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PATTERNS OF AGGREGATION IN NORWEGIAN SPRING SPAWNING HERRING (*CLUPEA HARENGUS* L.) DURING THE SPAWNING SEASON

by

Aril Slotte

ABSTRACT

Presently the Norwegian spring spawning herring utilises spawning grounds along the Norwegian coast from Lofoten in the north (69°N) to Lista in the south (57°N), and the spawning migration originates from the wintering area in Vestfjorden, northern Norway (68°N), in mid January. This paper is based on acoustical data of herring collected during the spawning season (February-March) in the 1990s. The herring occurred in different types of aggregations influenced by the stage of maturity (maturing, ripe, spawning, spent) and by external factors like ambient illumination (daylight/darkness), fish density within the area and bottom depth. Different aggregation patterns were also observed to the north and south of 62°N. The behavioural mechanisms leading to the differences in aggregation are discussed.

Keywords: aggregation, bottom depth, darkness, daylight, maturity.

Aril Slotte: Institute of Marine Research, P.O.Box 1870, N-5024 Bergen, Norway [tel: +47 55238500, fax: +47 55238600, e-mail: aril@imr.no].

INTRODUCTION

In recent years the Norwegian spring spawning herring has recovered to an estimated biomass of approximately 10 millions tonnes in 1997 (ICES. 1998). Presently this stock covers a large part of the Norwegian Sea during the feeding period (April-August), whereas the wintering period (September-January) is spent in Vestfjorden, Ofotfjorden and Tysfjorden, northern Norway (see Fig. 1) (Dragesund et al., 1997). The spawning migration commences in mid January and during February-March the stock distributes at spawning grounds from Lofoten (69°N) in the north to Lista (58°N) in the south, a range of approximately 1500 km (Johannessen et al., 1995; Dragesund et al., 1997; Slotte and Johannessen, 1997; Slotte and Dommasnes, 1998).

According to Pitcher and Parrish (1993) fish may aggregate in "shoals" or "schools", which is synonymous with the "social aggregations" and "polarised schools" definitions introduced by Norris and Schilt (1988). By definitions shoals are groups of fish that remain together for social reasons, whereas synchronised and polarised swimming groups are termed schools. Pitcher and Parrish (1993) reviews the hydrodynamic, antipredator and foraging functions of shoaling, and they emphasise that the proximate keys to understanding fish shoals are predators and food. In addition, the behaviour and patterns of fish aggregations is influenced by ambient illumination (daylight/darkness) (Helfman, 1993).

In recent years acoustical records of Norwegian spring spawning herring in February-March have been utilised in estimates of abundance by the Institute of Marine Research (IMR). During these surveys the herring has been recorded at all hours, at different levels of maturity and at a variety of environments from Lofoten (69°N) in the north to Lista (58°N) in the south. The aim of the present paper is to simply to categorise the different patterns of aggregations frequently occurring during the spawning season of Norwegian spring spawning herring, based upon these acoustical records collected by IMR. The main problem was to examine whether the aggregations were influenced by ambient illumination (daylight/darkness), the maturity level of the herring and geographical location.

MATERIALS AND METHODS

The present paper is based on acoustical data recorded with a 38 kHz SIMRAD EK 500 echo sounder and echo integrator during IMR's statutory research surveys in the spawning areas of Norwegian spring spawning herring in the 1990s. The different aggregation patterns occurring during the spawning season is illustrated with examples of echogram recordings (Fig. 2). In general increased density of herring is illustrated with red (pink) colour in these echograms, whereas dark areas denotes very high densities.

The aggregations shown in these echograms occur frequently for any year in herring at a given maturity level, within a given area and at a given illumination (daylight/darkness). The significance of each aggregation pattern, in terms of frequency of occurrence or distribution is not estimated, as the aim the present study simply was to categorise the aggregation patterns.

The maturity levels of the herring recorded acoustically was clarified by trawling and biological sampling using the common maturity stages (ICES. 1962). These data are, however, not presented in this paper.

RESULTS

In the spawning areas between 62°N and 69°N the herring often occurred in areas with bottom depths at 100-200 m, and the aggregation behaviour differed between daylight and darkness.

Daylight, north of 62°N (Fig. 3): The herring occurred in pelagic schools of different sizes and at varying depths, generally with high fish density (A1-A2). These pelagic schools consisted of: 1) maturing or ripe herring migrating towards the spawning grounds or 2) spent herring leaving the spawning grounds searching for food. The herring also occurred at the bottom in shoals formed as spikes (B). However, the herring was most frequently observed 10-40 m above the bottom line (C1-C6). Both the aggregations at bottom and above bottom consisted of maturing or ripe or spawning herring or a mixture of these maturity groups. When there was a low density of herring within an area, the herring occurred close to the bottom in either small and dense schools (C1-C2), or layers of low density (C5). As the density of herring increased within an area, the herring tended to form rather dense layers close to the bottom with no distinguishable schools (C3-C4, C5).

Darkness, north of 62°N (Fig. 4): During darkness the herring were recorded in pelagic layers closer to the surface regardless of maturity level or bottom depth (A4-A4). The fish density within these layers varied according to the fish density within the area. In addition herring were recorded to distribute vertically from the bottom to the upper layers of the water column (B1-B4). This type of aggregation behaviour during darkness, was only found in spawning herring. The echograms B1-B4 illustrate the specific spawning behaviour that could occur within large aggregations at the spawning grounds of Norwegian spring spawning herring. It seems that the actual spawning events occur through a movement between the upper layers and the bottom layers where the eggs are distributed. On the other hand herring with running gonads was also found to distribute only as a bottom layer during darkness.

South of 62°N the herring mainly occurred in areas with bottom depths less than 100 m. In fact at these grounds the major part of the spawning occurred at 30-70 m depths. Opposite to the aggregation patterns observed in the more deeper spawning grounds further north, the herring at the southern grounds appeared to have the same behaviour regardless of daylight and darkness.

Daylight/darkness south of 62°N (Fig. 5): Both during daylight and darkness the herring were recorded in pelagic and rather dense schools (A1-A3). These schools were not as large as those that could be observed north of 62°N (Fig. 3. A1). However, this was also maturing/ripe herring searching for a spawning location, or spent herring leaving the area. Anyway, the herring reaching the southern grounds was generally ripe at the arrival. Therefore, the major part of the herring recorded in this area was spawning. This is reflected in the observed aggregation patterns. Spawning herring were recorded as shoals forming spikes (B1-B4) or layers (C1-C3) at the bottom with high fish density. Sometimes these layers looked like carpets covering the bottom.

Darkness south of 62°N (Fig. 5): Although the major part of the herring at the southern grounds showed a similar behaviour in darkness as in daylight, there is one well documented exception. At a particular spawning location to the south of Bokn in the Karmøy area, the spawning depth exceeds 100 m. Echograms of herring spawning at these ground are given in D1-D3. Echogram D1 and D2, which are examples of the deepest part of this spawning loaction, shows herring also dispersed in pelagic layers during darkness. In echogram D3, which is an example of the shallowest part of the spawning location, there is no pelagic layer.

DISCUSSION

The present paper have demonstrated that the different types of aggregations in Norwegian spring spawning herring are influenced by the stage of maturity (maturing, ripe, spawning, spent) and external factors like ambient illumination (daylight/darkness), fish density within the area and bottom depth.

At the deepest spawning grounds north of 62°N, the herring tended to stay in dense shoals or layers close to the bottom during daylight and in more dispersed layers closer to the surface during darkness. What is the likely explanation to this observed day/night behaviour? Pitcher and Parrish (1993) emphasised that the proximate keys to understanding fish shoals are predators and food, as fish behaviour in general is influenced by the trade off between feeding/growing and avoidance of predators. In addition the feeding behaviour and antipredator behaviour generally differs between daylight and darkness (Helfman, 1993). However, the herring has only two aims during the spawning season: 1) to develop the gonads and spawn and 2) to survive until next spawning. By staying close to the bottom during daylight, it is less visible for predators. Similarly, when it occasionally migrates closer to the surface during daylight, it forms synchronised and polarised schools, which is important in predator avoidance Pitcher and Parrish (1993). On the other hand it is less understandable that it chooses to disperse closer to the surface during darkness. Certainly, the herring close to the surface is less visible for predators beneath if it occurs in rather dispersed layers, compared to dense layers. However, although it is dark, the herring is probably less visible for predators closer to the bottom. This indicates that the herring is gaining something else by migrating towards the surface at night. The herring is not gaining any energy during the spawning season, as it is not feeding. However, in the main spawning area off Møre the temperature at 50 m depth is approximately 2°C lower than that of 200 m depth during the spawning season (Aure and Østensen, 1993; Slotte and Dommasnes, 1998). Thus, by staying in colder water during the night the herring reduces the metabolic energy loss. At the time of spawning the fat content in the herring is very low (Slotte, 1996), and it is dependent upon feeding in the next months to survive until next spawning. It is therefore possible that the behaviour of the herring is aimed towards reducing the metabolic costs besides avoiding predators. This hypothesis may be supported by the fact that the herring has a similar vertical migration behaviour during the non-feeding wintering period in Vestfjorden (Foote et al. 1996).

At the shallow southern spawning grounds the herring maintained the same aggregation patterns in darkness as in daylight. The herring did not disperse closer to the surface during darkness, but stayed in touch with the bottom at all hours. The exception was herring spawning at a deeper location to the south of Bokn. Here it was observed both at the bottom, just above the bottom and as dispersed layers closer to the surface. This clearly indicates that the functions of vertical migration are reduced in shallow waters compared to deeper waters. If temperature is an important factor influencing the vertical migration behaviour, than the differences between staying at the bottom and closer to the surface is obviously less distinct at the shallow spawning grounds than at the deeper ones.

The observations of pelagic maturing/ripe schools and spent schools at all hours at the southern grounds are in agreement with detailed sonar studies on schooling behaviour in this area (Nøttestad et al. 1996). During the spawning season the herring arrive the southern grounds in schools at all hours, and they are usually ripe and ready to spawn (Johannessen et al. 1995). When the herring arrives at the spawning grounds it settles at the bottom, often vertically distributed in schools shaped like spikes. In areas with large fish densities the

herring tends to aggregate in layers at the bottom often covering large bottom areas like a carpet. After the spawning the herring aggregates into schools again and leaves the area.

At the deeper spawning grounds north of 62°N spawning herring could also be observed to distribute vertically from the bottom to the upper part of the water column during darkness, whereas maturing herring always distributed closer to the surface during these hours. Also in other fishes the day/night behaviour may change during the spawning period (Helfman, 1993). It seems that the actual spawning events during these occasions with vertical distribution from the bottom towards the surface, occurred through a movement between the upper layers and the bottom layers where the spawning products were distributed. Axelsen et al. (1998) observed a similar phenomena during school tracking of spawning herring of western Norway.

This paper does not provide any definite explanations to the aggregation patterns occurring in Norwegian spring spawning herring. There is obviously a lack of knowledge on the behavioural mechanisms leading to the observed aggregation patterns during the spawning season. Future research on this subject should include more detailed studies with use of sonar tracking. In addition there is need for a modelling approach to describe the life history consequences of the herring aggregation behaviour in relation to internal factors like energy resources and external factors like ambient light and temperature.

REFERENCES

Aure, J. and Ø. Østensen 1993. Hydrographic normals and long-term variations in Norwegian coastal waters (in Norwegian). Fisken og Havet (6).

Axelsen, B., Nøttestad, L., Fernø, A., Johannessen, A. and Misund, O. A. 1998. Await in the pelagic: herring compromising reproduction and survival within a vertically split school. ICES C. M 1998/J:19.

Dragesund, O., Johannessen, A. and Ulltang, Ø. 1997. Variation in migration and abundance of Norwegian spring spawning herring (*Clupea harengus* L.). *Sarsia* **82**, 97-105.

Foote, K. G., Ostrowski, M., Røttingen, I., Engås, A., Hansen, K. A., Hiis Hauge, K., Skeide, R., Slotte, A. and Torgersen, Ø. 1996. Acoustic abundance estimation of the stock of Norwegian spring spawning herring winter 1995-1996. ICES. C.M. 1996/H:33.

Helfman, G. S. 1993. Fish behaviour by day, night and twilight. Pb. 480-512 in Pitcher, T. J. (ed.) The Behaviour of Teleost Fishes, 2nd ed. , Croom Helm, London and Sidney.

ICES. 1998. Report of the Northern Pelagic and Blue Whiting Fisheries Working Group. ICES Council Meeting/ACFM:18.

ICES. 1962. Recommendations adopted by the Herring Commitee. Rapp. P.-V. Reun. Cons. Int. Explor. Mer. **1**: 71-73.

Johannessen, A., Slotte, A., Bergstad, O. A., Dragesund, O. and Røttingen, I. 1995. Reappearence of Norwegian spring spawning herring (*Clupea harengus* L.) at spawning grounds off southwestern Norway. In *Ecology of Fjords and Coastal Waters* (eds H. R. Skjoldal, C. Hopkins, K. E. Erikstad and H. P. Leinaas), pp 347-363.

Norris, K. S. and Schilt, C. R. 1988. Cooperative societies in three-dimensional space: on the origins of aggregations, flocks and schools with special reference to dolphins and fish. Ethol. And Sociobil. 9: 149-79.

Nøttestad, L, Aksland, M, Beltestad, A, Fernø, A, Johannessen, A, and Misund, O A (1996). Schooling dynamics of Norwegian spring spawning herring (*Clupea harengus* L.) in a coastal spawning area. *Sarsia* **80**, 277-284.

Pitcher, T. J. and Parrish, J. K. 1993. Functions of shoaling behaviour in teleosts. Pb. 364-439 in Pitcher, T. J. (ed.) The Behaviour of Teleost Fishes, 2nd ed. , Croom Helm, London and Sidney.

Slotte, A. 1996. Relations between seasonal migrations and fat content in Norwegian spring spawning herring (*Clupea harengus* L.). ICES C. M. 1996/H:11.

Slotte, A and Johannessen, A. 1997 b. Spawning of Norwegian spring spawning herring (*Clupea harengus* L.) related to geographical location and population structure. ICES C. M. 1997/CC:17.

Slotte, A. & Dommasnes, A. 1998. Distribution and abundance of Norwegian spring spawning herring during the spawning season in 1998. Fisken og Havet 5. Institute of Marine Research, P.O. Box. 1870. N-5024 Bergen, Norway.

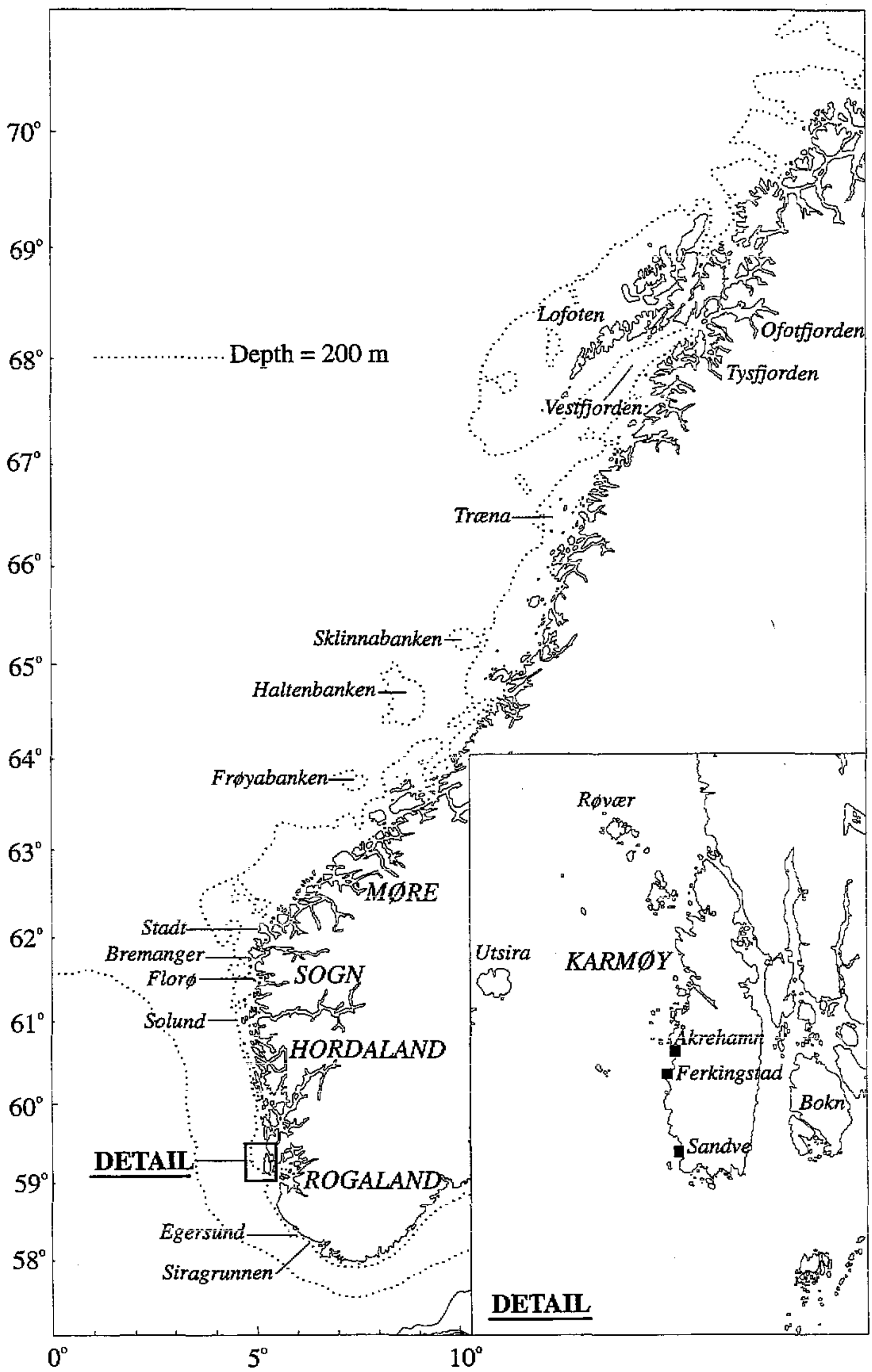
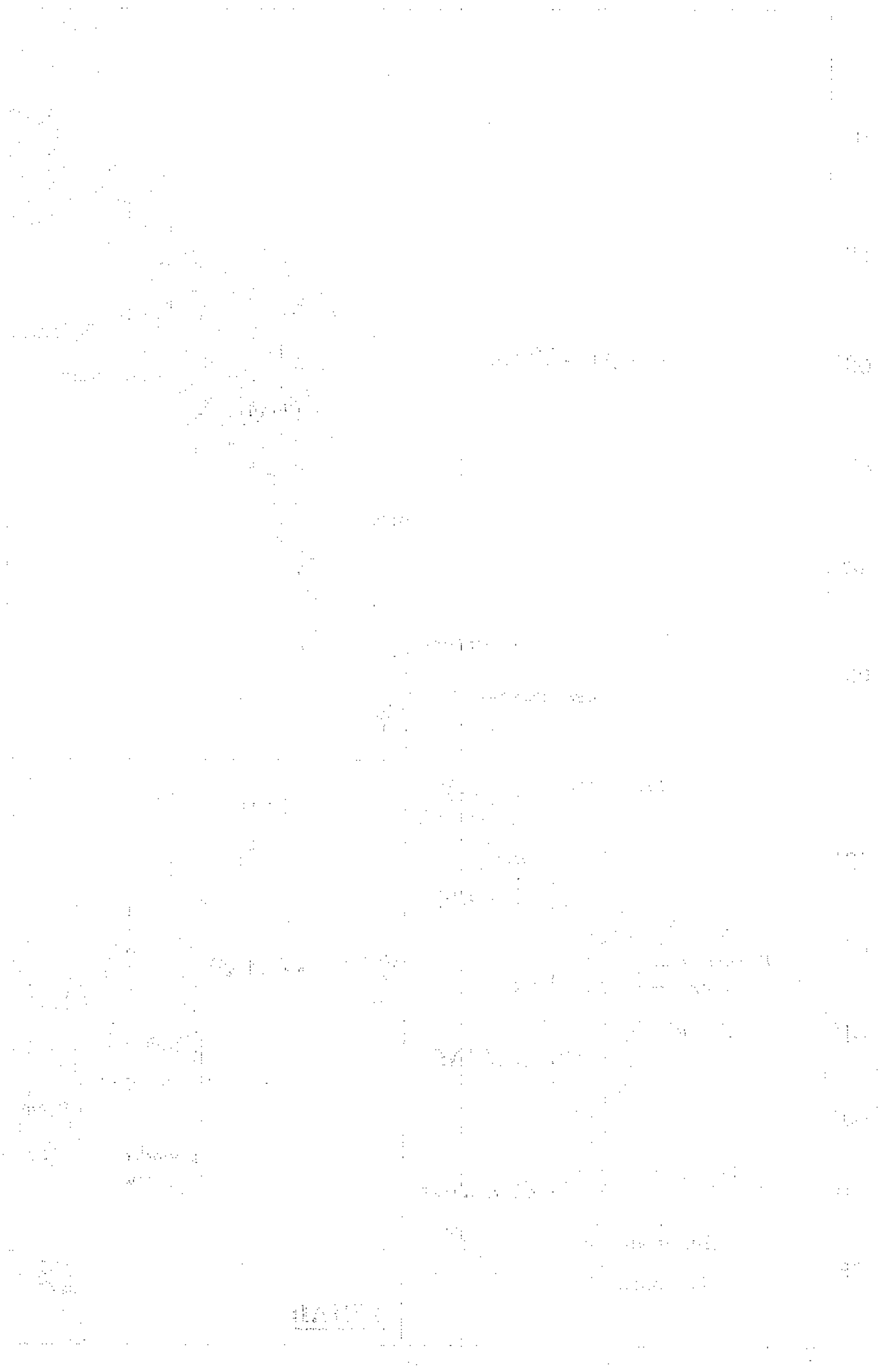


Fig. 1. Important herring districts and locations along the Norwegian coast.



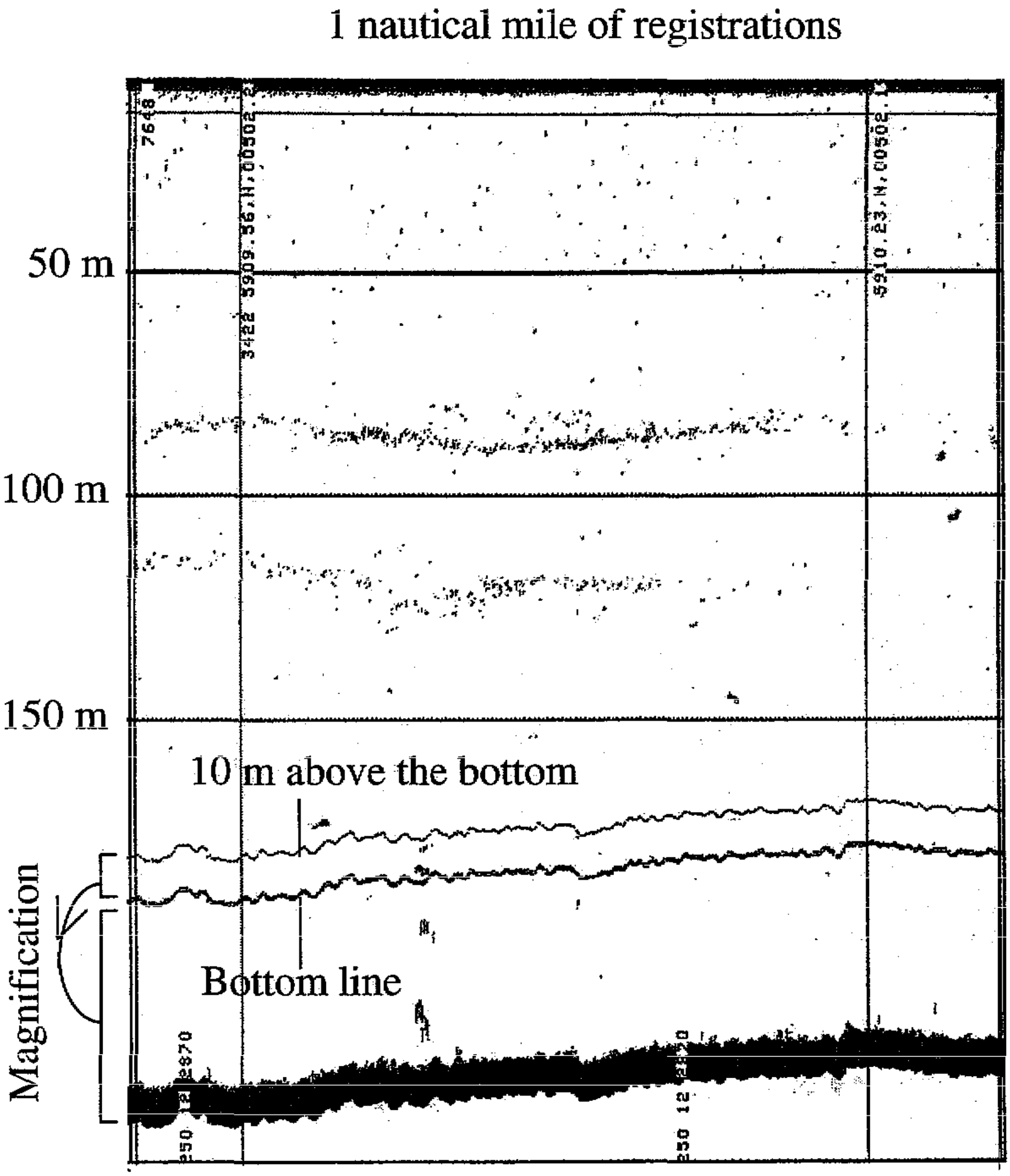


Fig. 2. Example of an echogram used in Figs. 3-5 with further information on depth lines.

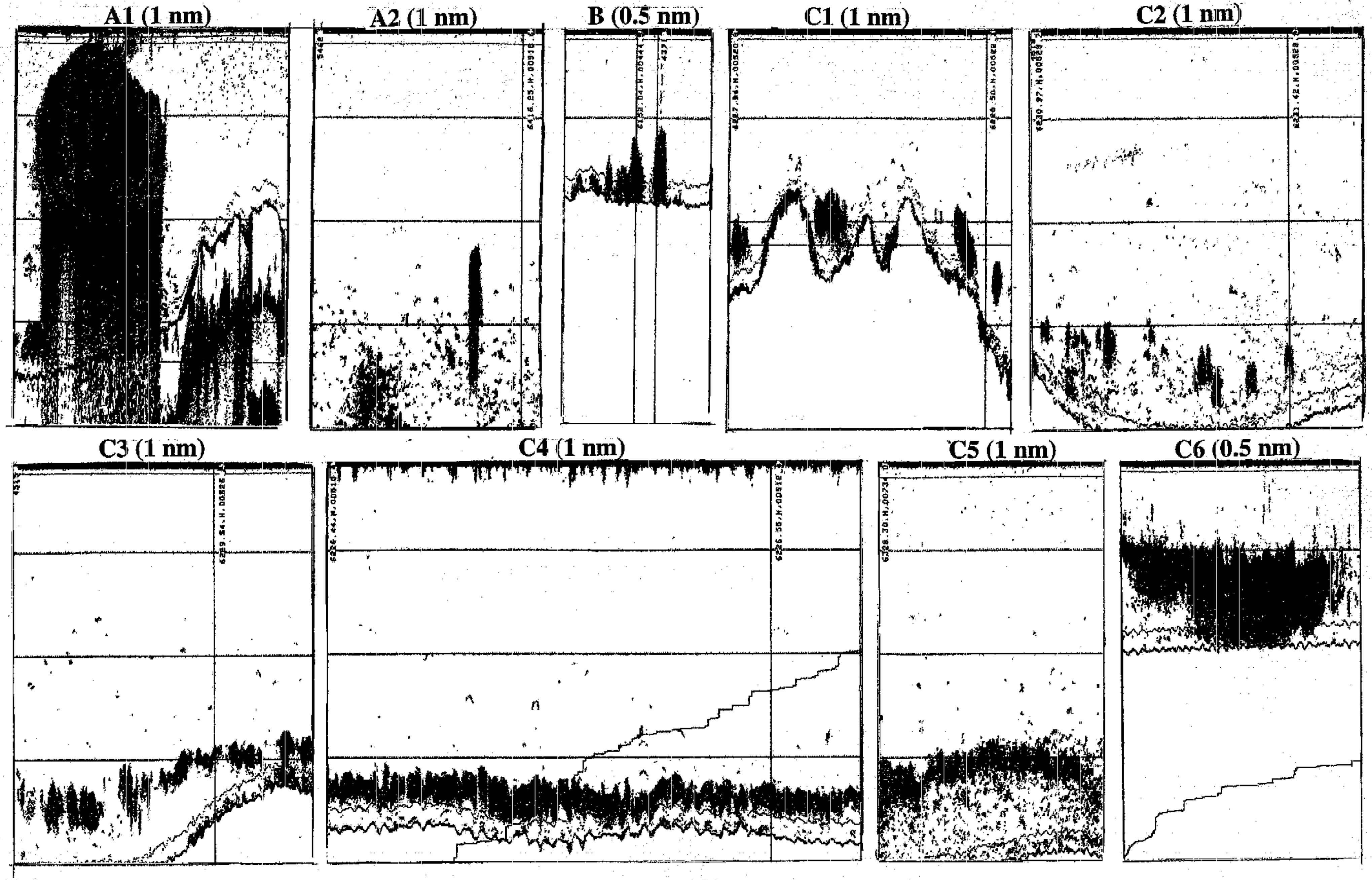


Fig. 3. General aggregation patterns in Norwegian spring spawning herring during daylight in the spawning season in areas north of 62°N. Examples of echograms showing pelagic aggregations (A1-A2), aggregations at bottom (B) and aggregations just above the bottom (C1-C6).

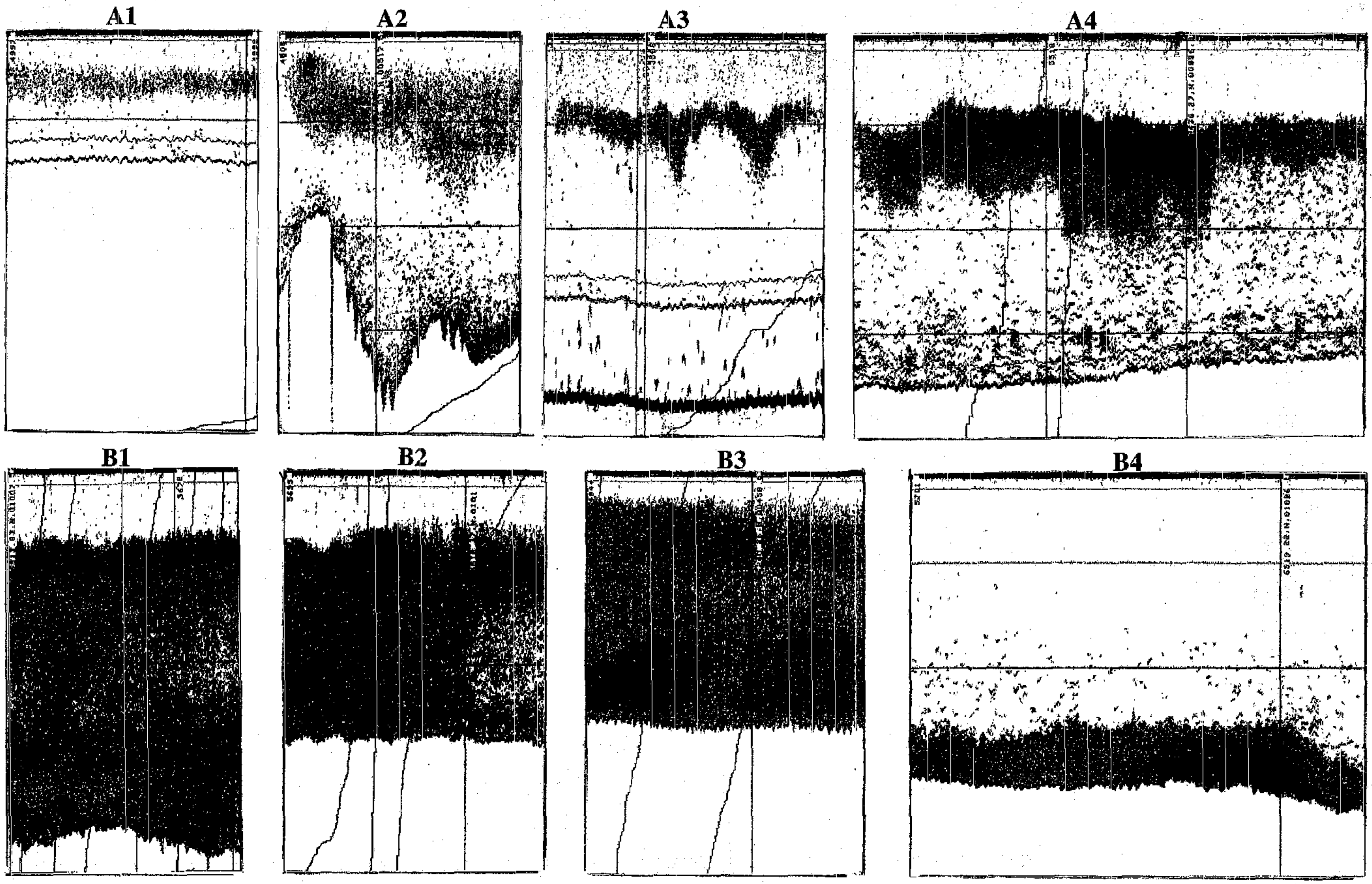
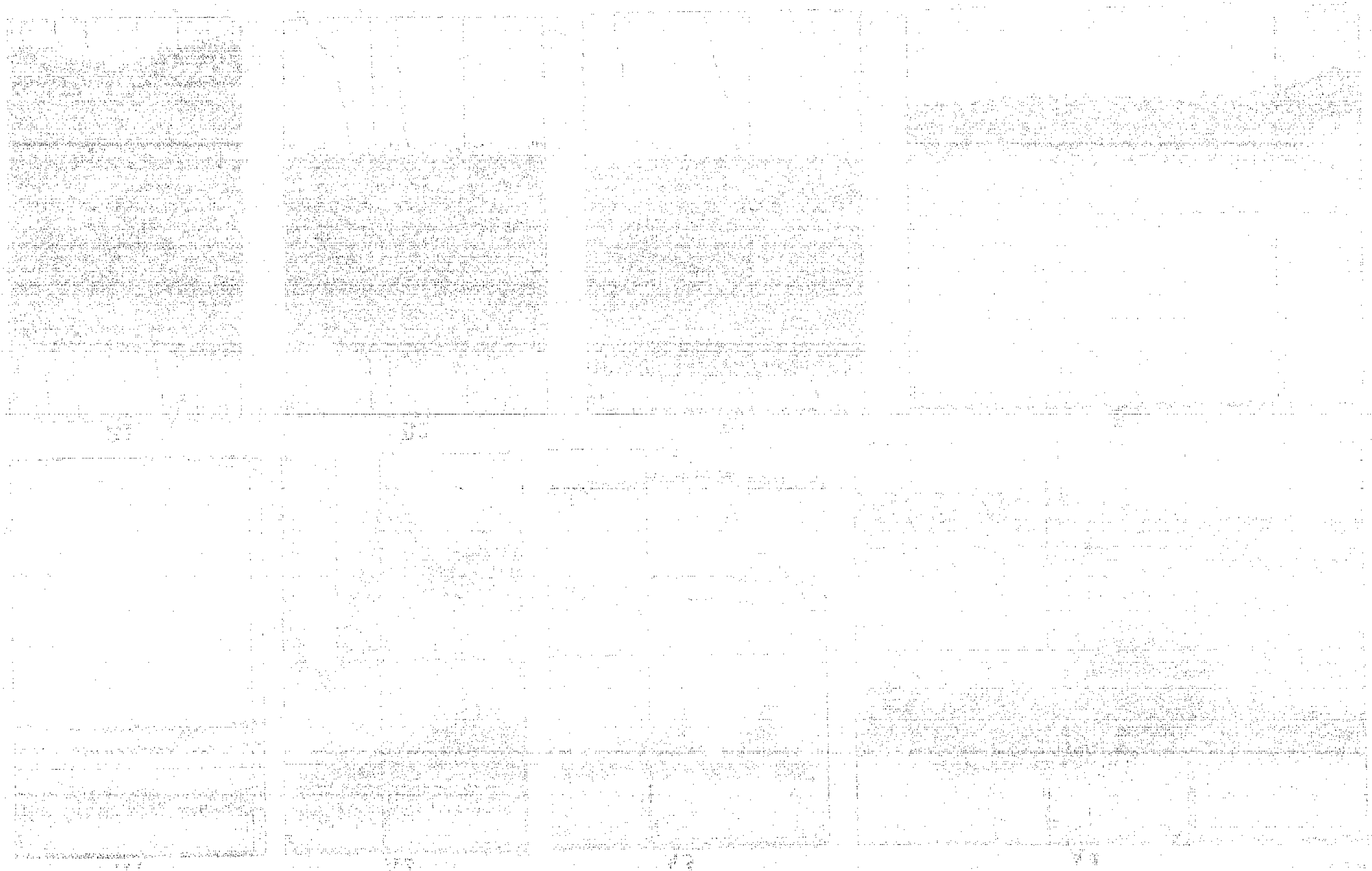


Fig. 4. General aggregation patterns in Norwegian spring spawning herring during darkness in the spawning season in areas north of 62°N. Examples of echograms showing pelagic aggregations (A1-A4) and aggregations distributed from the bottom to the upper layers of the water column (B1-B4). All echograms are recorded within 1 nm.



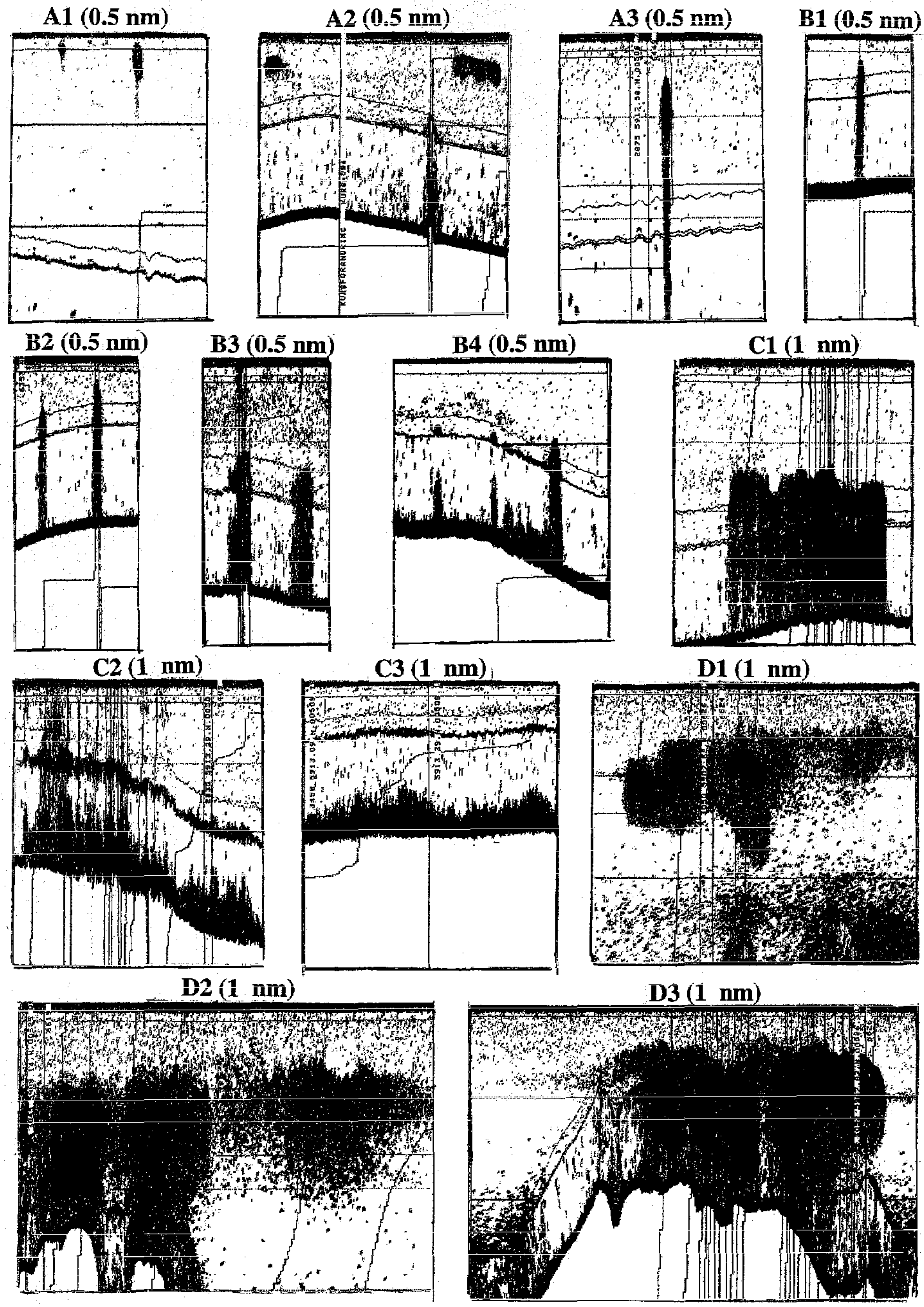


Fig. 5. General aggregation patterns in Norwegian spring spawning herring in the spawning season in areas south of 62°N. Examples of echograms showing aggregations commonly recorded both during darkness and daylight: pelagic (A1-A3), spikes (B1-B4) and layers (C1-C3) at bottom. Examples of pelagic and/or near bottom aggregations only recorded during darkness (D1-D3).