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Diel patterns in pelagic fish behaviour and distribution observed from a stationary, bottom-mounted, and upward-facing transducer

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Diel variation in pelagic fish distribution influences hydroacoustic abundance estimates. To study and quantify diel patterns in behaviour and spatial distribution in pelagic fish without causing avoidance reactions or attraction to any floating equipment or vessel we used a bottom-mounted, upward-facing transducer. Light intensities were measured as skylight and underwater light (at 5-m depth). The study was performed in a coastal area in the Baltic Sea, late July to mid-August in 2001 and 2002. The results provided additional information on fish behaviour and distribution valuable for future survey planning and in the analyses of hydroacoustic data from regular surveys in this area. At night, the data on hydroacoustic backscattering (s_A) were less variable, the vertical distribution of fish was more even, with fewer fish in the deepest layer, and the percentage of single-echo detections was higher. The tilt angle of fish seemed to differ day and night, but trawling and target-strength distribution results taken together also implied a partial diel change in the fish assemblage in the midwater layers. The processes of formation and disintegration of schools happened rapidly and coincided with day and night transition periods.

Keywords: diel variation, fish behaviour, stationary acoustics.

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Introduction

Pelagic fish behaviour plays a major part in hydroacoustic fish stock assessment surveys (e.g. Fernö and Olsen, 1994), but study of pelagic fish behaviour in the natural environment presents many complications. Fish can seldom be visually observed without being disturbed, especially at night; they often move over large areas and can occupy different areas and depth layers over the diel cycle and seasons (e.g. Neilson and Perry, 1990; Fréon and Misund, 1999; Fabi and Sala, 2002). Hydroacoustic techniques provide a means by which to overcome some of these problems, but they also introduce other complications (e.g. species identification). Vertical echo-sounding does not provide information about the layers close to the surface or bottom, the so-called blind and dead zones. The surface layer can be studied using upward-looking or horizontal hydroacoustics (e.g. Thorne, 1983; Kubecka and Wittingerova, 1998; Knudsen and Saegrov, 2002), or multibeam sonars (Gerlotto *et al.*, 1998). However, quantifying the horizontal and sonar techniques can be sensitive to weather conditions (MacLennan and Simmonds, 1992; Gerlotto *et al.*, 1998; Knudsen and Saegrov, 2002). Furthermore, both vertical and horizontal acoustic surveys are likely to cause avoidance reactions if the study is conducted from a vessel or float (e.g. Pitcher *et al.*, 1996; Soria *et al.*, 1996; Fréon and Misund, 1999; Fernandes *et al.*, 2000; Vabö *et al.*, 2002). The interpretation of acoustic data can be further complicated by diel variation in the behaviour of fish. In daytime, pelagic fish are often found close to the bottom, thus potentially in the dead zone, or congregated in schools that have a patchy distribution, which leads to variability in the results. At night, pelagic fish usually leave the bottom and schools disaggregate (Fréon *et al.*, 1996; Fréon and Misund, 1999). The aspect angle of individual fish day and night may be variable (e.g. Huse and Ona, 1996), and the fish assemblage in a discrete area, species, and size distributions, can change over the diel cycle (e.g. Neilson and Perry, 1990; Helfman, 1993; Kramer *et al.*, 1997).

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To investigate the effects of diel behaviour patterns in pelagic fish on hydroacoustic survey results, we developed and tested a specially designed rack for stationary hydroacoustics with an upward-facing transducer placed on the seafloor. Our goal was to study the proportion of hydroacoustic backscatter in the blind zone, possible diel differences in fish distribution, schooling behaviour, and the number and target strength (TS) of single-echo detections.

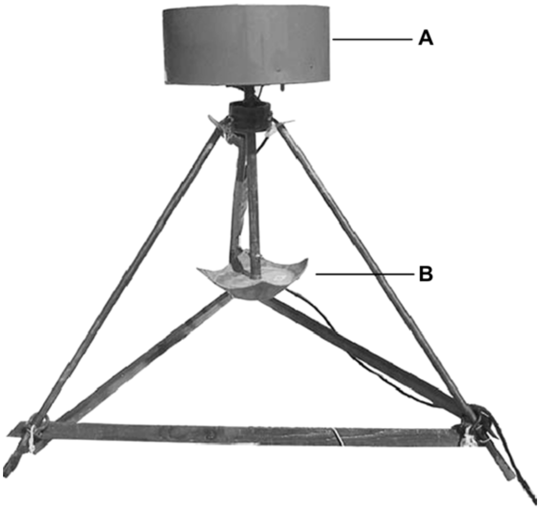

Figure 1. Rack for positioning an upward-facing transducer on the seafloor. The transducer is mounted in the holder (A) and kept in a horizontal position by a heavy weight (B). The total height is 1 m.

Material and methods

We performed stationary acoustics on four occasions (Table 1) at the same position (58°59.80′N, 17°45.23′E) in the Bay of Himmerfjärden in the northwestern Baltic Sea. This bay is a spawning and nursery area for spring-spawning Baltic herring (*Clupea harengus*) and in late summer the bay holds large numbers of fish larvae and juveniles, especially young-of-the-year herring (e.g. Rudstam *et al.*, 1992; Arrhenius and Hansson, 1999; Axenrot and Hansson, in press). The pelagic fish community in the bay also includes sprat (*Sprattus sprattus*) of age 1+ and older, and some freshwater species (mainly smelt (*Osmerus eperlanus*)).

We used a 70-kHz split-beam transducer (SIMRAD ES 70-11) and a portable scientific echosounder (SIMRAD EY500) calibrated with a standard copper sphere as recommended by the manufacturer and according to ICES standards (ICES, 1987). In all surveys we used a pulse length of 0.6 ms, bandwidth of 7.0 kHz, and pulse rate of 0.5 ping s^{-1}. To avoid disturbing the fish, the transducer was mounted on a rack that places the transducer on the bottom with the transducer face directed upwards (Figure 1). A gyroscope construction keeps the transducer face in a horizontal position regardless of the bottom slope. The rack was positioned at approximately 20-m depth (equal to the mean depth of the regular surveys), and the transducer was connected to a land-based echosounder with a 100-m long cable. Since we wanted to study fish behaviour that could bias results from regular surveys performed from a moving vessel with a downward facing transducer at 1-m depth, we placed the transducer at a representative position in the area of the regular surveys.

EP500 (version 5.5, SIMRAD 2000) and Sonar5-Pro (version 5.8.7; Balk and Lindem, 2002) were used for post-processing, scrutinizing, and analysis of the data. Post-processing thresholds for volume backscattering and TS (target strength for single fish) were set at −80 and −60 dB, respectively.

For the blind zone (in our regular surveys 0−3 m depth) analysis we focused on night-time data corresponding to periods when regular surveys are performed in this bay. In this analysis, each night was divided into seven periods of 30 min each (Table 1). In late July to early August, sunrise

Table 1. A. Study periods for stationary hydroacoustics in Himmerfjärden (58°59.80′N, 17°45.23′E) in the northwestern Baltic Sea. Acoustic recordings were occasionally interrupted for practical reasons. B. Survey periods and arithmetic mean of the nautical area scattering coefficients (s_A) for the total water column and the proportion of s_A found in the blind zone (0−3 m depth, if the study had been conducted from a ship with the transducer at 1-m depth and a near-field zone of 2 m). To estimate the variation (s.d.) within nights, each night was divided into seven periods of 30 min each.

A. Study periods − total time					B. Survey periods for blind zone analyses			
Dates			Start	Stop	Start	Stop	s_A (m^2 n.mile^{-2})	% s_A in blind zone
1−2	August	2001	16:35	12:00	23:45	03:15	758.6	8.1
16−17	August	2001	16:00	10:00	23:45	03:15	635.9	5.8
29−30	July	2002	21:10	(cont.)	23:45	03:15	635.9	12.4
30−31	July	2002		07:23	23:45	03:15	455.2	8.8
5−6	August	2002	20:03	(cont.)	23:53	03:23	576.8	10.6
6−7	August	2002		13:04	−	−	−	−
						Mean	612.5	9.1
						s.d.	110.0	2.5

and sunset take place at about 04.45 and 21.05, respectively. For comparison of day and night acoustics, excluding transition periods, we classified day and night as periods with light intensities (above the sea surface) >1000 lx and <0.1 lx, respectively. In the analyses, the hydroacoustic data through the survey periods were integrated over 5-min periods, matching the light measurement intervals. We defined schools as a group of fish where the individuals were so close to each other that echoes overlapped, moving in one direction.

Light was measured every 5 min through the survey periods with two sensors as skylight and underwater light (5-m depth; SDL 5000 light meter, Skye Instruments Ltd, Powys, UK). Water temperatures and salinities for the whole water column were measured once during each study period (STD-sond, Sensordata AS, Bergen, Norway). Midwater trawling (only 2002; 5-mm codend) and vertical gillnets (Hansson, 1988; mesh bars 4, 6½, 8, 10, 12, 15, and 18¾ mm) were used for fish sampling. All sampling activities were done in close proximity to the position of the stationary hydroacoustic equipment except for the trawling, which, for practical reasons, started about 0.3 nautical miles (550 m) to the west heading north.

Results

The proportion of the nautical area scattering coefficient (s_A) in the blind zone constituted 9% of the total s_A (arithmetic mean from five nights; Table 1). The proportion of traces in this layer was low (arithmetic mean 2%) compared to the other depth layers. The influence from wind and waves could be studied during the survey of 2001-08-01–2002, which had strong winds at the start (23:15) but which slowly decreased throughout the night. The highest numbers of traces were recorded during the calm period.

The daytime acoustics showed significantly higher variation in s_A values than the nights (standard deviations from day and night survey periods compared with t-test for samples with unequal variances; $n_{day} = 6$, $n_{night} = 4$, $t = 2.57$, d.f. = 5, $p < 0.02$; Figure 2). The coefficient of variation for daytime periods varied between 96% and 361%, and for night periods between 22% and 35%. The variation in mean s_A was also significantly higher among days than among nights (F-test: $F = 25.17$, d.f. = 5, $p < 0.02$).

The vertical fish distribution differed between day and night (Figure 3). At night, fish were more evenly distributed (night-time standard deviations, calculated as described in Figure 3, were significantly lower than the corresponding day values; Mann–Whitney U test; $U = 66$, $p < 0.02$). The ratio of the proportions of s_A above and below the thermocline ($s_{A,3-7\ m}/s_{A,7-17\ m}$) was significantly higher at night than at day (Mann–Whitney U test; $U = 2708$, $n_{day} = 230$, $n_{night} = 78$, $p < 0.0001$), showing that the fish were higher up in the water in darkness than during light hours.

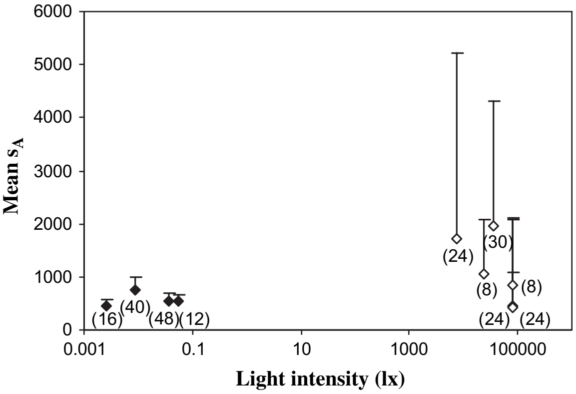

Figure 2. Arithmetic mean and standard deviation (error bars) for the nautical area scattering coefficient (s_A) recorded at day (open diamonds; skylight > 1000 lx) and night (solid diamonds; skylight < 0.1 lx). The day and night differences in both variation and means were significant (t-test: $t = 2.57$, $p < 0.02$ and F-test: $F = 25.17$, $p < 0.02$, respectively). Intervals for hydroacoustic data integration and light measurements were 5 min. Figures within parentheses denote the number of observations per data point. Data are from 1–2 August 2001, 29–31 July, and 5–6 August 2002.

Relative frequency distribution of mean TS from tracked fish showed a distinct bimodality at night (peaks at −58 and −49 dB), while only one peak (−44 dB) was found during the day (Figure 4). This difference was statistically significant (Kolmogorov–Smirnov test; $p < 0.001$). The coefficient of variation of TS within tracks was significantly

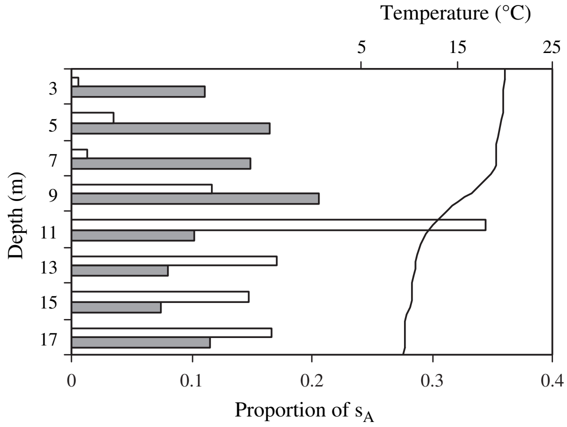

Figure 3. The proportion (arithmetic mean) of the nautical area scattering coefficient (s_A) in different depth layers. Results are reported separately for day (open bars, skylight > 1000 lx; n = 235) and night (filled bars, skylight < 0.1 lx; n = 78). For statistical analysis, vertical profiles were calculated separately for each day and night providing standard deviation in proportions at different depths. These were used as indexes of evenness in vertical distribution, and the values were compared with a Mann–Whitney U test ($U = 66$, $n_{day} = 16$, $n_{night} = 16$, $p < 0.02$). Data from 5–7 August 2002. The line shows the water temperature vertical profile.

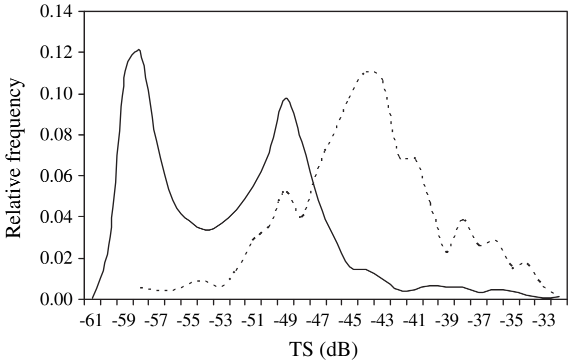

Figure 4. Relative frequency distributions of the mean target strength (TS; arithmetic mean grouped in 1 dB bins) from tracked fish at day (skylight > 1000 lx; n = 807 – broken line) and night (skylight < 0.1 lx; n = 1331 – continuous line). Distributions were significantly different (Kolmogorov–Smirnov test; $p < 0.001$). Data from 5–7 August 2002.

higher during the day than at night (Figure 5; Mann–Whitney U test; U = 224211, $p < 0.001$). The proportion of single fish echoes (arithmetic mean) relative to the estimated total number of fish was more than two times higher at night (23%) than in the day (10%).

We studied the occurrence, formation, and breaking-up of schools during the study periods of 30–31 July and 6–7 August 2002. Schools were regularly detected during daytime, but absent at night. During both survey periods, the frequency of schools decreased rapidly within 30 min at dusk, starting from 21:30 and 21:15, respectively, when light intensities (sky/underwater) were 218/12.3 and 183/1.72 lx. On both occasions, the last school appeared at 21:35, at 144/7.98, and 24.8/0.280 lx. At dawn, the first schools appeared at 04:25 (151/8.23 lx) and 04:20 (36.0/1.26 lx), respectively, and rapidly increased in frequency.

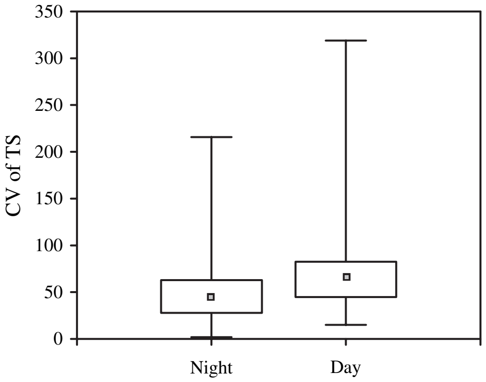

Figure 5. Coefficient of variation (CV) of target strength (TS) within tracks from single fish detections at day (skylight > 1000 lx; n = 566) and night (skylight < 0.1 lx; n = 1350). The day and night CV difference was significant (Mann–Whitney U test; U = 224211, $p < 0.001$). Point – median, box – 25–75% and whiskers – min–max. Data from 5–7 August 2002.

In comparison with the vertical gillnets, trawling caught considerably more juvenile fish and fish larvae. In numbers, herring, sprat, smelt, and gobies (juveniles only) constituted 99% in the trawl catches. Herring, mainly young-of-the-year juveniles, was the most common species and made up 65% of the total catches (Axenrot and Hansson, in press). On 30 July 2002, fish caught in the vertical gillnets were recorded in 2.5-m depth layers. The proportion of fish in the upper panel of the nets, approximately representing the blind zone in our regular surveys (0–3 m), was 6.7% (n = 165 for total catch), and consisted mainly of the freshwater species bleak (*Alburnus alburnus*), roach (*Rutilus rutilus*), and perch (*Perca fluviatilis*), ranging from 100 to 155 mm (total length).

Discussion

We did not observe any fish behaviour that indicated avoidance or attraction to the equipment. A natural shortcoming with stationary hydroacoustics is that data are recorded from a relatively restricted water volume. To detract significance from this drawback we suggest that the purpose of the survey should be clear and the position of the transducer carefully chosen. Based on experience from this study we believe that using more than one transducer could have improved our data analyses, especially regarding possible horizontal migration (e.g. Fabi and Sala, 2002).

The backscattering in the blind zone at night was comparatively high, supported by the hydroacoustic results on vertical fish distribution (Figure 3) and the result from the vertical gillnets (30 July 2002). We noted, however, that the proportion of s_A derived from traces increased as wind and waves decreased. This suggests that wind-induced bubbles in the surface layer could have caused part of the backscattering (cf. Dalen and Lövik, 1981), which could lead to an overestimate of fish abundance from this layer. However, we have no data on the occurrence of bubbles to support this hypothesis.

The s_A values were less variable at night because of a more homogenous fish distribution (cf. Fréon and Misund, 1999; Gauthier and Rose, 2002), and showed little variation both within and among nights. These results suggest that night-time surveys should be preferred in this area for fish abundance assessments, and that day and night results should not be combined or compared on an equal basis (Huse and Korneliussen, 2000).

The day and night differences in TS distributions from single-echo detections (Figure 4) indicate that fish behaviour influences TS values. The differences could also originate from changes in fish assemblage. The body posture of fish – the tilt angle – is assumed to be more horizontal and less variable in daytime when fish are schooling, which is expected to result in a higher mean TS (e.g. Fréon and Misund, 1999). This could explain why TS peaked at a higher value during daytime. At night, the swim/sink/glide strategy, proposed by Huse and Ona (1996), could result in lower backscattering as well as the observed bimodal TS distribution (Figure 4). However, the lower variation of TS within single fish tracks at night (Figure 5) does not support this explanation. The midwater trawling at night caught large numbers of small juvenile fish, mainly young-of-the-year herring. Since there is no corresponding low TS peak (−58 dB) in daytime, our interpretation is that these juvenile fish perform diel migration, presumably from the bottom layer, into the pelagic midwater layers, where they were found at night.

The rapid transition periods at dusk and dawn started just after sunset and before sunrise, respectively, at both periods studied. When planning surveys this needs to be considered, especially in the light of the indicated differences in variability between day and night backscattering.

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