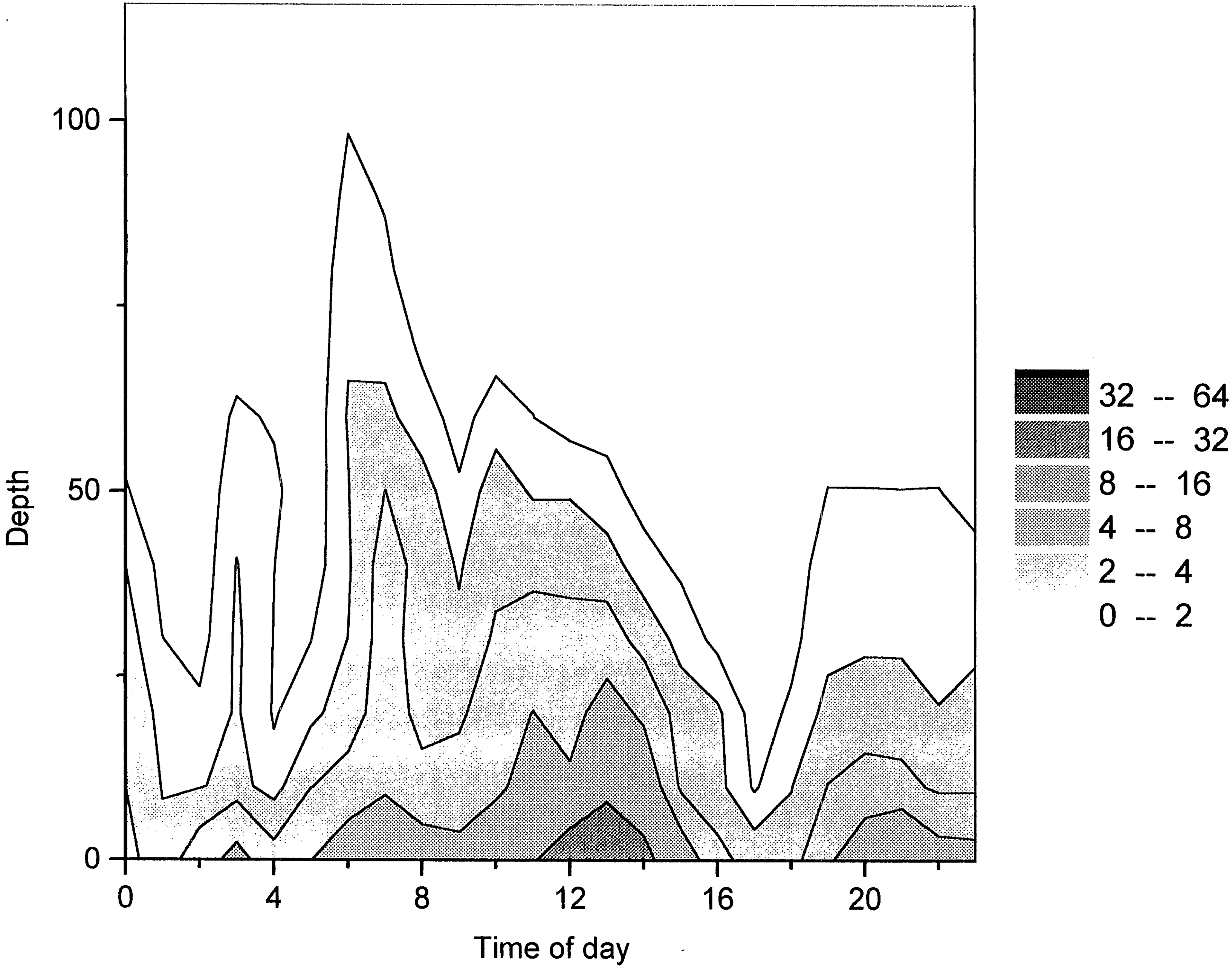

Figure 4. Acoustic volume density (s_A per 10 m depth) averaged within hourly intervals for the whole period. The values are shown as an isopleth, relative distance from bottom and the time of day (UTC). The legend represents the steps in average s_A, starting point with zero and increasing with a log s((with darker shading).

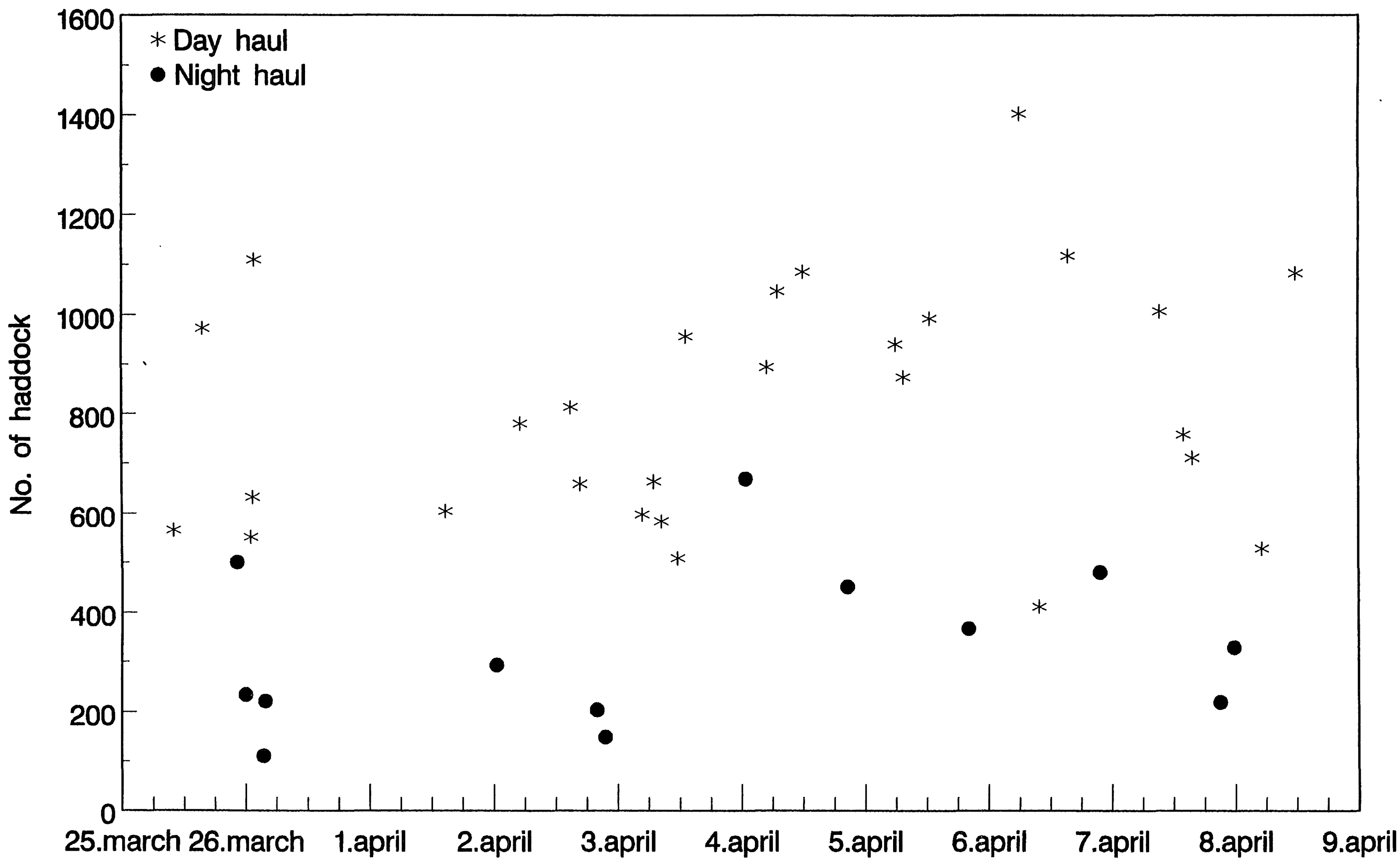

Figure 5. Bottom trawl catch rates (number per nautical mile) of haddock by station, shown in a time scale. Asterix: stations taken during the day, filled circles: stations taken at night

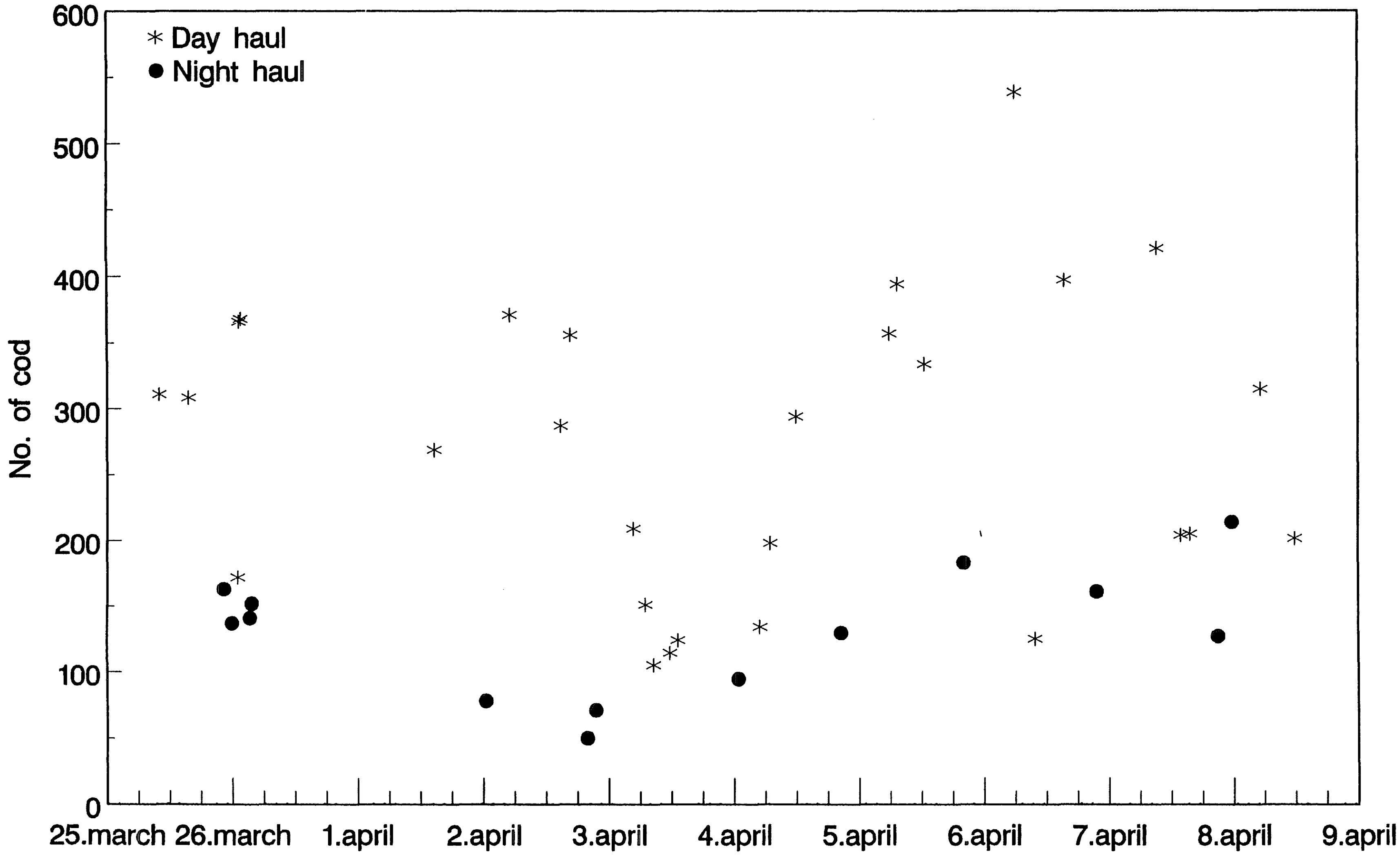

Figure 6. Bottom trawl catch rates (number per nautical mile) of cod by station, shown in a time scale. Asterix: stations taken during the day, filled circles: stations taken at night

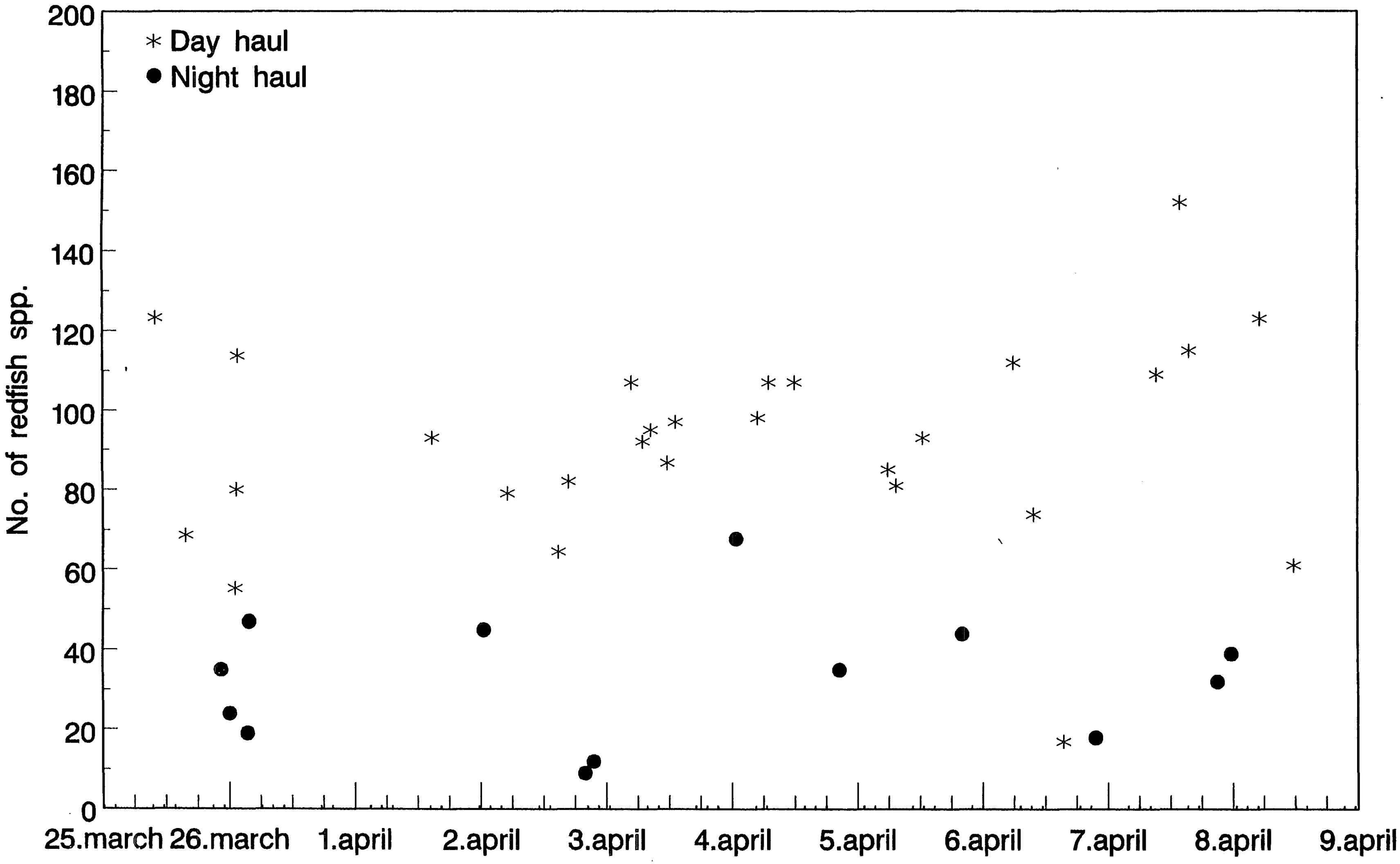

Figure 7. Bottom trawl catch rates (number per nautical mile) of redfish by station, shown in a time scale. Asterix: stations taken during the day, filled circles: stations taken at night

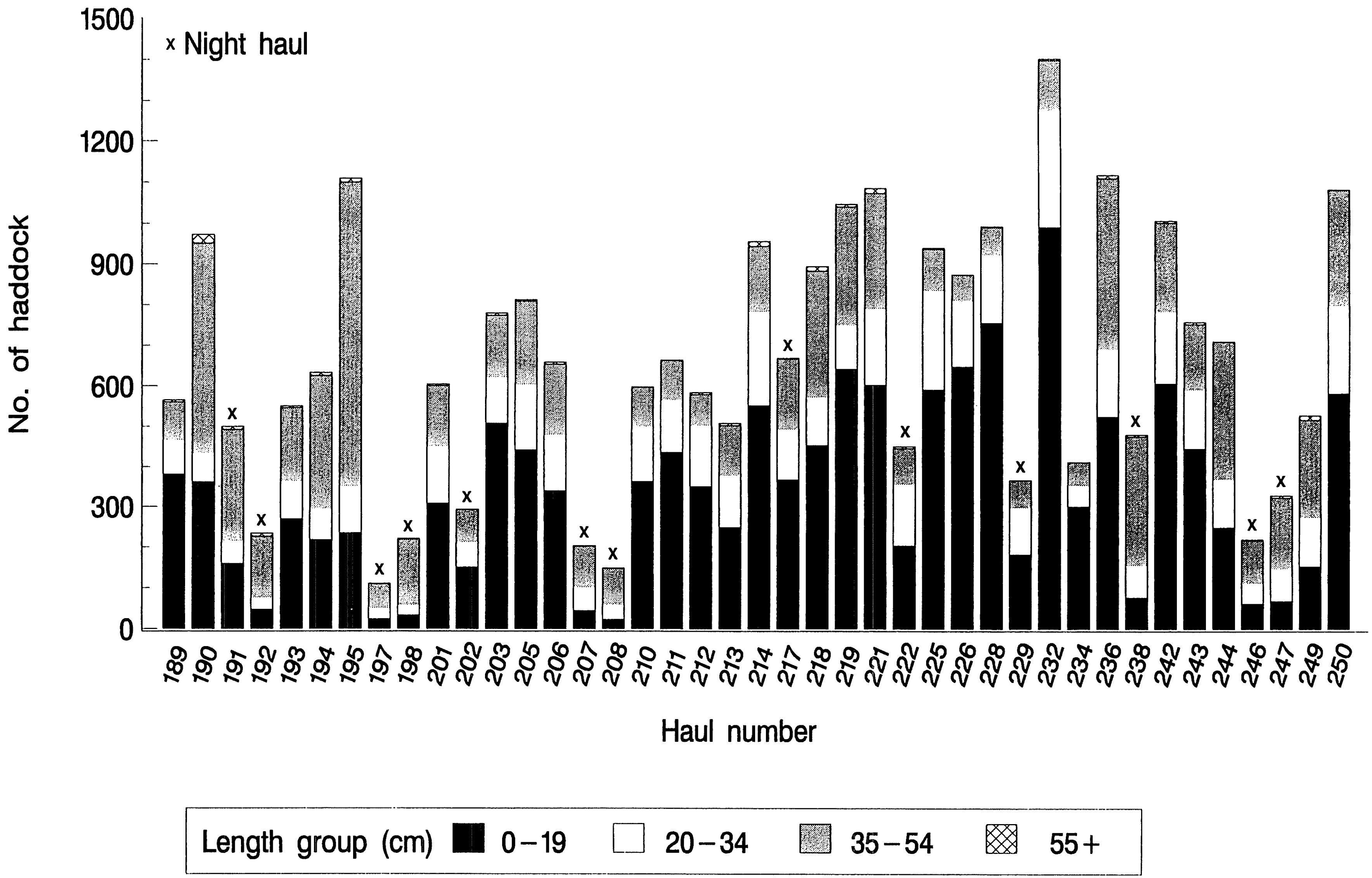

Figure 8. Bottom trawl catch rates (number per nautical mile) of haddock by size group and station. X: stations taken at night

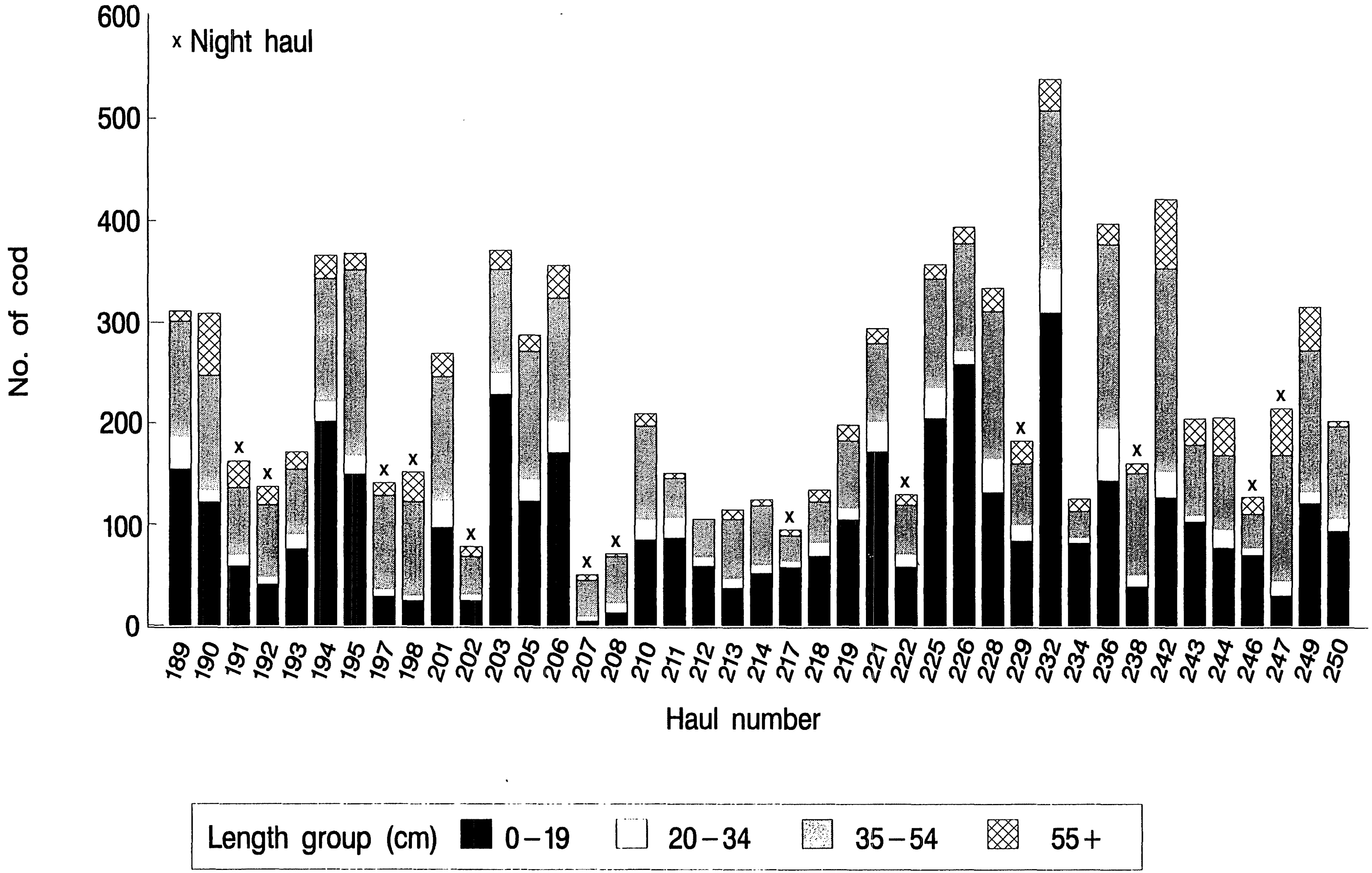

Figure 9. Bottom trawl catch rates (number per nautical mile) of cod by size group and station. X: stations taken at night

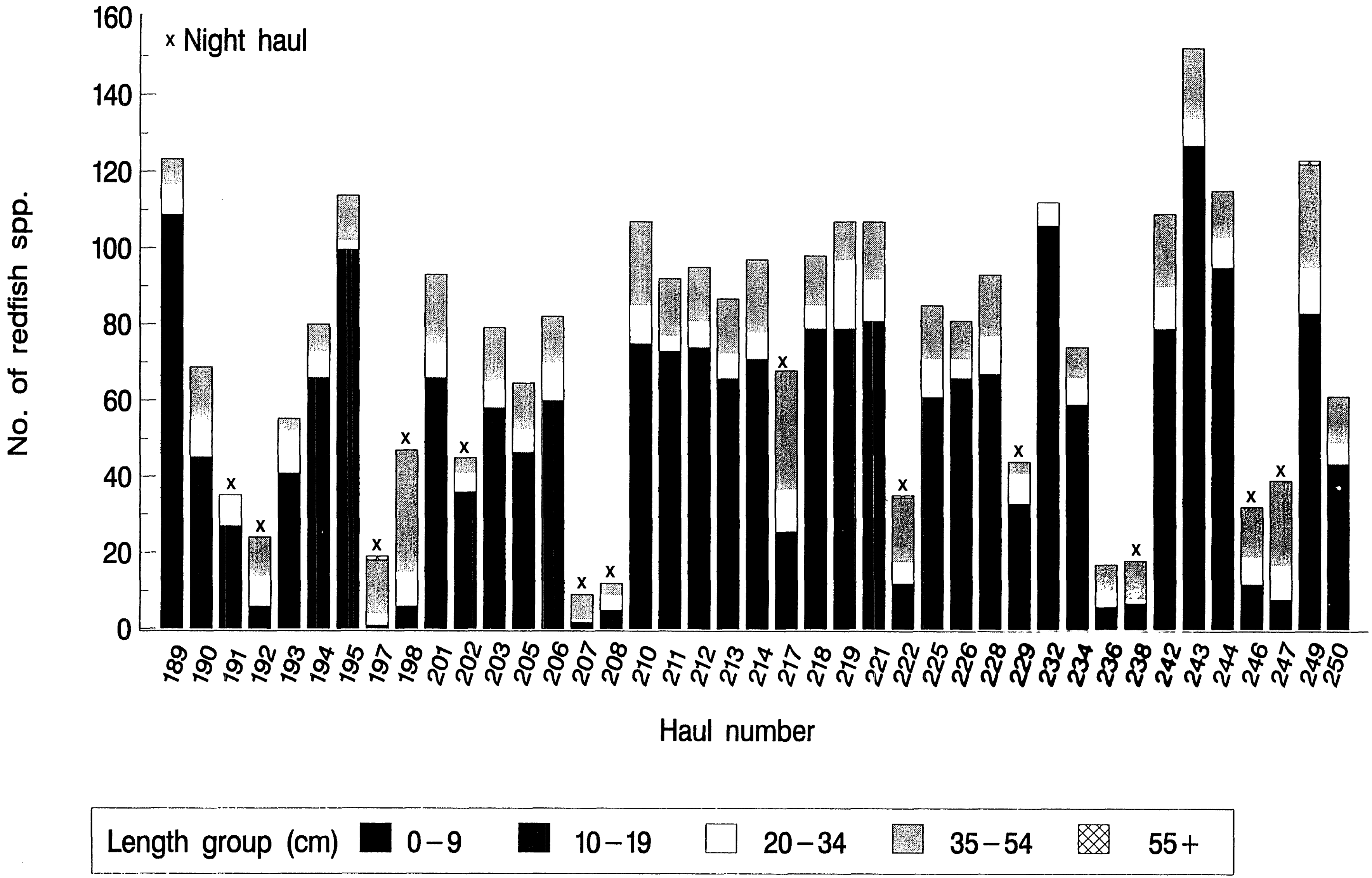

Figure 10. Bottom trawl catch rates (number per nautical mile) of redfish by size group and station. X: stations taken at night

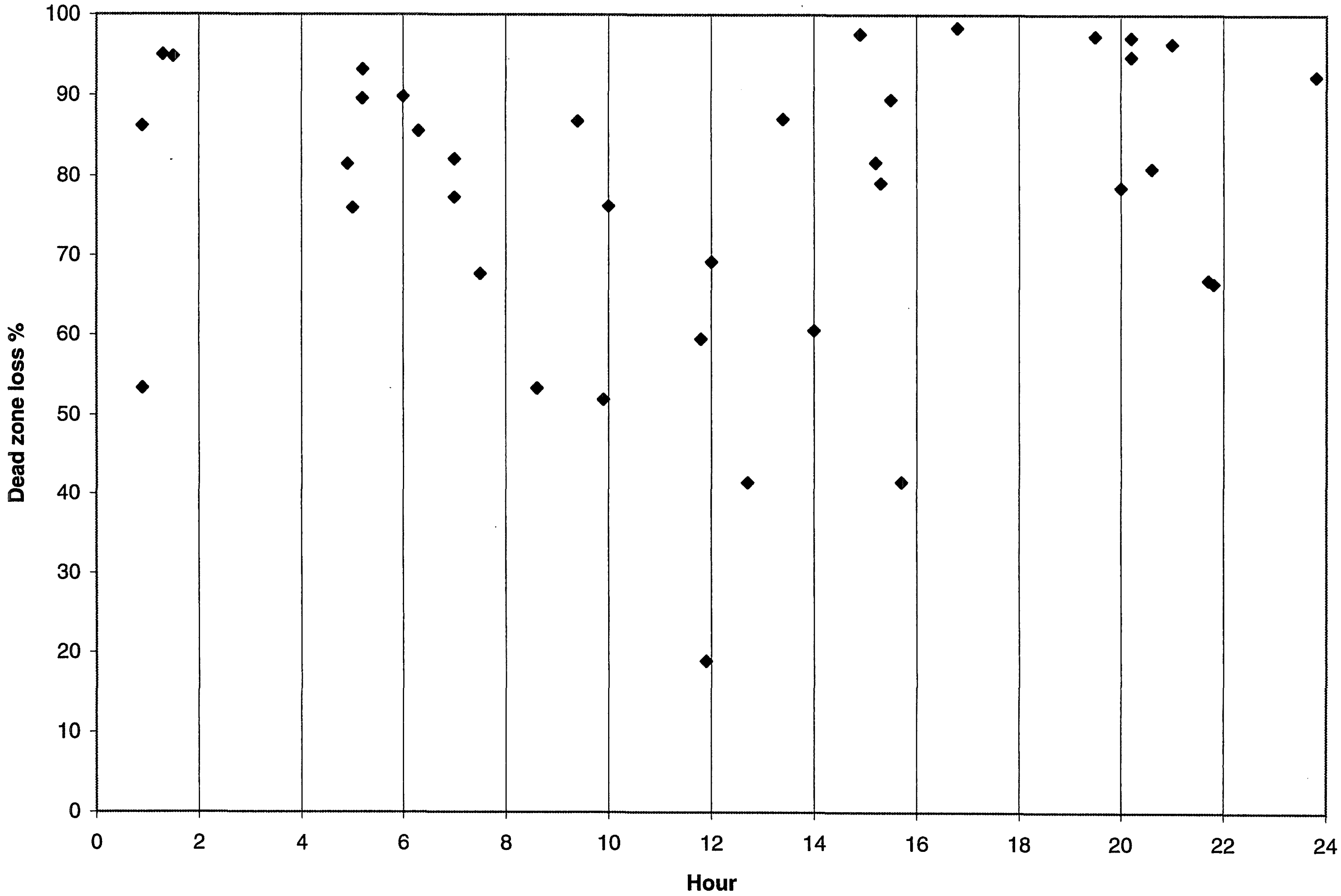

Figure 11. Dead zone loss by station. Loss is estimated as the difference between s_A calculated from the bottom trawl catch and the observed value in the lower 4 m, expressed as percentage of the value calculated from the catch.