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# IMPACT OF HERRING SPAWNING BEHAVIOUR ON ACOUSTIC ABUNDANCE ESTIMATES

by

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## ABSTRACT

Spawning dynamics of Norwegian spring spawning herring was studied in south western Norway 29 March to 3 April 2000 using hydroacoustics. The horizontal distribution of the spawning layers shifted in a south-easterly direction during the study period indicating directional spawning. A diurnal spawning pattern was found, with layers of spawning herring recorded at night from 18 to 24 UTC (= local time - 2 hours), few herring recordings during the night from 24 to 06, and most herring recorded pelagically during the day. Recorded fish density was highest in the period 15 to 18 and lowest from 21 to 03, and schools staying pelagically had higher density than bottom layers. The observed behaviours are likely to influence acoustic abundance estimates, particularly when surveying during the night towards the end of the spawning season.

Key words: herring, spawning, behaviour, acoustic abundance estimation, school dynamics

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# INTRODUCTION

Acoustic surveying is commonly applied to estimate stock levels (Gunderson, 1993). The main advantages of this method are the high sampling intensity and the ability to cover large volumes. Due to biases inherent to the methodology, however, the estimates are often considered as relative indexes. The ability to identify and quantify sources of bias and experimental errors is therefore crucial, particularly if the estimates are considered in absolute terms (Gunderson, 1993). The behaviour of the fish affects acoustic estimates through horizontal and vertical migration (Engås and Soldal, 1992; Gunderson, 1993) and avoidance reactions to the surveying vessels (Olsen *et al.,* 1983; Ona and Godø, 1990; Misund and Aglen, 1992). Knowledge about the behaviour is therefore crucial both for survey design and interpretation of the results.

Norwegian spring spawning herring (NSS-herring) spawn demersally on selected grounds along the west coast of Norway (Runnstrøm, 1941; Johannessen et al., 1995). Acoustic surveys were previously conducted annually along the Norwegian coast to estimate the spawning stock abundance (Slotte and Dommasnes, 2000), but the time series was terminated in 2000 as the estimates were not in coherence with estimates from the wintering area and considered unreliable. However, surveys during the spawning season are important as independent estimates, and attempts have been made to adjust for the behavioural caused bias (Axelsen and Misund, 1997).

Factors causing inconsistency in the spawning stock estimates are only known in part, but the spawning areas are open systems with herring migrating in from the wintering area and out to the feeding areas (Runnstrøm, 1941; Johannessen *et al.,* 1995; Nøttestad *et al.,* 1996) and this introduces a bias to the surveys. Rapid changes in aggregation density, size and shape of herring schools with changing maturity state have been demonstrated on small scale within a spawning location (Nøttestad *et al.,* 1996; Axelsen *et al.*, 2000), but the impact on large scale acoustic estimates is unclear.

The aim of this study was to monitor the behaviour of herring on a spawning location in order to find general trends in the spawning dynamics. The implications of the behaviour on acoustic abundance estimates are addressed, and timing of acoustic surveys based on the observed behaviours is suggested.

# MATERIAL AND METHODS

## Study area, vessels and surveys

The study was carried out off Karmøy, on the west coast of Norway, during March/April, 2000 (Fig 1a). Abundance estimation and mapping of distribution areas were carried out on large scale in the spawning area covering about 30 $nm^2$ (here 1 nm=1852 m) (Fig 1a), and a study on schooling dynamics and spawning behaviour on small scale within a spawning location covering about 2 $nm^2$ (Fig 1b).

Three vessels were involved in the study (Tab 1). RV "Michael Sars" was conducting Survey A as part of the annual distribution and abundance survey for NSS-herring along the coast of Norway and the data obtained were used for estimation of abundance and mapping of distribution on large scale.

A spawning location with high density was selected to study schooling dynamics on small scale (Fig 1b), and two survey grids were designed to cover the main locations for spawning herring schools (Survey B and C, Fig 1b). Two long term stations were carried out on locations where spawning layers had been detected (Tab 1).

## Hydroacoustic recordings

Bergen Echo Integrator system (BEI) (Knudsen, 1990) was applied to post-process EK 500 data from the long term stations, and all data used for estimation of abundance and mapping of the distribution areas. Sonardata Echoview v. 2.10© software (www.sonardata.com) was applied for the post-processing of all data used in the analyses of small scale schooling dynamics. In BEI acoustic backscattering areas ($S_A$) recorded during Survey A were averaged for 5 nm and 0.1 nm intervals for abundance estimation and mapping of distribution areas, respectively. During Survey B and the long term stations $S_A$-values were averaged for 0.1 nm and 10-minute intervals, respectively. The acoustic recordings were scrutinized according to catch composition and echogram features characteristic for herring aggregations. In Echoview recorded herring aggregations were separated as regions, and scattering intensities were resolved down at the ping level. Each ping with backscattering from the separated regions was treated as a separate sample, giving 35 580 samples from a total of 246 regions. For statistical comparisons mean values for each region were used.

The relation $TS = 20.0 \cdot \log L - 71.9$ between average total fish length (*L)* in cm and target strength (*TS)* was applied (Foote, 1987). An estimate for *L* was based on bottom trawl samples during the first three repetitions of Survey A, and gill net samples during Survey B and the last repetition of Survey A (Tab 1).

A map for the herring distribution on large scale was made in Surfer v. 6.0© software based on acoustic recordings from Survey A.

To examine diurnal schooling dynamics, the day was divided in eight 3-h time periods. Three school parameters were considered: Volume backscattering strength ($S_V$), vertical school extension (m) and school distance above bottom (m) measured from the bottom to the midpoint of the school. Mean $S_V$-values (averaged in the linear domain), mean vertical school extension and mean school distance above bottom were calculated for each time period.

Recorded herring were categorised according to position in the water column: Pelagic schools when >90 % of the herring was located **above** the 10 m bottom channel, spawning layers: >90 % was located **in** the bottom channel, and transition schools: 10-90 % was located in the bottom channel and 10-90% above the bottom channel (Fig 2). For each school category mean $S_V$-values were calculated weighted according to the intensity of the backscatter in each sample.

The second long term station was terminated at 05 UTC (= local time - 2 hours) due to bad weather.

## Biological sampling

Herring and predator samples were obtained using gill net and trawl (Tab 1). Herring samples were obtained daily from 30 March to 3 April using 25 m long by 4 m high gill nets (mesh size: 37 mm when stretched with a force of 5 kg) set on the seabed overnight. Soak time was 10-12 hours and a total of 5 samples were obtained. Total length, wet weight and gonadal maturity (1-8) were determined. Two predator samples were obtained using 25 m long by 4 m high gill nets (90 mm meshes), and one sample using a Super Campelen demersal shrimp trawl. Individual length, total sample wet weight for each species and stomach content were determined.

# RESULTS

## Herring distribution and abundance off Karmøy

The large scale distribution pattern of herring from Survey A (n=4) is shown in Fig 3. Highest densities ($S_A$=10000-150000 $m^2/nm^2$) were recorded in a small area between Ferkingstadøyane and Karmøy, and high densities ($S_A$>10000 $m^2/nm^2$) were also recorded between Utsira and Karmøy and in a limited area south of Karmøy. The areas south of Ferkingstadøyane had low densities ($S_A$<1000 $m^2/nm^2$) throughout.

Herring biomass in tonnes estimated for the large scale area decreased throughout the period from 15 March (53000 tonnes) to 1 April (900 tonnes) (Fig 4).

## Distribution and abundance at the spawning location

There was a displacement in distribution of herring with time within the small scale spawning location (Fig 5). Spawning layers shifted in a south easterly direction, and overlaps in distribution areas were only observed between the first two study days (29 March and 30) and third and fourth day (31 March and 1 April).

During three of four repetitions of Survey B estimated herring abundance at the spawning location was about 1/20 (around 50 tons) of the estimated large-scale abundance (Fig 6). The fourth estimate from 09 on 31 March was four times as high (>200 tons).

## Spatial and temporal schooling dynamics

Spawning layers were primarily recorded at night (18 to 24). The frequency of pelagic school registrations was highest from 12 to 18, and no pelagic schools were detected between 21 and 03. Few herring were recorded during the night, and only during the long term stations. The $S_V$-values differed significantly with school categories (GLM ANOVA, p=0.002) (Fig 7), and transition schools had significantly higher $S_V$-values than spawning layers (HSD, α=0.05).

The $S_V$-values also changed significantly with time (General Linear Model (GLM) ANOVA, p=0.001) (Fig 8). Mean $S_V$-values were low (<0.0008 $m^2$) from 18 to 03 compared to the rest of the day (>0.0010 $m^2$). The highest values were recorded between 15 and 18 (0.0020 $m^2$), and the mean value in this period was significantly higher than in all other periods (Tukeys Studentized Range (HSD) Test, α=0.05). No significant differences were found between other time periods.

School distance above bottom also changed significantly with time (GLM ANOVA, p=0.000) (Fig 9). Schools stayed higher in the water column during the day than during the night. Mean distance above bottom was <5 m between 18 and 03, while the distance exceeded 8 m during the rest of the day. Schools stayed significantly closer to the bottom between 21 and 24 than in all periods from 06 to 18 (HSD, α=0.05), from 18 to 21 than in the two periods between 09 and 15, and from 24 to 03 than between 12 and 15 (HSD, α=0.05).

Few recordings during the night and differences in school distance above bottom during day and night were also seen when looking at the long term stations separately. Herring densities were low ($S_A$<1000 $m^2/nm^2$) from 21 to 04 (Fig 10a), but increased abruptly around 04 during both stations, shown as layers a few meters above the bottom on the echogram. From 04 to 12, 40-100 % of the herring was recorded in the pelagic (>10m over the bottom) (Fig 10b), while the registrations from the period 21 to 04 were mostly done in the bottom channel during both stations.

## Biological samples

Gonadal statuses for herring sampled in the gill nets are given in Fig 11. Maturing (GMI 5) individuals dominated (>35%), and the proportion of spent herring increased with time.

Medium-sized pollack (average 43.6 ± 5.8 cm) dominated the predator samples (n=98). Cod, haddock and saithe (n=42, 23 and 4) were also caught, all three species frequently (72-78 %) observed with herring eggs in their stomachs, but no stomach contained herring.

# DISCUSSION

Herring may avoid survey vessels biasing acoustic recordings (Misund and Aglen, 1992). However, vessel avoidance has been reported to play a minor role during the spawning period (Mohr, 1964; Nøttestad *et al.*, 1996; Axelsen *et al.,* 2000), and no avoidance behaviour to the vessels was observed during our study.

The densest herring registrations off Karmøy were on the same locations throughout the study period, in accordance with earlier findings showing that herring select certain spawning locations according to substrate, temperature and current (Runnstrøm, 1941). The strong decrease in herring abundance from mid-March to the beginning of April is also consistent with previous observations (Johannessen *et al.,* 1995), indicating that our study on schooling dynamics took place near the end of the spawning season.

The distribution pattern of herring on large scale showed that the location selected for the small scale study on schooling dynamics had the densest herring concentrations during all surveys. However, within this location the layers of herring were not stationary, but moved in a south easterly direction from day to day. Similar directional horizontal spawning has been reported in North Sea herring (Stratoudakis *et al.*, 1998), and may be connected to the abundance of eggs on the spawning substrate. Thick egg layers might result in retarded development and high mortality rates for the deeper layers of the egg mat due to low oxygenation (Taylor, 1971; Johannessen, 1986; Stratoudakis *et al*., 1998), but this should not be crucial as eggs deposited in the uppermost egg layer should not suffer from such an effect. Directional horizontal spawning could instead be a strategy to avoid eggs being consumed by predators, as thick egg layers should represent favourable areas for egg feeders (Høines *et al.,* 1995). The change in herring distribution caused by the shift in spawning locations should be taken into account during surveys. During our study, the shift in spawning location directed herring out of the survey area of Survey B and could partly explain the difference between estimates.

The fish densities within registrations varied with time of the day and within school categories. Densities were low for spawning layers and high for transition schools. Low density spawning layers have been reported before (Nøttestad *et al.,* 1996). Continuous reorganisation of schools during egg deposition could lead to loose structure of the spawning layers. The chance of encountering widespread layers is greater than encountering vertically extended pelagic schools, while pelagic schools give relatively higher contributions to the estimates. When designing a survey, the relation between probability of school encounter and shape and density of the schools encountered should thus be considered.

The vertical distribution of herring within the spawning location was dynamic. Pelagic schools were most frequently registered at daytime and spawning layers in the evening whereas there were few registrations at night. The observed pattern could be due to predator avoidance. The predator pressure at Karmøy is high during the spawning season (Toresen *et al.*, 1991; Høines *et al.*, 1995) and even though none of the predators caught had herring in their stomachs, the size suggested that most of them were potential predators for herring (Høines *et al.,* 1995). An archetypal pelagic fish like herring is vulnerable to predators on the bottom due to reduced number of escape routes and reduced mobility (Pitcher and Parrish, 1993; Axelsen *et al.,* 2000). Egg deposition on the bottom should therefore be less risky during the dark hours, since visual predators are less active with low light levels (Løkkeborg and Fernö*,* 1999).

The low densities associated with night time registrations cannot be explained by predator avoidance. Fish could have avoided the vessels, but there were no indications of this. The low densities at night may be a result of disaggregation of schools, but a more plausible explanation is that schools stay within 0.5 m above the bottom, where fish echo and bottom echo are undistinguishable (Ona and Mitson, 1996). Problems with herring staying within this acoustic deadzone have been reported before (Johannessen *et al.,* 1995), and are in accordance with our observations during the long term stations where nearly all herring were recorded at night within 10 m from the bottom. Based on our findings, spawning stock surveys for NSS-herring should not be conducted at night.

We have seen that herring on a limited spawning location at the end of the spawning season may have a directional horizontal spawning pattern, and that diurnal variations appear with low-density spawning layers during the evening, high-density schools swimming more pelagically during the day and few recordings during the night. The results are, however, not in coherence with earlier results from both this and other herring spawning areas with spawning layers recorded during the day and high acoustic recordings obtained during the night (Runnstrøm, 1941; Slotte, 1998). The contradicting results confirm that the spawning behaviour in herring is flexible and can e.g. differ between deep and shallow spawning grounds (Slotte, 1998). The differences in behaviour at different times of the spawning season within the same spawning area can also be seen as an adaptation. In the middle of the spawning season the competition for a successful deposition of spawn at the bottom could be strong (Fernö *et al.,* 1998), and with limited possibility to postpone deposition of eggs and sperm (Hay, 1986), herring may have to spawn during the day despite the higher predation risk. Lower competition at the end of the spawning season could allow herring to be more cautious towards predators and spawn exclusively at night. It is difficult to design robust surveys in such complex systems, but knowledge of behaviour can be used to justify some generalisations in the methodology, and contribute to interpretation of results.

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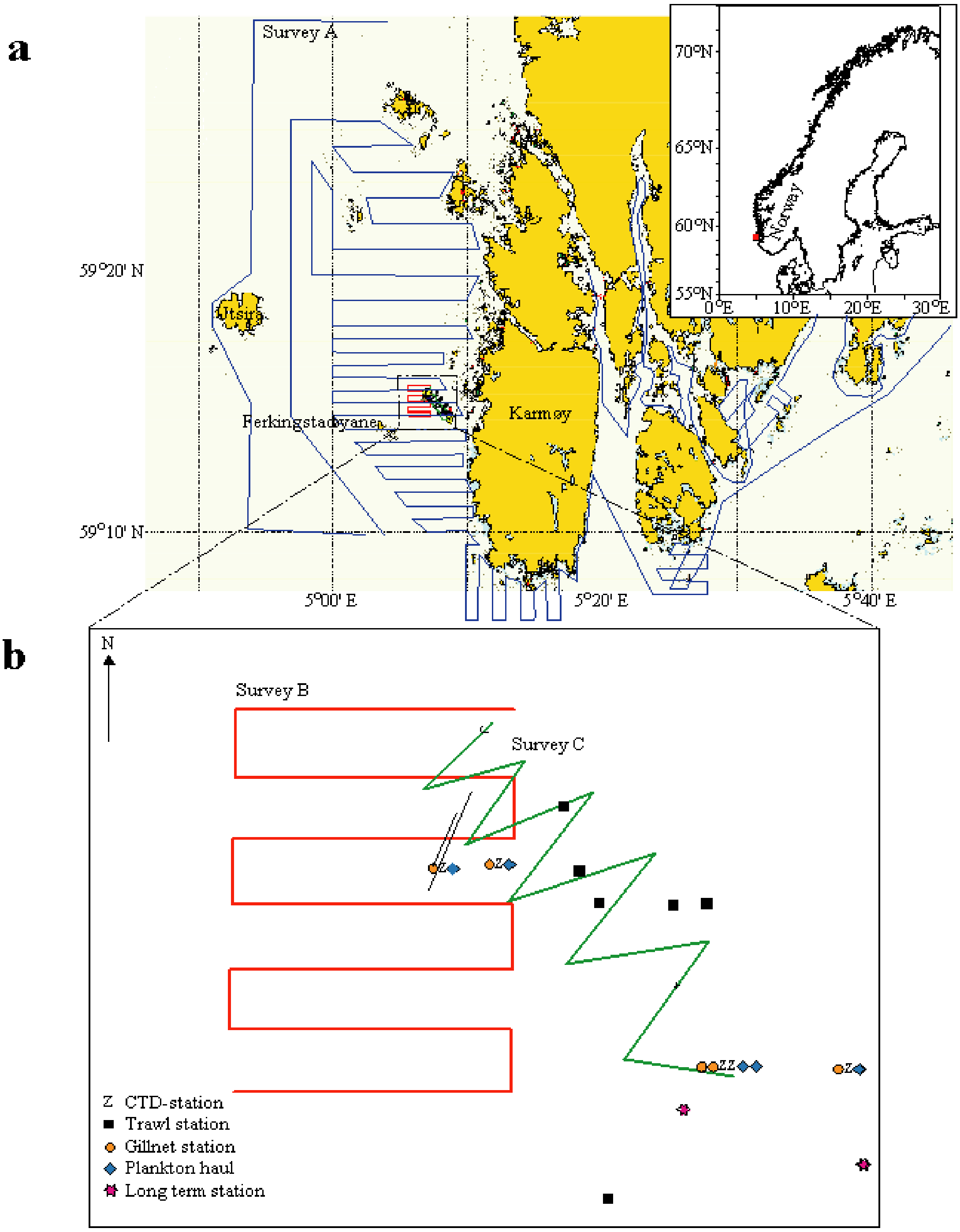
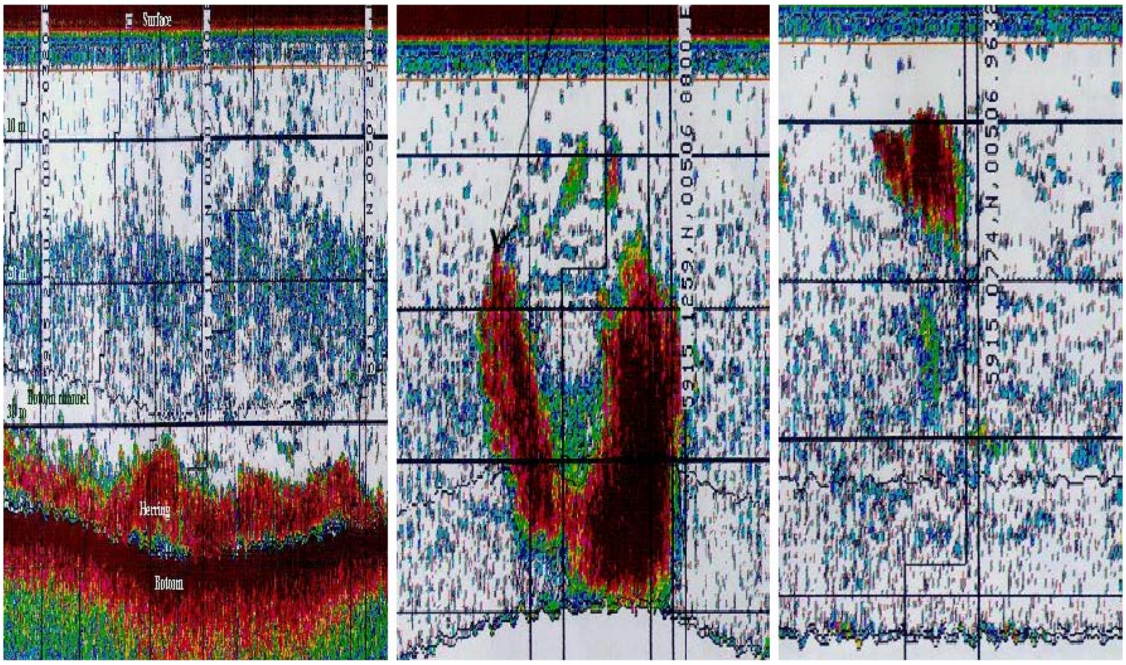



**Fig 1.** Map of the study area. **a)** The entire study area, with the blue grid indicating Survey A, which was conducted four times in the period from 15 March to 1 April. **b)** The 2 square nautical miles ($nm^2$) spawning location with the red grid indicating Survey B and the green grid Survey C. Long term stations and stations for trawling (starting positions) and gillnets are indicated.

**Tab 1.** Vessels utilized, surveys conducted and acoustic instruments applied during the study. EK 500 echosounder and integrator was applied during Surveys A and B, while the EQ 55 echosounder was applied during Survey C. Name*: MS=RV "Michael Sars", HM=RV "Håkon Mosby" and HB=RV "Hans Brattstrøm". LT**: Long term station=The vessel kept a permanent position within an area of 25 $m^2$ using a Dynamic Positioning System. TrawlD=Demersal trawl, TrawlP=Pelagic trawl.

| Vessel | | | Survey | | | Acoustic instruments | | Biological |
|---|---|---|---|---|---|---|---|---|
| Name* | GRT | Bhp | Number | Date | Time (UTC) | Echosounder | Frequency | sampling |
| MS | 690 | 1500 | A | 15-17, 18-21 and 22-23 March | * | EK 500 | 38 kHz | TrawlD |
| HM | 710 | 1500 | A | 31 March-1 April | * | EK 500 | 38 kHz | TrawlD, P |
| | | | LT** | 1-2 April and 2-3 April | 23-13 and 21-19 | | | |
| HB | 96 | 1300 | B | 30, 31 March (twice) and 1 April | 14, 09, 21 and 09 | EK 500 | 38 kHz | Gill net |
| | | | C | 1 April (twice) and 2 April | 19, 20 and 19 | EQ 55 | 49 kHz | |




**a** **b** **c**

**Fig 2.** Typical shapes for the three different categories of registrations. **a)** Spawning layer **b)** Transition school **c)** Pelagic school.

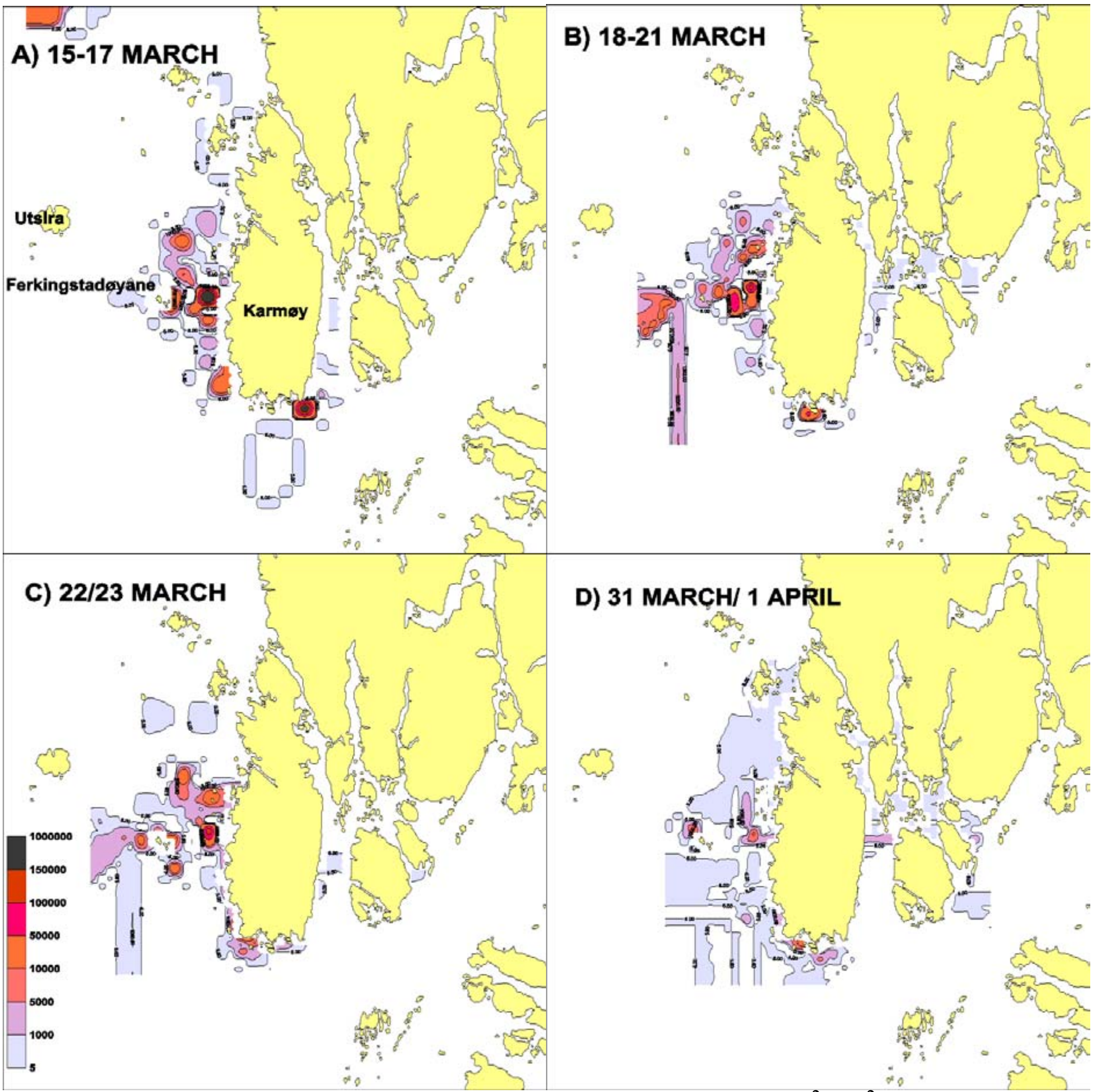



**Fig 3.** Recorded area backscattering coefficients ($S_A$ expressed in $m^2/nm^2$) of herring during four repetitions of Survey A.

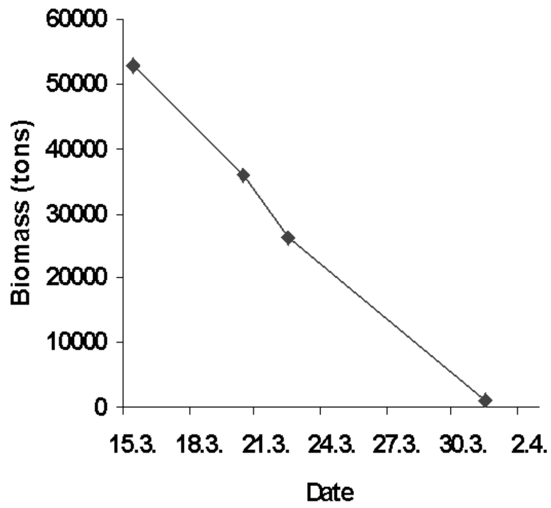



**Fig 4.** Estimated herring biomass in tonnes during four repetitions of Survey A.

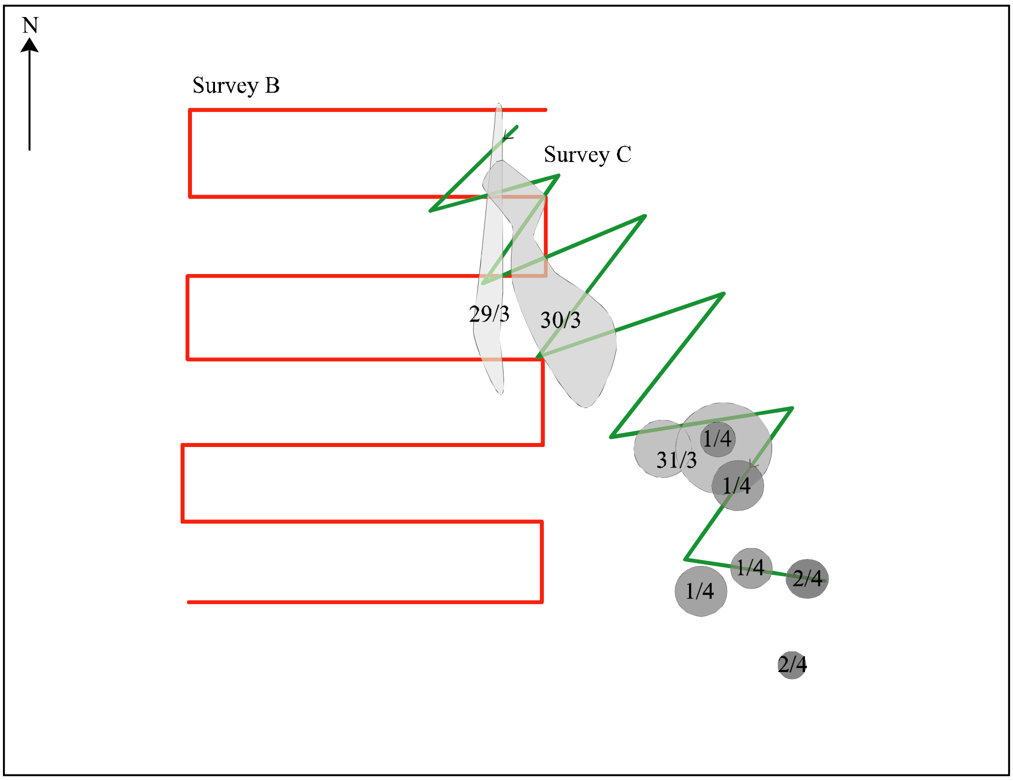



**Fig 5.** Distribution areas of the spawning layers from day to day at the spawning location. Recordings are done between 18 and 24 UTC, and herring distributions from different days are represented by different shadings. The distribution areas for 29 March and 30 March are defined within the outermost geographical positions where spawning layers were recorded, and the areas for 31 March, 1 April and 2 April are circles fitted around herring recordings along survey lines. The red line indicates the transect grid of Survey B, and the green line the grid of Survey C (Fig 1b).

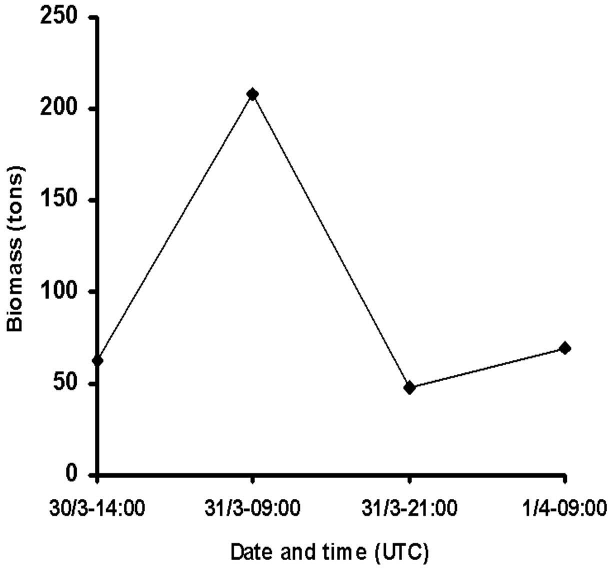



**Fig 6.** Estimated herring biomass during four repetitions of Survey B.

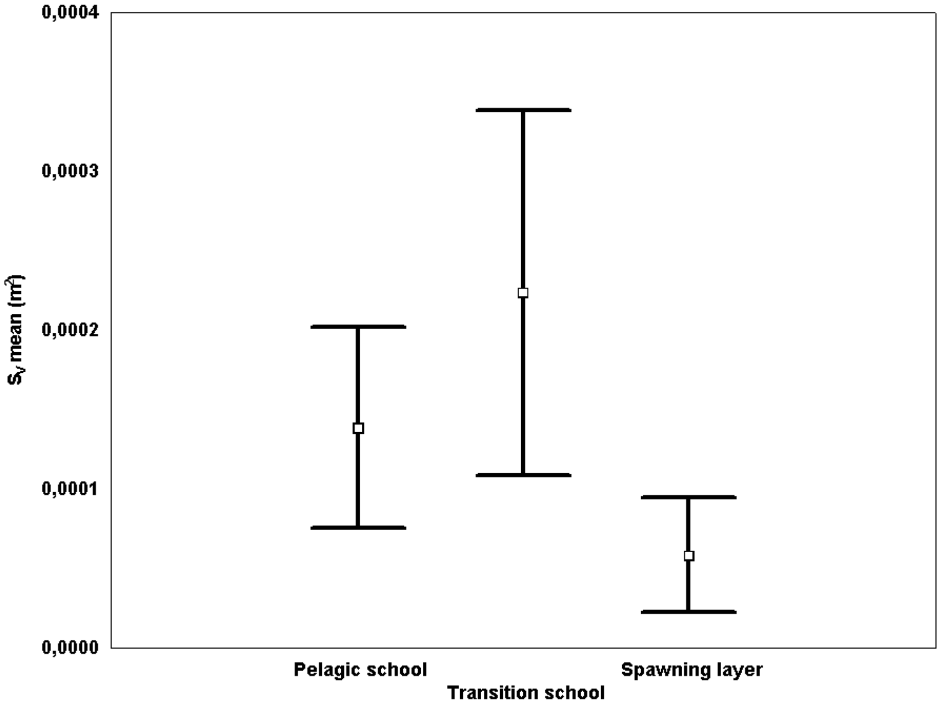



**Fig 7.** Mean volume backscattering strength ($S_V$ expressed in $m^2$) of herring ±2SE for the different school categories.

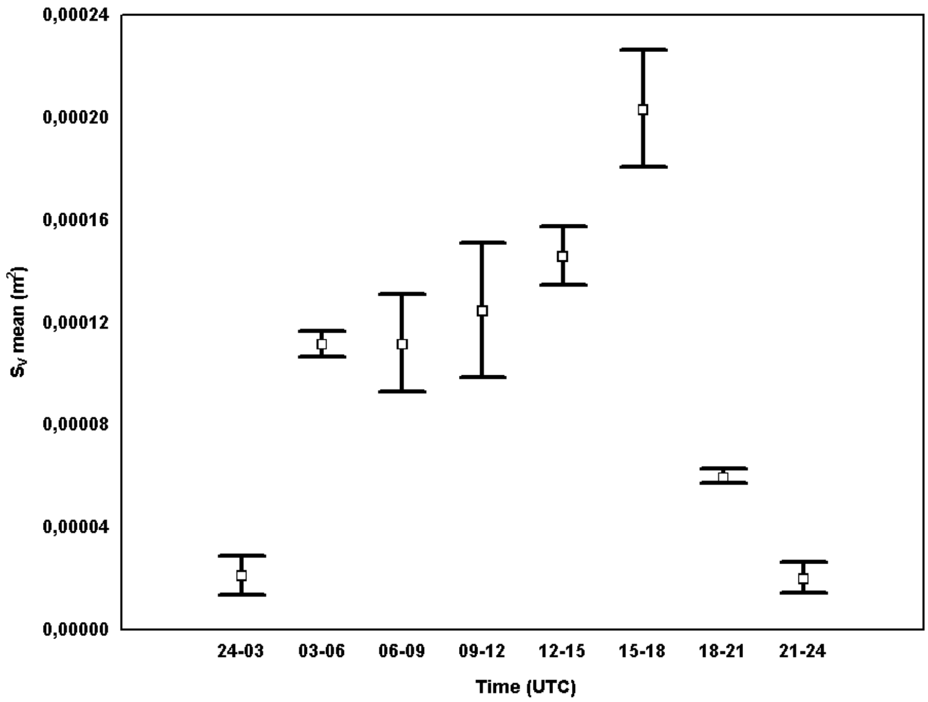



**Fig 8.** Mean volume backscattering strength ($S_V$ expressed in $m^2$) of herring ±2SE during the day.

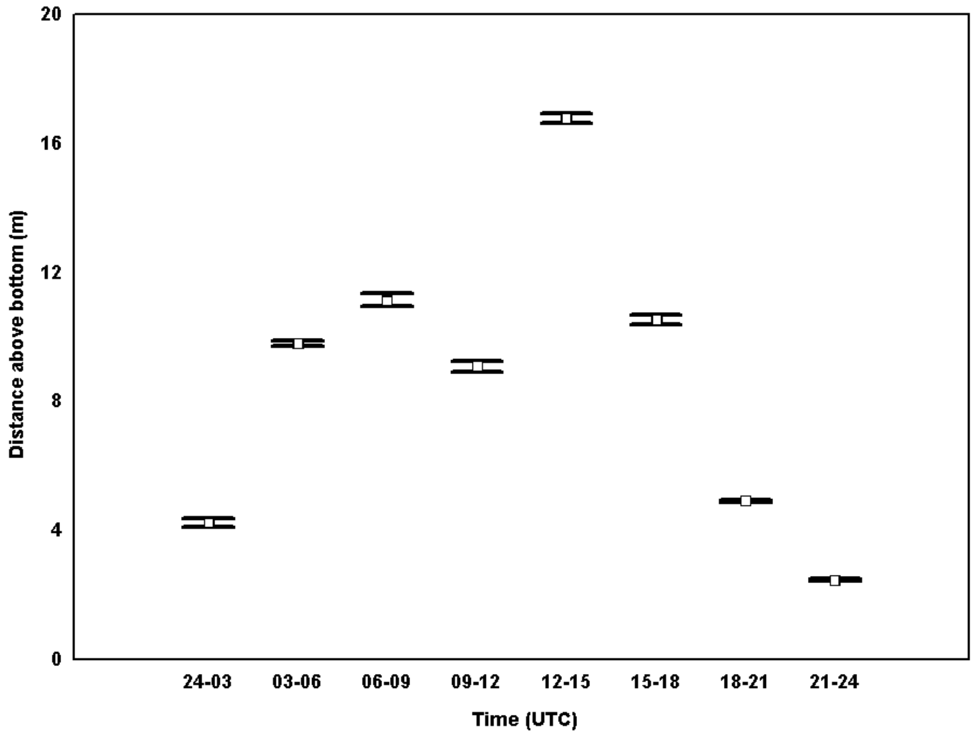
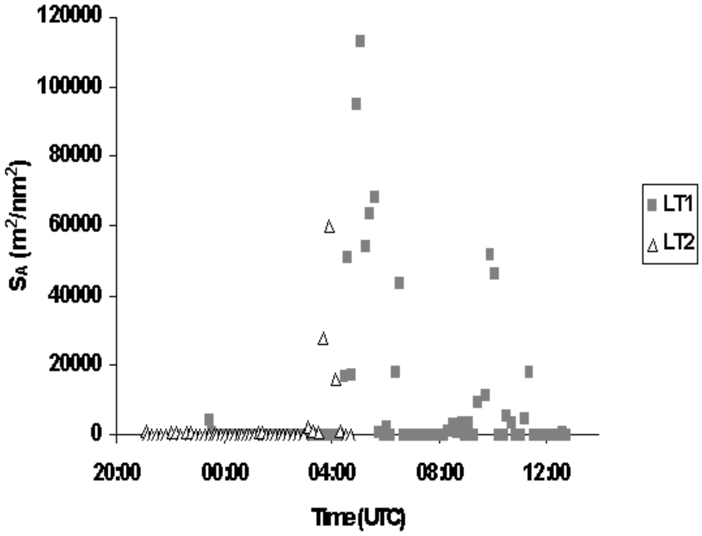



**Fig 9.** Mean distance above bottom in m ±2SE during the day.

a




b

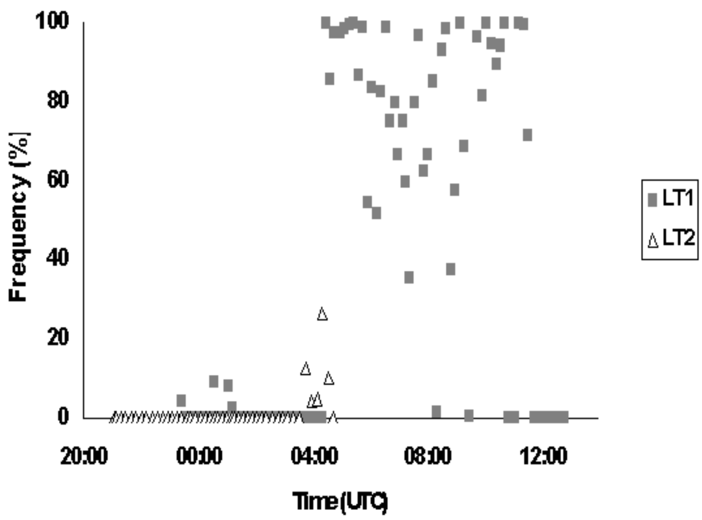



**Fig 10a.** Mean area backscattering coefficients ($S_A$ expressed in $m^2/nm^2$ and averaged over 10 minutes time intervals) of herring during the long term stations. **10b.** Percentage of herring detected in the pelagic (>10 m over the bottom). LT1 and LT2 are long term stations 1 and 2, respectively.

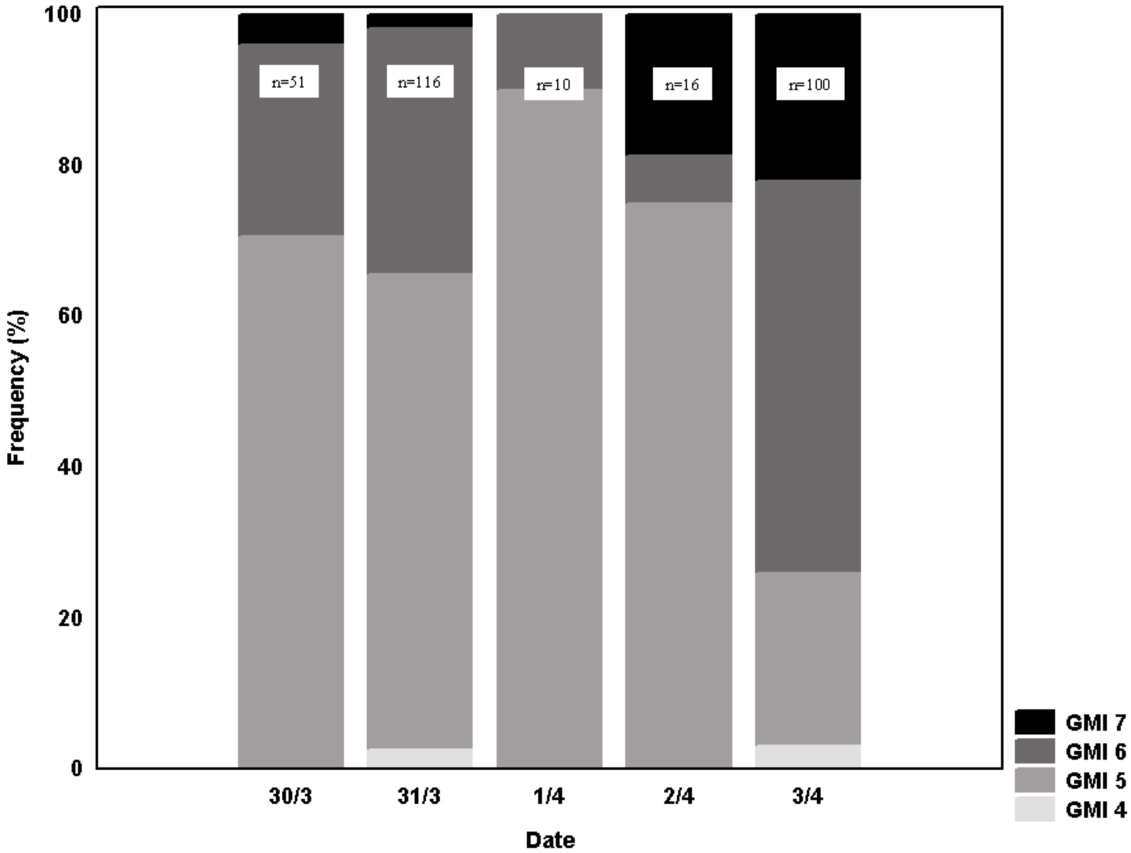



**Fig 11.** Distribution of gonad maturity indexes (GMI) from day to day in the gillnet samples. GMI 4,5: pre-spawning; GMI 6: running; GMI 7: spent.