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Migration behaviour of Norwegian spring spawning herring when entering the cold front in the Norwegian Sea

by

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Abstract

The distribution of Norwegian spring spawning herring when migrating to the feeding areas in the Norwegian Sea in spring has been mapped by surveys in April 1995 and 1996. The schooling behaviour of the herring have been recorded by a high resolution sonar, and the swimming speed and swimming direction have been quantified by tracking individual schools for up to one hour.

In early April the herring is migrating westwards in the Norwegian Sea between 66° north to 68° north and the continental shelf off Norway and westwards to 0°. When reaching the cold front at about 0° the herring turn southwards along the front. The herring is migrating in large schools or extended layers at 300 - 400 m depth in daytime. At night the herring rise to surface, and disperce or maintain schooling.

Introduction

The large scale migration behaviour of the herring in the Norwegian Sea during its summer feeding migrations, autumn aggregation migrations, and winter spawning migrations is quite well documented. The knowledge of the migration of this transoceanic herring stock has been gathered by tagging experiments, acoustic recordings and by analysis of fisheries data. By tagging experiments, Fridriksson and Aasen (1950) showed that the herring occuring north of Iceland in the summer months were spawning at the coast of western Norway in winter. By use of sonar and echo sounder onboard a previous R/V "G.O. Sars", Devold (1951, 1953) recorded the herring in the cold water areas east of Iceland/north of the Faroes Islands in late autumn, and followed the spawning migration across the Norwegian Sea to the Norwegian Coast. During these periods the herring occured in large schools or extended layers at 300 - 400 m depth in daytime, and rose to the surface at night. At the spawning grounds the herring occured in large midwater or bottom schools and bottom layers in daytime, and scattered in extended layers at night (Devold, 1963). In early summer in May/June the herring were found in dense schools near surface or midwater at depths up to 300 m (Jakobsson, 1963; Østvedt, 1965). As evident from fisheries, the herring were mainly feeding in the areas north and north east of Iceland during the summer months and early autumn (Jakobsson, 1961). In the sixties there were also a subpopulation that were feeding in the northern Norwegian Sea south west of Bear Island (Devold, 1968), but that migrated to the east coast of Iceland during autumn 1966 and joined the rest of the stock (Jakobsson, 1968). After the stock collapse in the late sixties, the stock have been feeding off Northern Norway in summer, aggregated and hibernated in fjords in Western and Northern Norway, and spawned at the traditional grounds off western Norway (Røttingen, 1992). When the stock recovered during the eigthies and early nineties, the herring made more extended feeding migrations in the Norwegian Sea in summertime, and migrated back to the Ofoten/Tysfjord area in autumn (Røttingen, 1992).

A critical periode for the spatial distribution of herring in summertime in the Norwegian Sea is the behaviour of the herring along the front between cold Artic water in the East Iceland Current and the warmer Atlantic water in the central Norwegian Sea. In the sixties, the herring were found feeding along the cold front east of Iceland in sea temperatures above 2° C in early May, but went through the front and entered the feeding areas north of Iceland in early June (Østvedt, 1965). The herring could then be found in areas with sea temperature down to 0° C.

To investigate the migration behaviour of the herring in relation to environmental features when entering the cold front in Norwegian Sea, we have conducted a series of exploratory cruises in the Norwegian Sea in April 1995 and 1996. The distribution and migration behaviour of the herring have been recorded by echo integration and sonar, and the plankton community and hydrographic conditions along the migration route have been quantified.

Surveys

A first exploratory survey was conducted in April 1995 in the area 66° - 68° north, 02° west to 02° east (Fig. 1). The purpose of the survey was to map the distribution of herring, and track selected schools for quantification of migration behaviour and school dynamics. A second survey was conducted in April 1996 in an area from about 67° north to 68° 30' north and about 5° east to 2° west (Fig. 2). The area was first investigated by an exploratory survey to map the distribution of herring. Tracking of schools for quantification of migration behaviour and school dynamics was then conducted along a southward transect along 0° starting at about 68° north, and along a westward transect along about 67° north starting at about 0° to 1° 20' west.

Methods

The surveys were conducted by R/V "G.O. Sars" (70 m LOA, 1663 GRT). Continuous acoustic recordings of fish and plankton were made by a calibrated echo integration unit consisting of a 38 kHz Simrad EK500 (Bodholdt et al., 1989) working at a range of 0 - 500 m. A 95 kHz Simrad SA950 sonar (Misund et al., 1995) connected to a computer with real time school detection software was used to record and to track selected schools in the study areas (Misund et al., 1994).

To record migration behaviour and school dynamics, selected schools were tracked for up to about one hour. The schools were then continously recorded by the sonar system, and the vessel manouvered carefully to keep the school within a distanse of 100 - 300 m. In April 1996, accurate position of the vessel was obtained from a Starfix differential global positioning system. The migration speed and direction of the schools was calculated by procedures written in the SAS software (Misund et al., 1996). The dynamics of the schools were noted continously by a rapporteur in cooperation with a sonar operator, both watching the sonar display. These observations will be reported elsewere.

Acoustic recordings of fish were identified by use of the Åkra-trawl (Valdemarsen and Misund, 1994), which has a vertical opening of about 30 m. By ordinary rigging the trawl can be used to catch deep recordings, but the trawl can also be rerigged to catch recordings near the surface.

Plankton was sampled in 4 to 8 discrete depths by a MOCNESS sampler in oblique tows starting from 200 m, 400 m or 700 m depth. Temperature, salinity, light absorption, and fluorescence were monitored by a CTD sonde up to 500 m depth. In addition, temperature, salinity, and fluorescence were monitored continuously from an inlet at 5 m depth in the hull of the vessel. In this paper, the swimming behaviour of the schools will be analyzed in relation to the temperature distribution only.

Temperature distribution

In April 1995 there were clear horizontal and vertical gradients in the sea temperature in the study area. At surface the temperature was about 6.4^{o} C around 2^{o} east, dropping to about 5^{o} C around 0^{o} ,and further to about 3^{o} C at around 2^{o} west. At 300 m depth the temperature dropped generally by about 0.5^{o} C - 3^{o} C compared to that at surface, and was about 5.7^{o} C at around 2^{o} east, and about 2.0^{o} C at 0^{o} and further west to 2^{o} west (Fig. 3).

In April 1996 there was a similar decline horizontally in the surface temperature from east to west as the previous year, and aslo vertically from surface to 300 m depth. That at 300 m showed a 'tongue' of warmer water intruding the cooler Artic water extending from northeast to southwest (Fig. 3).

Herring distribution and migration

In April 1995 herring schools were recorded all over the study area between 66° - 68° north, 02° west to 02° east (Fig. 1). The herring were from 21 to 38.5 cm in length, and from 4 - 12 years old. During daytime the herring occured in large schools at 300 - 400 m depth, and at night the herring were found in distinct schools or dense shoals from surface to about 100 m depth (Fig. 4). 28 schools were tracked from about 5 to 65 min, and the horizontal speed varied from 0.51 m s^{-1} to 1.52 m s^{-1} (average 0.82 m s^{-1}, SD = 0.26 m s^{-1}). The horizontal speed of the schools was faster the higher the prevailing sea temperature in the range 1.0° C to 6.3° C ($r = 0.57$, $p < 0.05$). Some schools were swimming in rather straight tracks, other changed heading frequently, and a few were circling around. Most schools (6 out of 10) around 2° east showed a clear western migration, while most schools (12 out of 18) west of 1° east showed a clear south eastern migration (Fig. 1). The average migration direction for the schools tracked was 174°, and the average migration speed in that direction was 0.15 m s^{-1}. There was no significant correlation between the northwards migration component of the schools and the prevailing sea temperature in the range 1.0° C to 6.3° C ($r = 0.14$, $p > 0.05$), but the eastwards migration component of the schools was negatively correlated to the prevailing sea temperature in the range 1.0° C to 6.3° C ($r = -0.67$, $p < 0.05$).

In April 1996 herring were recorded across the continental slope from 66° north to 67° north, along 67° north to 1° 20' west, along 68° north between 0° and 3° 30' east, and between 68° north and 66° 40' north and 0° and 1° 20' west (Fig. 2). The herring were from 21 to 39.5 cm in length (average = 28.5 cm, SE = 3.0 cm), and were from 3 to 13 years old. As in the pervious year the herring were schooling at 300 - 400 m depth during daytime, and at night the herring rose to the surface and occurred both in distinct schools or dense shoals (Fig. 4). 25 schools were tracked for 4.2 - 121.8 min in an area between 66° 53' north to 68° 06' north and 0° 22' east to 1° 11' west. 16 of the schools were tracked for more than one hour. The horizontal speed of the schools varied from 0.45 m s^{-1} to 1.51 m s^{-1} (average 0.94 m s^{-1}, SD = 0.28 m s^{-1}). In contrast to the previous year, the horizontal speed of the schools was not correlated to the prevailing sea temperature in the range 1.0° C to 5.7° C ($r = 0.27$, $p > 0.05$). The swimming pattern varied from rather straight tracks, to frequent sideways turns, and even circling around. The migration speed of the schools therefore varied from 0.05 m s^{-1} to 1.34 m s^{-1}. North of 67° 70' north most schools were heading east (7 out of 13), but south of 67° 70' north most schools were heading south (7 out of 12). The average migration speed of the schools tracked was 0.10 m s^{-1} in an average direction of 165°. There was no significant correlation neigther between the northern migration component of the schools and the prevailing sea temperature in the range 1.0° C to 5.7° C ($r = 0.36$, $p > 0.05$), nor between the eastern migration component of the schools and the prevailing sea temperature in the range 1.0° C to 5.7° C ($r = 0.06$, $p > 0.05$).

Most tracked schools were rather large. However, estimation of school size was not attempted because the schools occuring at great depth were tracked by operating the sonar with a tilt angle > -45°, and reliable measurment of school area thus not possible. Likewise the area backscattering strength obtained from the deep schools when recording them by the echo integration unit was about one order of magnitude lower than that expected from the size of the schools on the echogram. In many cases the vertical extent of the schools was more than 50 m.

Discussion

The herring migrate towards and along the cold front in the Norwegian Sea in large, dense schools at 300 - 400 m depth during daytime, and rise to the surface and scatter or remain in dense aggregations at night. Both the large school size and the great swimming depth in daytime may indicate that the herring try to minimize the predation risk (Fernø et al., 1996). At such great depths the herring are probably out of the effective feeding depth of fin whales that were frequently observed in the study areas. The formation of large schools enhance the migration precision (Larkins and Walton, 1964), and there is possibly an hydrodynamic advantage by swimming close to other individuals in school (Abrahams and Colgan, 1985).

MOCNESS-sampels of plankton in the actual areas show that the prey organisms most relevant for herring were most abundant at 200 - 400 m depth (Dalpadado et al., 1996). By swimming at great depth the herring thereby also increase the probability of encounter prey patches. In fact, stomach samples indicate that the herring has been feeding at the migration depths of 300 - 400 m.

The absolute speed of the herring schools indicate a swimming speed of about 3 bodylengths s^{-1} which is within the limit of the sustained swimming speed for herring (Viedeler and Wardle, 1991). The average migration speed was about 0.10 - 0.15 m s^{-1} because the schools were not swimming in straigth tracks, but made frequent side to side movements and even turns. This may indicate that the herring migration is influence by oceanographic cues as food availability, sea temperature, and current, and that the sideways movements can be explained by search for directional gradients in such cues. The change of swimming direction may occur through the synchrokinesis in which the individuals at the perimeter of the school first become aware of unfavourable conditions and increase the speed and turn slightly untill the whole school has changed to a more favourable heading (Kils, 1986).

When entering the front areas, the herring were exposed to clear east - west gradients in the prevailing sea temperature of about 2° C in the different depth layers. Similarly, during the diurnal vertical migrations in the front areas, the herring faced temperature gradients in the range of about 0.5° C - 3° C. Having arrived in the western, colder part of the front areas, most schools were migrating southwards along the front. This indicate that the low sea temperatures in these areas has forced a shift in the migration of herring from a westwards to a southwards heading. No schools were recorded in areas with prevailing sea temperature lower than 1° C. Probably, this indicate that there exists a temperature barriere which the herring do not cross at this time of the year. However, the temperature tolerance of the herring can probably change with the season, as herring were recorded in areas with pervailing sea tempertaure down to about 0° C when crossing the cold front on the migrations to the feeding areas north of Iceland in the sixties (Østvedt, 1965).

In 1995 there were clear correlations between the horizontal speed, the eastwards migration component, and the prevailing sea temperature. These correlations were not present in the 1996 recordings, but that year the front structure in the area studied was rather complicated by the intrusion of a warmer 'tongue' into the western colder part of the front. Our recordings therefore indicate that the prevailing sea temperature in the cold front in the Norwegian Sea influence the migration behaviour of the herring, and that the herring seem to avoid prevailing sea temperature lower than 1° C in early April. However, the inconsistency in the correlations between prevailing sea temperature and the recorded swimming behaviour between the two years indicate that there must also exist other cues as food availability and current which also influence the herring migrations in the cold front areas in the Norwegian Sea

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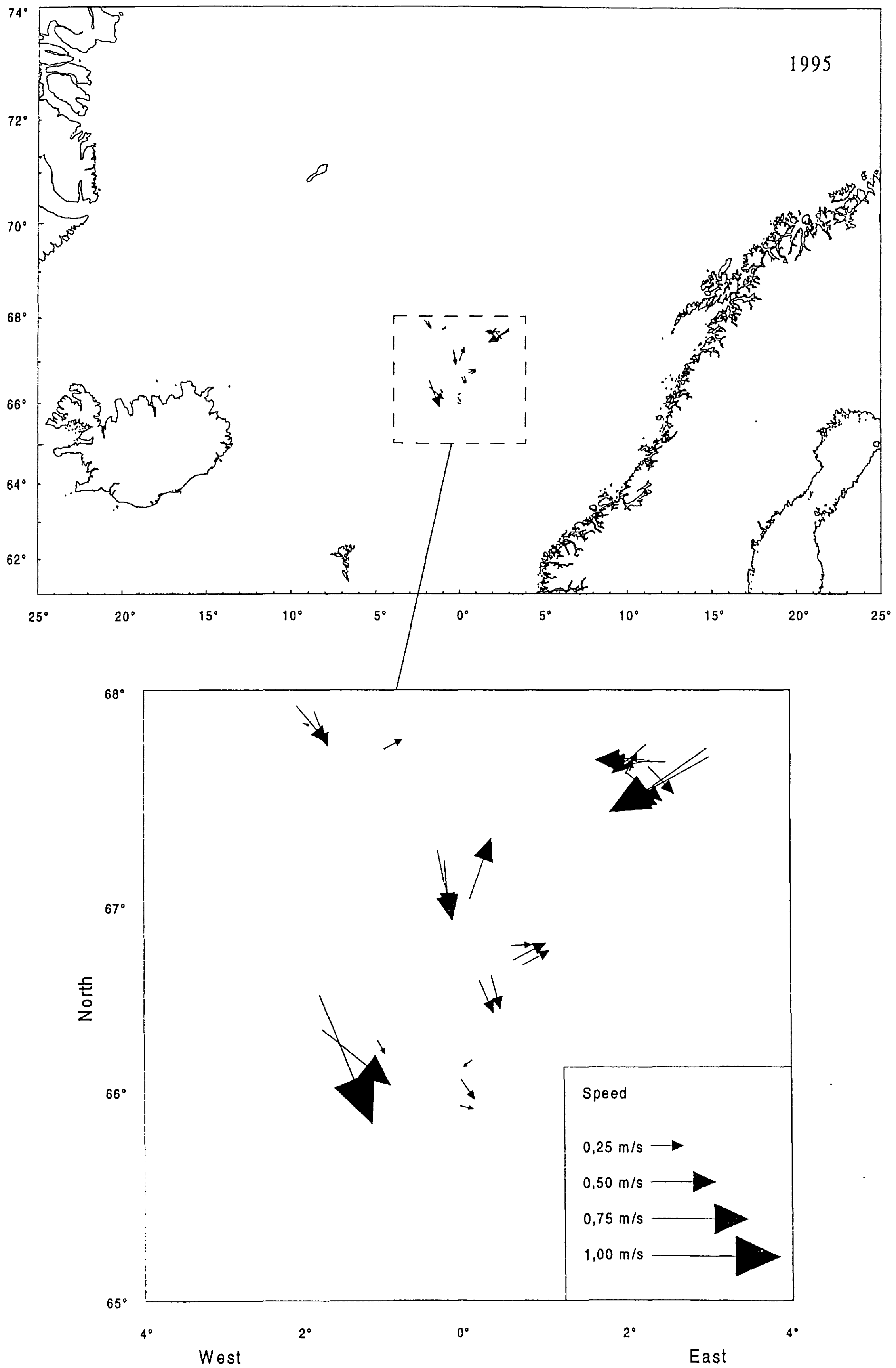

Figure 1. Study area (upper) and migration vectors (lower) of herring schools tracked for 5 - 65 min in April 1995.

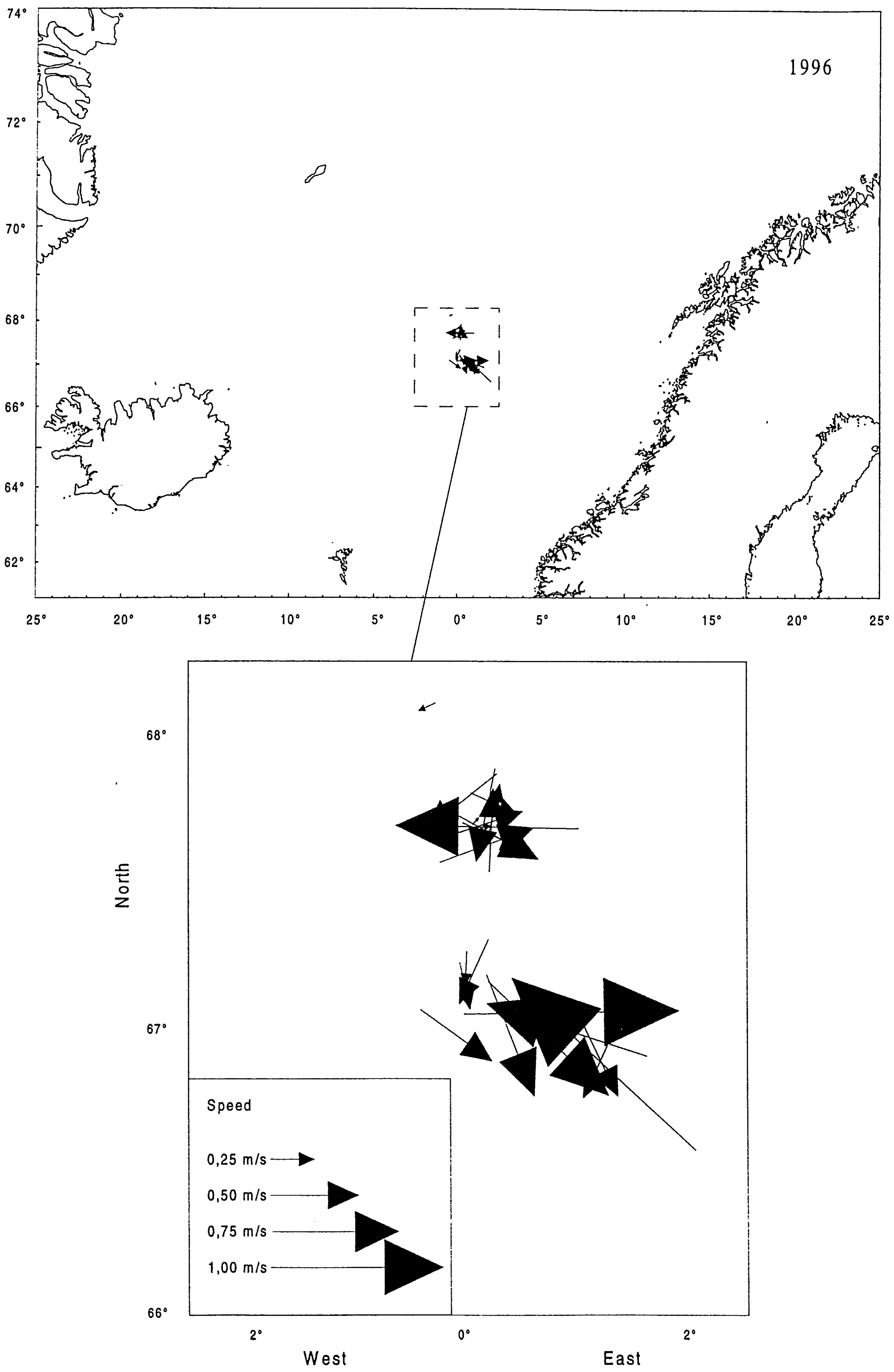

Figure 2. Study area (upper) and migration vectors (lower) of herring schools tracked for 4.2 - 121.8 min in April 1996.

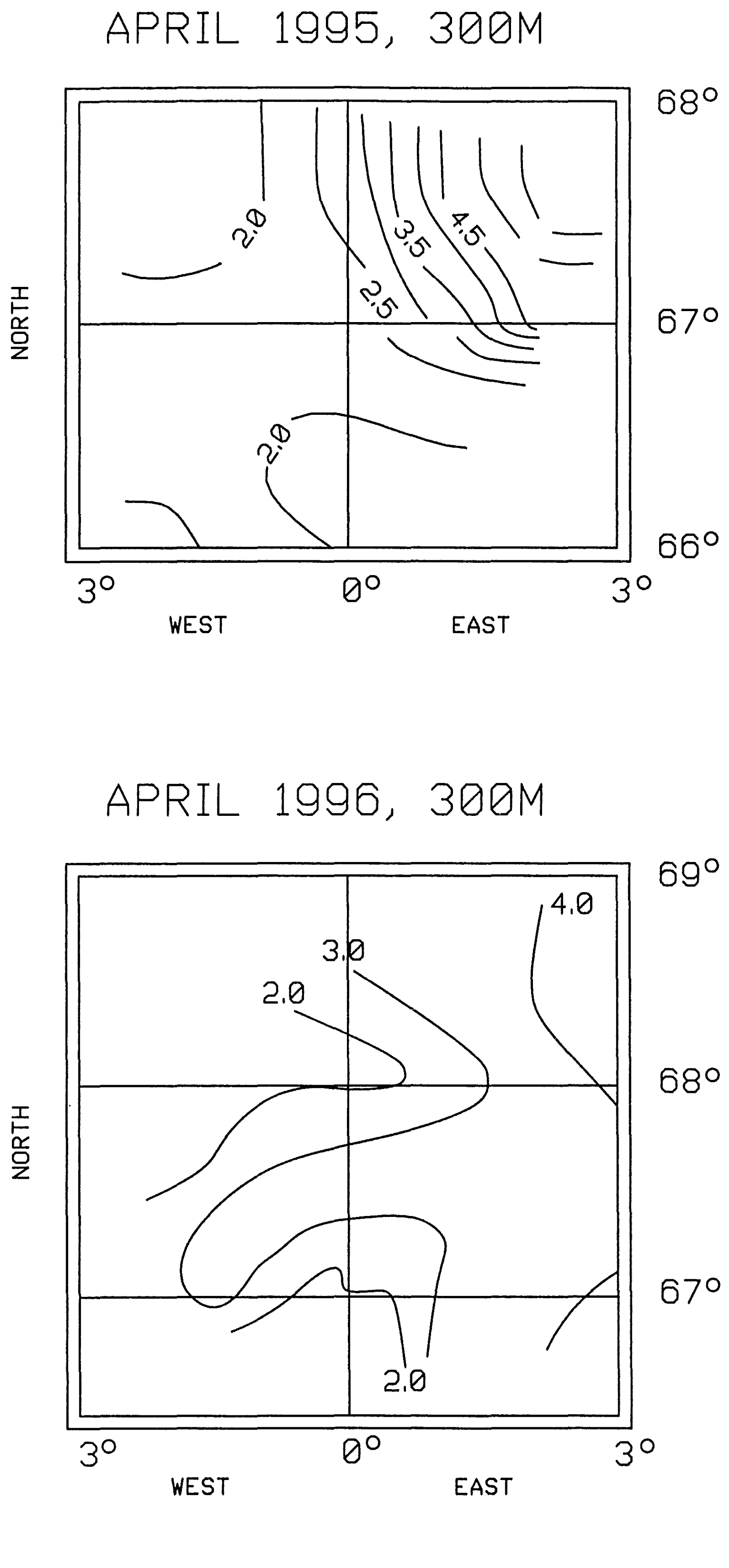

Figure 3. Temperature distribution in 300 m depth in the study areas in April 1995 (upper) and April 1996 (lower).

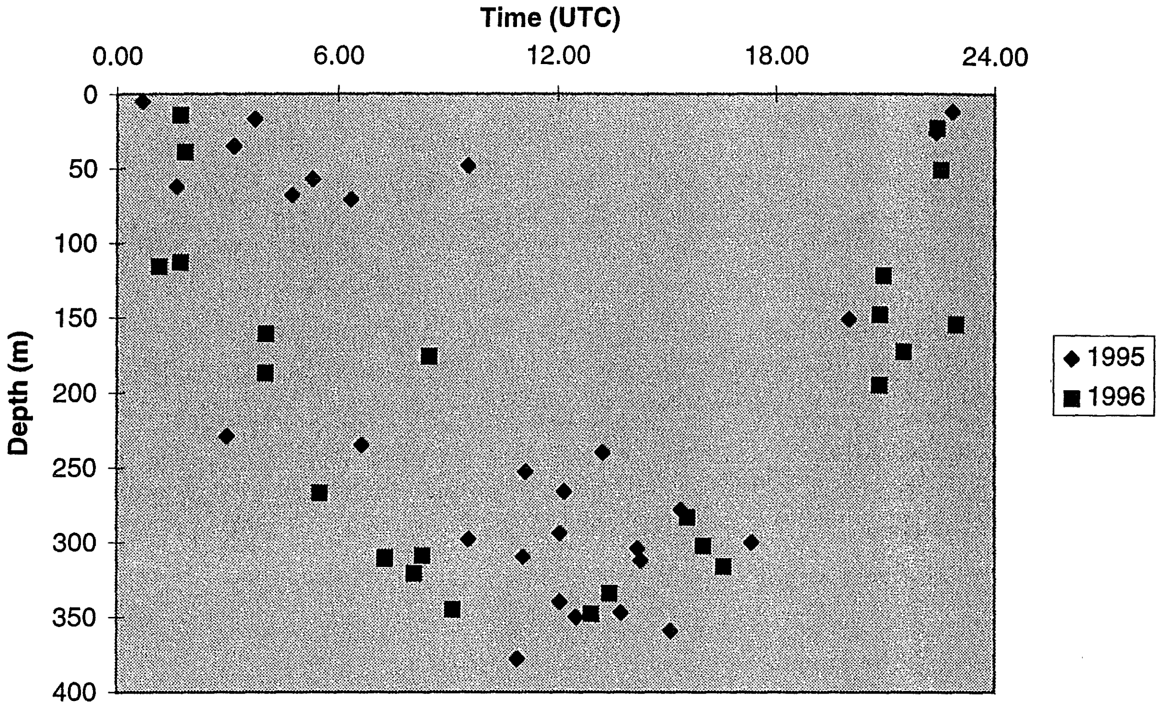

Figure 4. Vertical distribution of herring schools tracked in April 1995 and 1996 related to time of day.