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Migration behaviour of herring along the cold front in the Norwegian Sea in April 1997

by

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Abstract

The behaviour of Norwegian spring spawning herring when migrating to the feeding areas in the Norwegian Sea in April was mapped by an acoustic survey in 1997. The distribution of herring was recorded by conventional echo integration, and the swimming behaviour of selected herring schools was recorded by a high-resolution sonar. Individual schools were tracked for up to one hour.

The herring were recorded in an area between 66° and 68° north, 2° east to 3° 30' west. The western part of the area was influenced by the southbound, cold East Icelandic current which induced a termal front within the area. Schools far east of the front had a western migration direction, while schools closer to the front had a southern migration direction. The migration behaviour of the herring schools seemed to be influenced by the temperature distribution in the front. The herring were recorded in large dense schools at 200 - 400 m during daytime. At night the schools rose to surface and scattered or remained as distinct schools.

Introduction

A research crusie was conducted in April 1997 to study the relationship between the physical and biological environment and the migration behaviour of herring schools when entering the cold front in the Norwegian Sea. The cruise was designed to map parts of the distribution of the Norwegian spring spawning herring in the Norwegian Sea, and possibly to provide an estimate of abundance of the herring in the area surveyed. The cruise was a part of the ICES coordinated survey activity on Norwegian spring spawning herring and the environment in the Norwegian Sea that have been established between EU, the Faroes, Iceland, Norway and Russia (Anon, 1997).

The survey was also part of the *Mare Cognitum* research program at Institute of Marine Research, Bergen. The purpose of this program is to explore the physical environment and biological ecosystem in the Norwegian Sea. This research program requires specific sampling procedure with frequent CTD and MOCNESS stations, and trawl sampling troughout the whole water column from surface to 600 m depth.

To fullfill these purposes, the cruise was attempted to be run as a combination between an acoustic exploration survey of fish resources, an acoustic abundance estimation survey, and an environment exploration and monitoring survey. The survey has therefore been conducted with predetermined transects, continous acoustic recording, tracking of selected schools for about one hour, aimed trawling on recordings and regular environmental stations.

Methods for recording, sampling and abundance estimation of fish

Continuous acoustic recordings of fish and plankton were made by a calibrated echo integration unit consisting of a 38 kHz Simrad EK500 working at a range of 0 - 500 m. The integration unit was connected to a Bergen Echo Integrator (BEI) for postprocessing of the recordings and allocation of area backscattering strengths (s_A) to species. The s_A - recordings per nautical mile were averaged over five nautical miles. The echo sounder was operated with the following settings: max. power: 4000 W, time varied gain: 20 log R, pulse length: 1 ms, bandwidth: wide, angle sensitivity: 21.9, 2-way beam angle: -21.0 dB, Sv transducer gain: 25.0 dB, TS transducer gain: 24.9 dB, 3 dB beamwidth: 7.0 dB.

A 95 kHz Simrad SA950 sonar was used to record schools near surface at a range of 50 - 300 m to the side of the vessel, and to track selected schools in the survey area. The sonar was operated with the following settings; TX power: max, range: 300 m, pulse: FM auto, gain: 9, display gain: 9, TVG: 30 log R, AGC: weak, Normalization: weak, Ping-to-ping filter: weak. The sonar is connected to a HP 9000 work station with software for detection and measurements of schools. This school detection system was operated with the following settings; minimum range: 50 m, maximum range: 300 m, colour detection threshold: 15, detection radius: 30 m, minimum gap 5 m, minimum width 5 m, minimum interval 5 m, minimum detection pings: 4.

To record migration behaviour and school dynamics, selected schools were tracked for up to 60 minutes. The schools were then continuously recorded by the sonar system, and the position of the vessel was obtained from a global positioning system (GPS). The migration speed and direction of the schools was calculated by procedures written in SAS software (Misund et al., 1997). The dynamics of the schools were noted continuously by a rapporteur in cooperation with a sonar operator, both watching the sonar display.

Acoustic recordings of fish were identified by use of the Åkra-trawl, which has a vertical opening of about 30 m (Valdemarsen and Misund, 1995). Subsamples of up to 100 specimens of herring and blue withing were taken from the trawl catches. The length down to nearest 0.5 cm, weight, sex, maturation stage, and stomach content were recorded. Scales from 100 herring and otholits from 50 blue withing were taken for age reading. The stomachs from 30 herring and 3 from each cm group of blue withing from each subsample were frozen for later analysis. Other fish species were length measured, weighted or frozen for later analysis.

The echo recordings were post-processed by the BEI-system, and s_A-values of defined recordings allocated to herring according to the trawl catches and the appearance of the recordings. To estimate the abundance of herring , the allocated s_A-values were averaged for statistical squares of 1° latitude and 2° longitude. For each statistical square, the area density of herring (ρ_A) in number per square nautical mile (N n.mile^{-2}) was calculated by the equation;

$$\rho_A = s_A/\sigma \qquad (\text{N n.mile}^{-2}) \quad (1.1)$$

where:

$$\sigma = 4\pi \cdot 10^{1/10 \cdot TS} \qquad (1.2)$$

$$TS = 20 \log L - 71.9 \qquad (1.3)$$

Insertion of equation 1.3 to 1.2, and 1.2 to 1.1 give:

$$\rho_A = s_A \cdot 1.23 \cdot 10^6 \cdot L^{-2} \qquad (N\ n.mile^{-2}) \quad (1.4)$$

The length (L) applied in eqn. 1.3 and 1.4 was calculated as the average length in the herring samples for the area surveyed. To estimate the total abundance of herring, the area abundance for each statistical square was multiplied by the number of square nautical miles in each square, and then summed for all the statistical squares in defined sub-areas and the total area. The biomass was calculated by multiplying the total abundance by the average weight of the herring for the area surveyed.

Survey area

The survey started with hydrograpic, nutrients, plankton and sediment sampling and monitoring at the regular stations of the Svinøy transect (Fig. 1). For mapping distribution, recording abundance and tracking selected herring schools, an area between 66° - 67° 30' N and 2° E - 4° W was surveyed by a regular grid with 30 nautical mile spacing north - south.

The weather conditions were rather bad during the survey, and we had wind stronger than 25 m/s (Beaufort force 6) for 12 of the 15 days at sea. In 3 occasions when the wind was about 45 m/s (storm) we had to turn the vessel up againts the waves and reduce the speed. The CTD (62 cases) and pelagic trawl station (21 cases) taken during the cruise are shown in Fig. 1 and 2.

Temperature distribution

The temperature in the area surveyed was characterized by a distinct front from east to west which had its direction north - south at about 0° (Fig. 3). At 50 m depth the temperature was about 4° C at about 0° , decreasing westwards and increasing eastwards. At 300 m depth the temperature was about 2° C around 0°, and similarly decreasing westwards and increasing eastwards (Fig. 4).

Herring distribution and abundance

The herring were recorded mainly between 65° 30' - 67° 30' N, 003° 30' W - 002° E (Fig. 5). In 9 cases a proper herring sample was caught by the pelagic trawl. The herring in the area averaged 31.3 cm and 0.203 kg, with a certain tendency to larger herring in the catches taken in the south-western area (Fig. 5). The herring catches contained more than 50 % females (Fig. 6). The total abundance of herring in the area investigated was estimated to $11.9 * 10^9$ individuals or $2.4 * 10^6$ tonns. However, these numbers are most likely underestimates because the herring schools were often recorded at a depth which probably is beyond the validity of the target strength relationship applied (Ona, 1990). In addition, there were probably substantial attenuation due to surface airbubbles during recordings in bad weather.

Preliminary inspections of stomach content showed *C. finmarchicus*, *Euphausiids* and *Chaetognaths* to be important food items. At one station apparent feeding on larger food items, *Chaetognaths* and *C. hyperboreus* at almost 400 m depth during day time was observed.

Herring school migration

A total of 32 schools were tracked for up to 60 min during the cruise. The schools were distributed all over the survey area, and occured at depths from about 20 m to about 350 m. Generally, the schools were swimming at depths from 150 m to 350 during daytime (08:00 - 18:00), ascended to the surface during the evening, and descended during the night (Fig. 7). Schools recorded west of 0 occured at greatest depth (Fig. 8).

The swimming behaviour of the schools varied considerably. Average horizontal swimming speed varied between 0.5 - 2.2 m/s, with a tendency for schools recorded during the night to swim fastest (Fig. 9). The average migration speed in the migration direction varied between 0.05 - 1.8 m/s, and most schools headed in a western direction (Fig. 10). The average migration speed tended to be faster for schools heading westwards, and faster for schools recorded in the evening and at night (Fig. 11). The heading of the schools was independent of time of day (Fig. 12).

Herring school dynamics

A total of 30 herring schools were tracked. The schools were relatively stable and the event rate was low compared to what has been observed in other situations (Pitcher at al., 1996). However, both joining and splitting of schools were repeatedly observed (Table 1), indicating adaptive adjustments of school size to the prevailing conditions. Intraschool events such as clumping and reorganization were also observed, as well as ring formation.

Herring schools were observed to migrate vertically during the tracking period. When passing over the school after tracking to estimate school size and vertical extent, some but not all schools dived rapidely downwards up to 100 m. The diving reaction reflecs antipredator behaviour, and the response variation may be caused by differences in the state of the schools. However, no mammal predators were observed visually in the distribution area of the herring schools, nor were any fish predators caught during the rather intensive trawling.

Table 1. Summary of schools and behavioural events. Speed is average migration speed, and Head is average migration direction, Eph is events per hour, NB is number of neighbouring schools. T is temperature. S is salinity.

Date	#	Latitude	Longitude	Track time (hr)	Split	Join	Eph	NB	Depth	Area	Speed (m/s)	Head (°)	T	S
08.apr	1	64 45,00 N	00 05.54 W	0,20			0,00	3	168	66	1,03	355		
09.apr	2	65 41,05 N	002 16,04 W	1,10			0,00		327	562	0,34	237	1,9	34,9
09.apr	3	65 45,00 N	002 24.7 W	1,00			0,00	1	259	956	0,36	248	2,0	34,9
09.apr	4	65 49,00 N	002 34.80 E	1,00	1		1,00		250		0,21	134	1,9	34,9
10.apr	5	65 51,09 N	002 44,80 W	0,60			0,00		159	269	1,09	271		
10.apr	6	65 54,01 N	002 45,40 W	1,08		2	1,85	10+ 6	164	390	0,07	54	3,4	34,9
10.apr	7	66 00,61 N	003 24,40 W	1,02	1	1	1,97		359	100	0,32	297	1,4	34,9
11.apr	8	65 59,6 N	000 31,4 E	0,95	1	1	2,11	1	226	173	0,22	60	3,5	34,9
11.apr	9	65 59.9 N	000 38,8 E	0,17	1		6,00		128	785	0,82	253		
12.apr	10	66 29,23 N	002 00.99 E	0,17			0,00		111	168	1,15	278	6,2	35,1
12.apr	11	66 30,00 N	02 00,00 E	0,08			0,00						6,4	35,1
12.apr	12	66 30,3 N	001, 53.16 E	0,62	1	2	4,86	2	208	293	0,18	51	5,4	35,1
12.apr	13	66 29,70 N	000 34,98 E	0,33			0,00	5	219	79	0,34	203		
12.apr	14	66 29,93 N	000 31,80 E	0,42			0,00	1	206	77	0,358	58		
12.apr	15	66 29,78 N	000 25,34 E	0,35			0,00		216	118			3,1	34,9
13.apr	16	66 29,88 N	002 07,84 W	0,45			0,00	10+	257	113	0,48	297		
13.apr	17	66 03,09 N	002 09,00 W	1,00			0,00	1	253	638	0,13	347	2,3	34,9
13.apr	18	66 29,83 N	002 49,28 W	1,00			0,00		137	752	0,31	84	2,3	35,0
14.apr	19	66 59,9 N	001 59 W	1,00	1		1,00	2	289	560	0,45	264	2,2	35,0
14.apr	20	66 59,6 N	001 51,4 W	1,00	1	1	2,00	1	163	445	0,1	220	2,4	34,9
14.apr	21	67 00,61 N	001 21,11 W	0,52			0,00	10	11	59	0,8	298		
14.apr	22	67 00,50 N	000 53,79 W	0,32	1	4	15,79		12	58	1,22	263		
15.apr	23	66 59,62 N	000 33,05 W	0,25	1		4,00	10+ 4	27	43	1,75	271		
15.apr	24	66 59,85 N	000 21,03 W	1,05	3	2	4,76	4	137		0,45	267	4,1	35,1
16.apr	25	66 59,86 N	000 49,20 E	0,52	1		1,94		178	770	0,17	240		
16.apr	26	67 30,03 N	000 35,24 W	0,52			0,00	3	353	56	0,4	215		
16.apr	27	67 30,08 N	000 32,60 W	0,58	3		5,14	2	310	139	0,58	150	2,3	35,1
16.apr	28	67 29,9 N	001 01,3 W	0,52			0,00	1	336	79	0,98	228	2,1	34,9
16.apr	29	67 29,8 N	001 08,3 W	1,00	2	1	3,00	2	311	112	0,25	30	2,3	34,9
16.apr	30	67 29,3 N	001 19,4 W	0,98	1	1	2,03		148	452	0,35	166		
17.apr	31	66 42,2 N	001 27,1 W	1,00	1		1,00	1						
17.apr	32	66 38,93 N	001 16,35 W	1,00	1	1	2,00	2					2,4	35,0
18.apr	33	66 13.52 N	000 07.52 W	0,98			0,00						1,7	34,9

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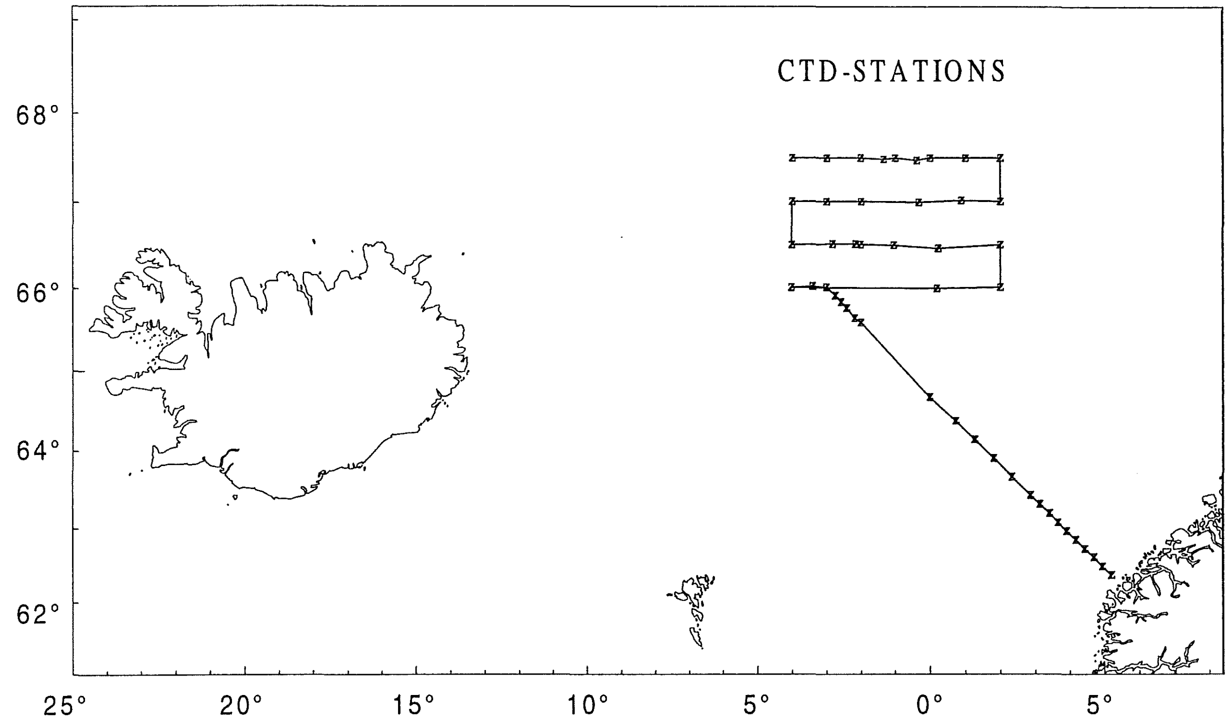

Fig. 1. CTD-stations.

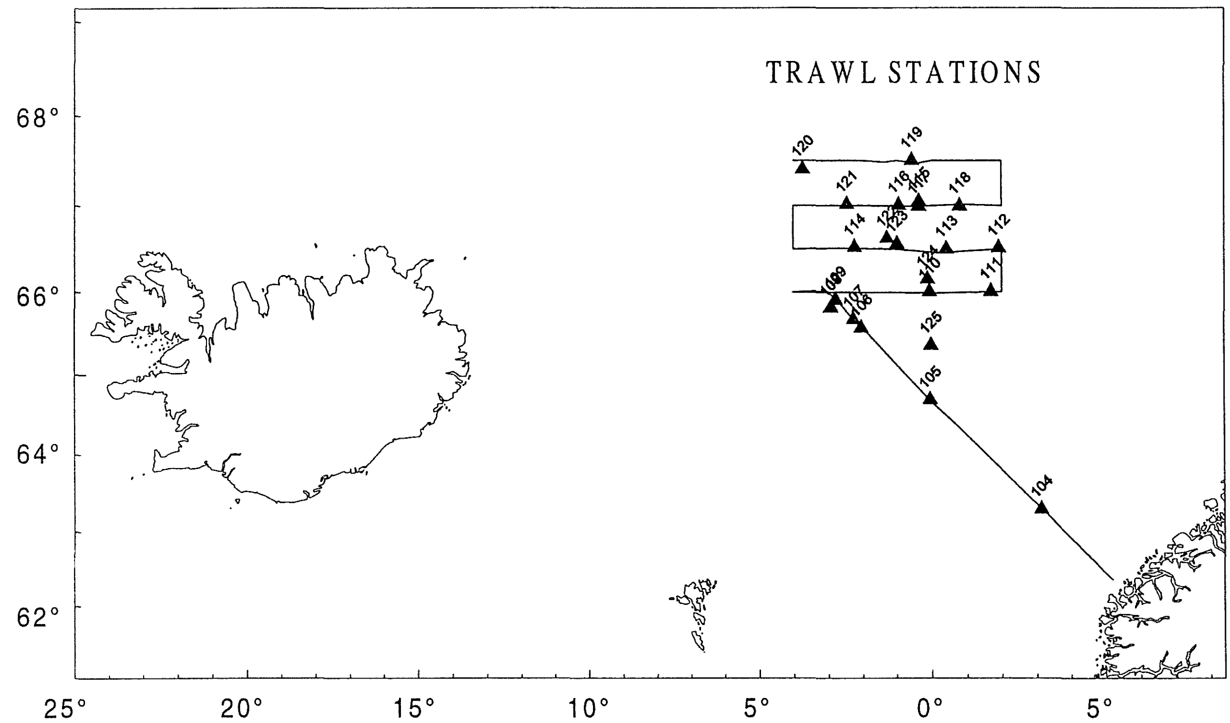

Fig. 2. Pelagic trawl-stations.

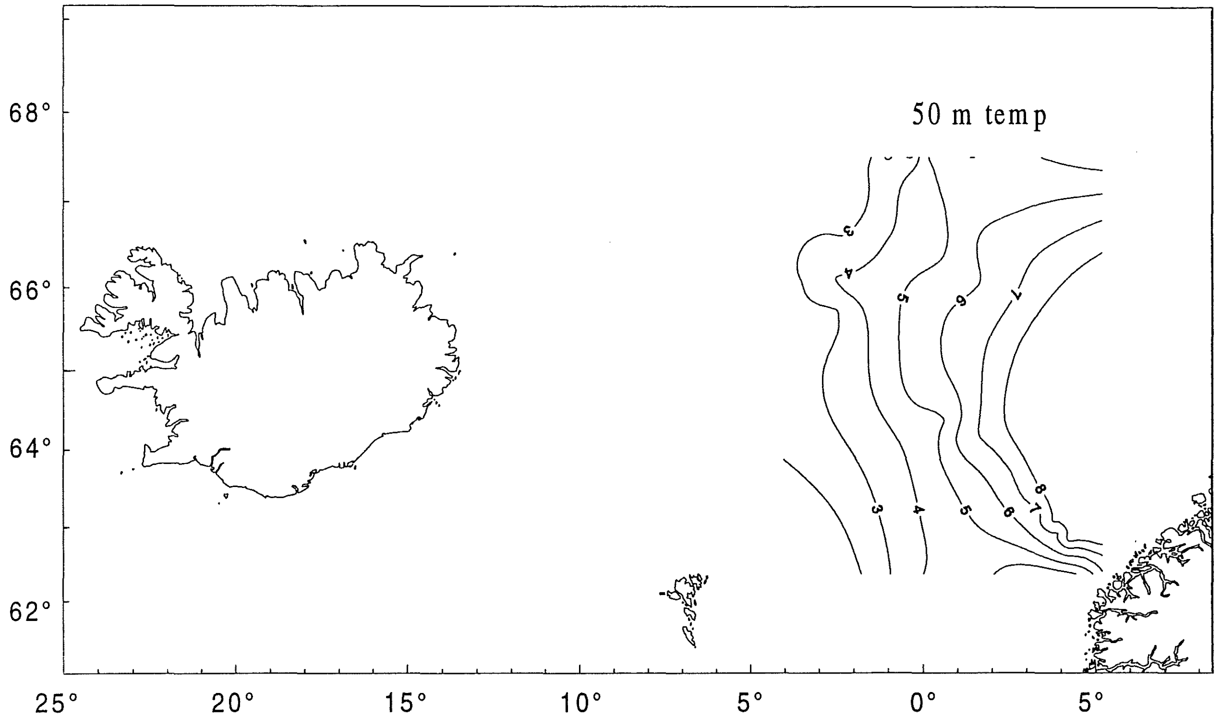

Fig. 3. Temperatures at 50 m depth.

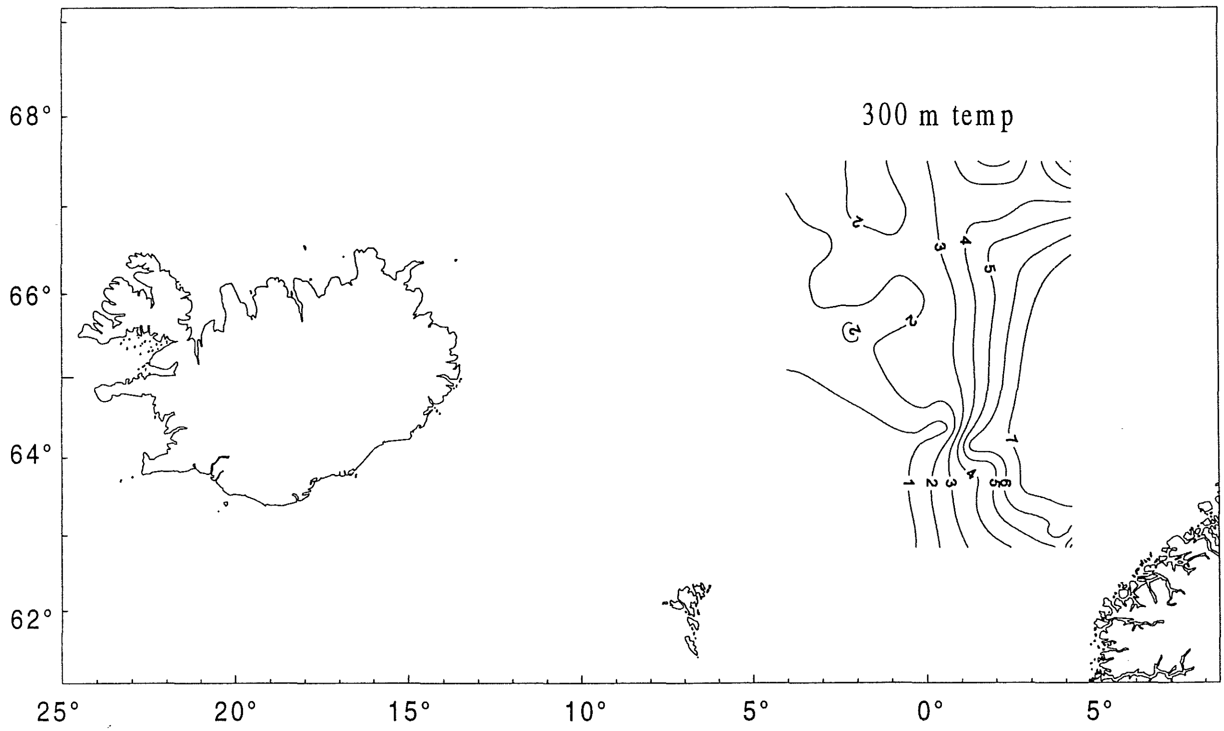

Fig. 4. Temperatures at 300 m depth.

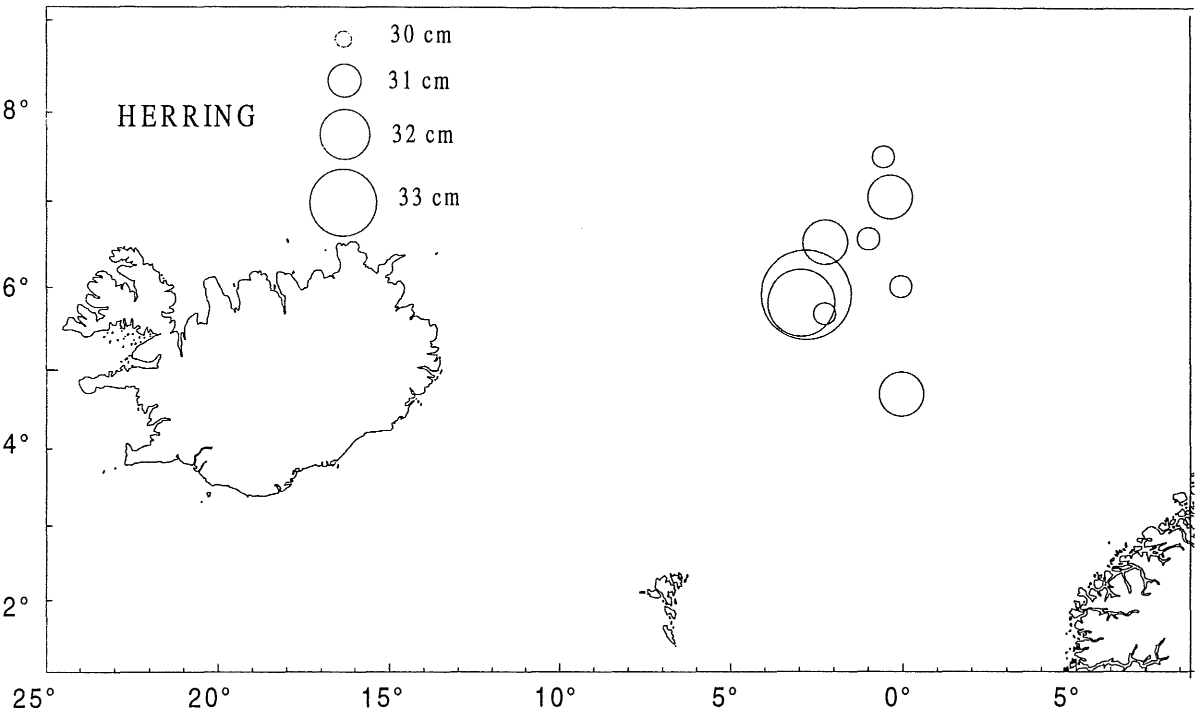

Fig. 5. Positions of herring catches with mean length groups.

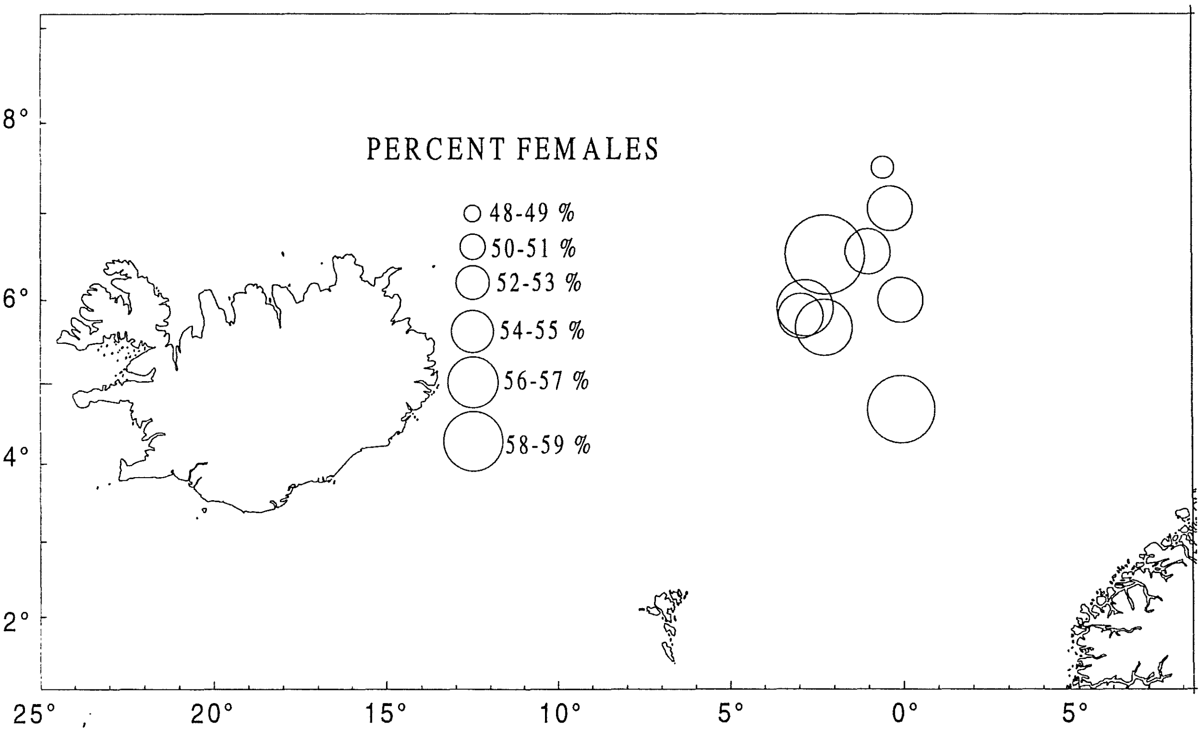

Fig. 6. The percetage of females in the herring catches.

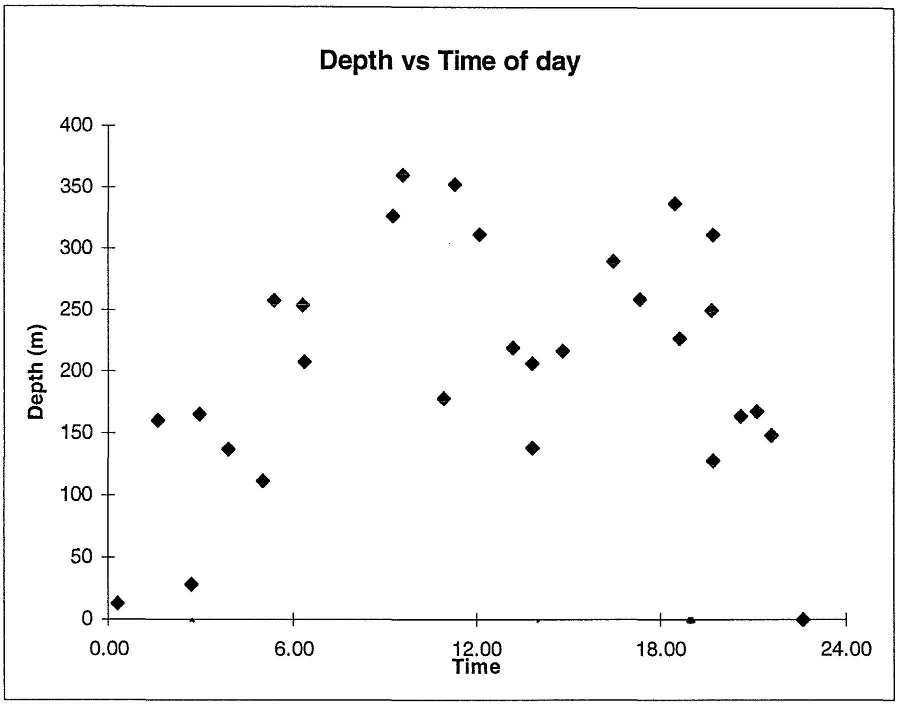

Fig. 7. The relation between depth and time of day for herring schools recorded with sonar.

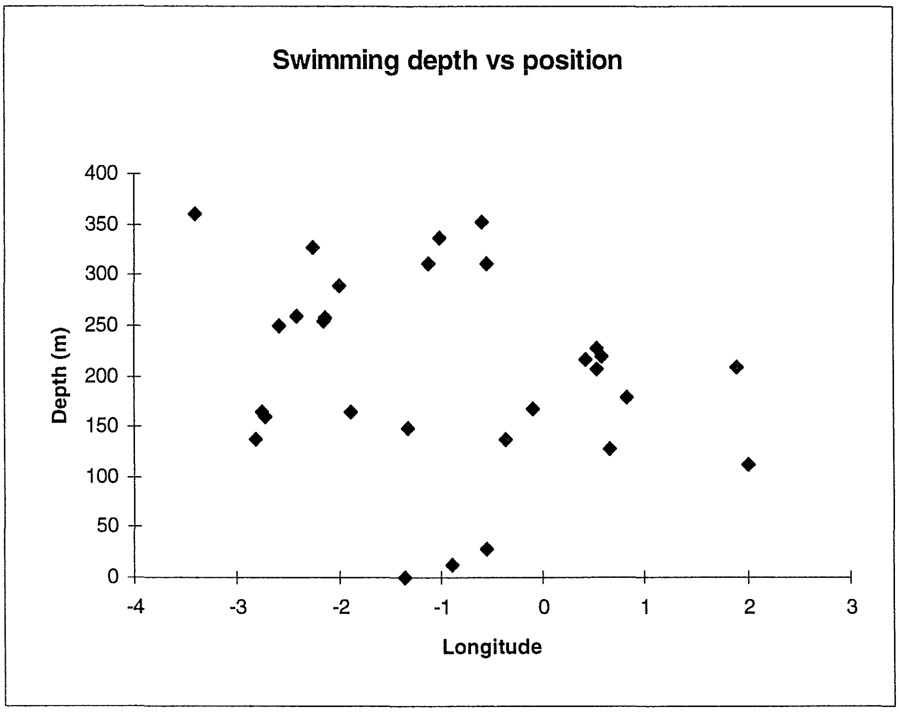

Fig. 8. The relation between depth and position for herring schools recorded with sonar.

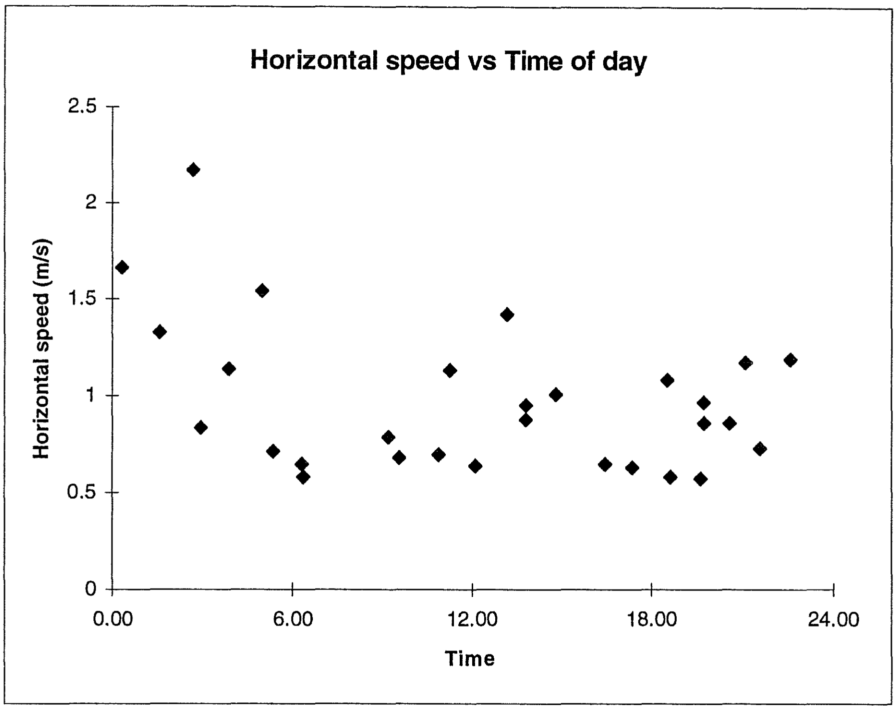

Fig. 9. The relation between horizontal speed and time of day for herring schools recorded with sonar.

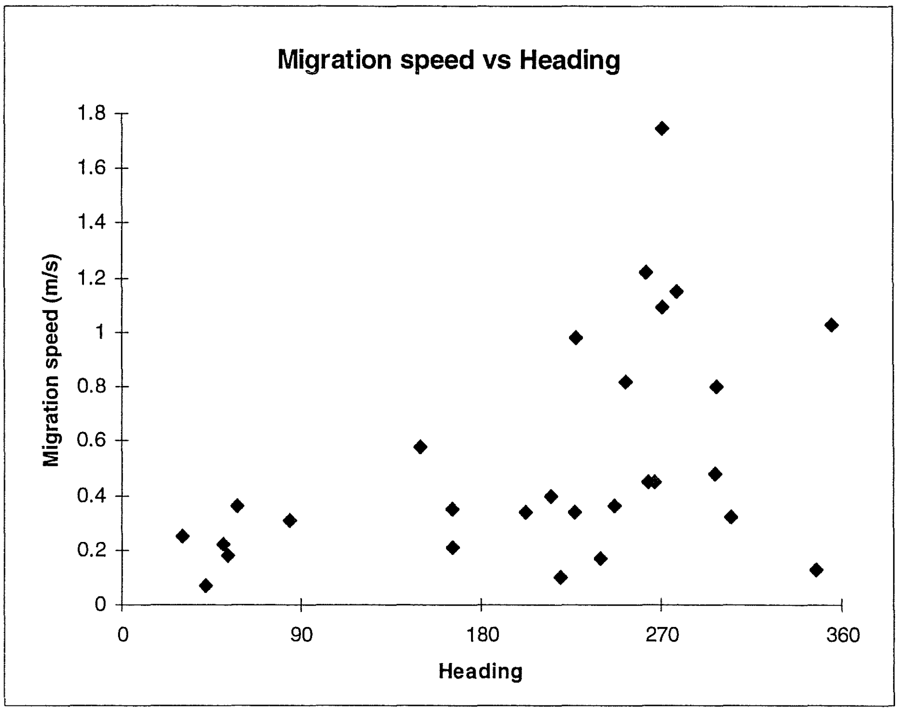

Fig. 10. The relation between migration speed and heading for herring schools recorded with sonar.

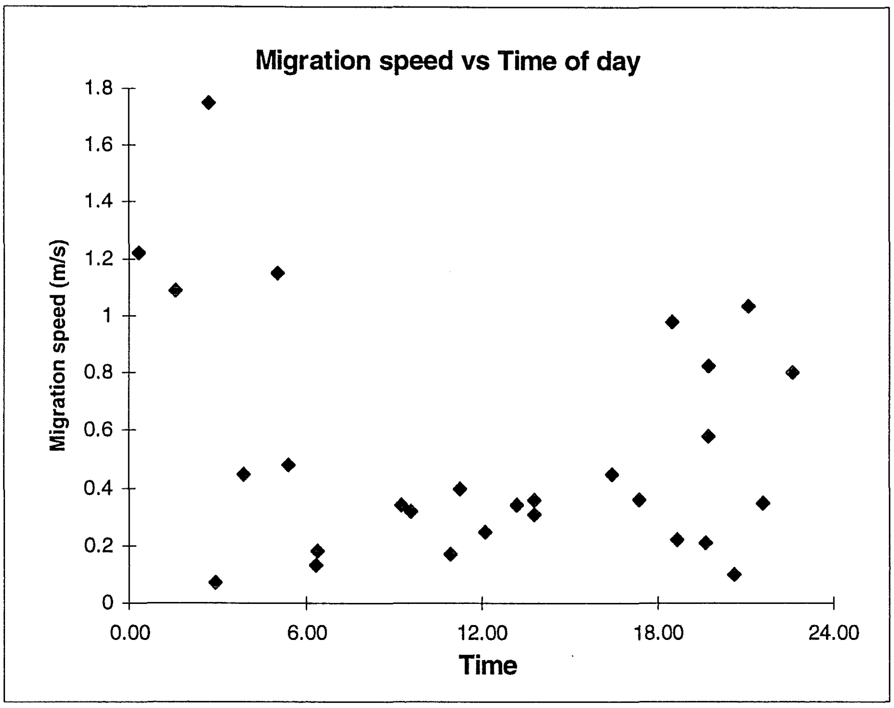

Fig. 11. The relation between migration speed and time of day for herring schools recorded with sonar.

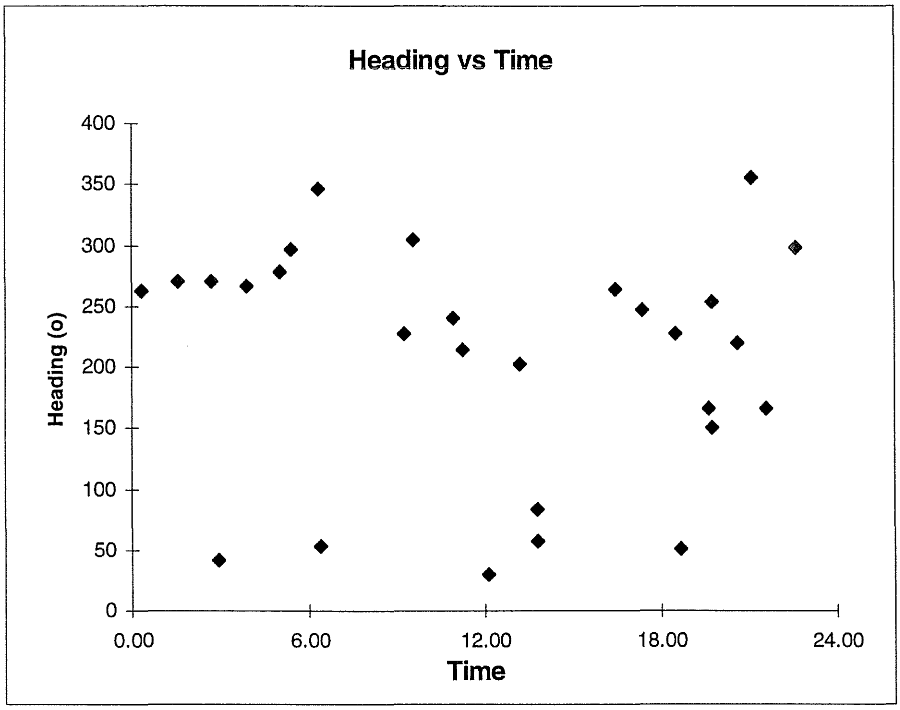

Fig. 12. The relation between heading and time of day for herring schools recorded with sonar.