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Dynamics of wintering Norwegian spring-spawning herring at the entrance to Tysfjorden, December 1996

by

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ABSTRACT

The entrance region to Tysfjorden was acoustically surveyed a total of eleven times during the December 1996 abundance survey of the spawning stock of Norwegian spring-spawning herring (*Clupea harengus*). The observations are summarized through maps of the distribution, vertical sections, and statistical measures of acoustic density in each of two strata. Experimental variograms are modeled, yielding parameter values that summarize the major properties of aggregation. The collective measures of density and aggregation portray a highly dynamic situation with strong diel variation but a general persistence of the fish distribution over the eleven days of its repeated observation.

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INTRODUCTION

Norwegian spring spawning herring (*Clupea harengus* L.) winters in Tysfjord and two adjacent fjords in northern Norway (Røttingen et al. 1994). The stock has been acoustically surveyed while wintering, and the surveys have been combined with survey-methodology development, including both acoustic methodology (e.g. Røttingen et al. 1994) and behaviour studies pertinent to the survey situation (Huse and Ona 1996).

As the herring is not feeding during wintering, its behaviour is characterized by predator avoidance and minimized energy expenditure (Huse and Ona 1996). Still, the herring can exhibit dynamic behaviour, particularly in terms of vertical and horizontal movement. Shoals are seen to be dispersed between the surface and 400-m depth during the night, while concentrating in dense, deep schools during the daytime (Huse and Korneliussen 1995).

The present investigation addresses the dynamics of wintering herring at the entrance region of Tysfjord observed as variation in acoustic backscattering during numerous repeated surveys within a short time frame.

MATERIALS AND METHODS

The observations were carried out during the December 1996 abundance survey of the wintering stock (Foote et al. 1997). The entrance region to Tysfjorden was acoustically surveyed a total of eleven times. The survey was conducted with R/V "Johan Hjort", using an EK500 echo sounder system (Bodholt et al. 1989). The primary frequency was 38 kHz, with pulse duration 1 ms and receiver bandwidth 3.8 kHz. The pulse repetition rate was nominally about 1/s, but was modulated by the bottom depth and simultaneous recording at several frequencies. The cruising speed during surveying was about 8 knots.

The data were processed with the Bergen Echo Integrator (BEI) (Foote et al.1991), and stored with vertical resolution of 10 m and horizontal resolution of 0.1 nautical miles (NM). The data were subsequently compensated for acoustic extinction (Foote 1990), assuming that the ratio of extinction to backscattering cross sections is 2.41.

Results of echo integration are expressed through the area backscattering coefficient, denoted s_A. Mathematically, this is the integral of the extinction-compensated volume backscattering coefficient throughout the water column, assuming for simplicity the simple case of pure herring occurrence. In mixed-species situations, the numbers are apportioned according to catch data, other biological information, or more subjective criteria.

The s_A-values have been presented in four different ways: through maps of the distribution, vertical sections, tabulated statistical measures of acoustic density, and tabulated model parameters of geostatistical variograms. These are based on fitting the experimental variogram by simple models Cressie (1991). In the present case, two spherical functions with different ranges are sufficient, hence

$$\gamma(h) = A_S\, S_1(h) + (1 - A_S)\, S_2(h) \quad , \qquad (1)$$

where A_S is the amplitude of the first spherical function and $1 - A_S$ is that of the second, $0 \leq A_S \leq 1$, and

$$S(h)=1.5\ h/a - 0.5\ (h/a)^3 \quad . \qquad (2)$$

The visualizations and computations are performed for each of two strata, that describing outer Tysfjorden including the entrance region and the more southerly central region of Tysfjorden.

RESULTS AND DISCUSSION

Averaged s_A-values are presented with 0.1-NM resolution in Figs. 1 and 2 for the respective daytime and night-time surveys. The acoustic density is proportional to the circle area. The immediate impression must be that the daytime distributions are patchy, with regions of extremely high as well as vanishing density in close proximity. In contrast, the night-time distributions show a high degree of uniformity.

Vertical distributions of acoustic density provide another way of visualizing the dramatic day-and-night differences observed in Figs. 1 and 2. Examples taken from transects *T1* and *T2* indicated in Fig. 1A are presented in Figs. 3 and 4, respectively. In fact, the day-and-night differences are strong for the first transect, shown in Fig. 3, but apparently inconsistent in Fig. 4. However, only the first section in Fig. 4 qualifies as being daytime, for the second and third on the left side represent the deep-twilight period, resembling the deep night-time period represented by the three sections on the right side.

The several qualitative impressions are confirmed by the statistics of acoustic density presented in Table 1. Admittedly, the second and third daytime entries, like those in Fig. 4, include the period of deep twilight, but the division of the numbers into two distinct classes suggests the dominance of the respective lighting regimes. To be more specific, the daytime acoustic densities are of the order of 110000 and 40000 m^2/NM^2 in the two strata, while the corresponding night-time densities are 20000 and 10000 m^2/NM^2, respectively. The less pronounced diurnal effect in the southern stratum compared to that in the northern stratum may be explained by the duration of the several surveys and comparatively short period of civil twilight in the middle of the Arctic day during this winter solstice period.

Given the similarity of daytime numbers over the period 7-17 December and similarity of night-time numbers over the period 7-18 December, the long-term association of the respective daytime and night-time distributions with the entrance region is clear. If the fish quantity is assumed to be the same over the extent of the survey region, then some interesting speculations may be entertained as to the source of variation.

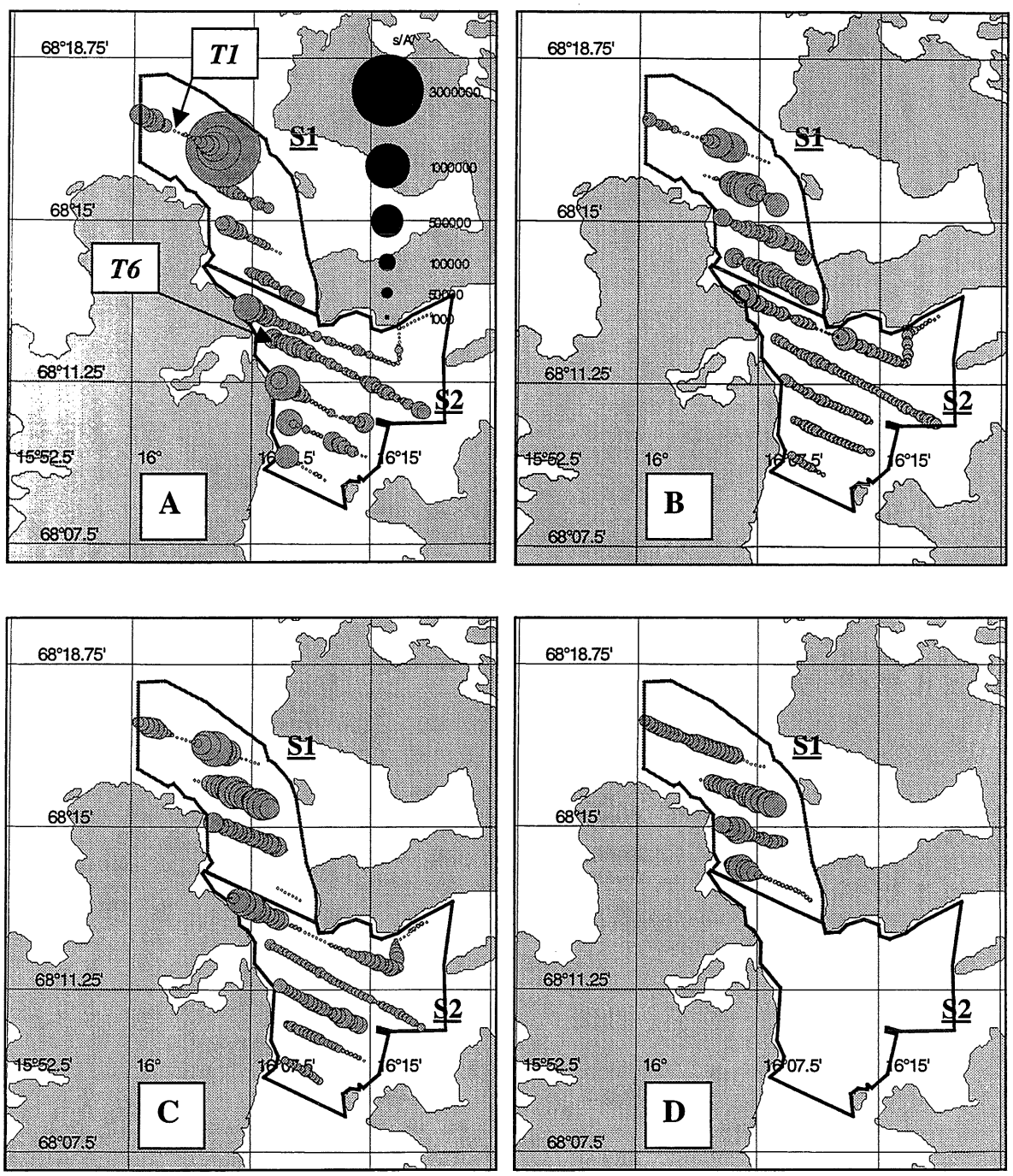

Figure 1. Acoustic density distributions of herring at the entrance to Tysfjorden during daytime according to the acoustic survey in winter 1996:

A. 7 December 1996, 0936 - 1305 UTC
B. 15 December 1996, 1139 - 1535 UTC
C. 16 December 1996, 1134 - 1457 UTC
D. 17 December 1996, 0750 - 0924 UTC

The measure of density is the area backscattering coefficient s_A, expressed in units of square meters of backscattering cross section per square nautical mile. Circle areas are proportional to the area backscattering coefficient s_A. The legend pertaining to all presented maps is shown in Panel A.

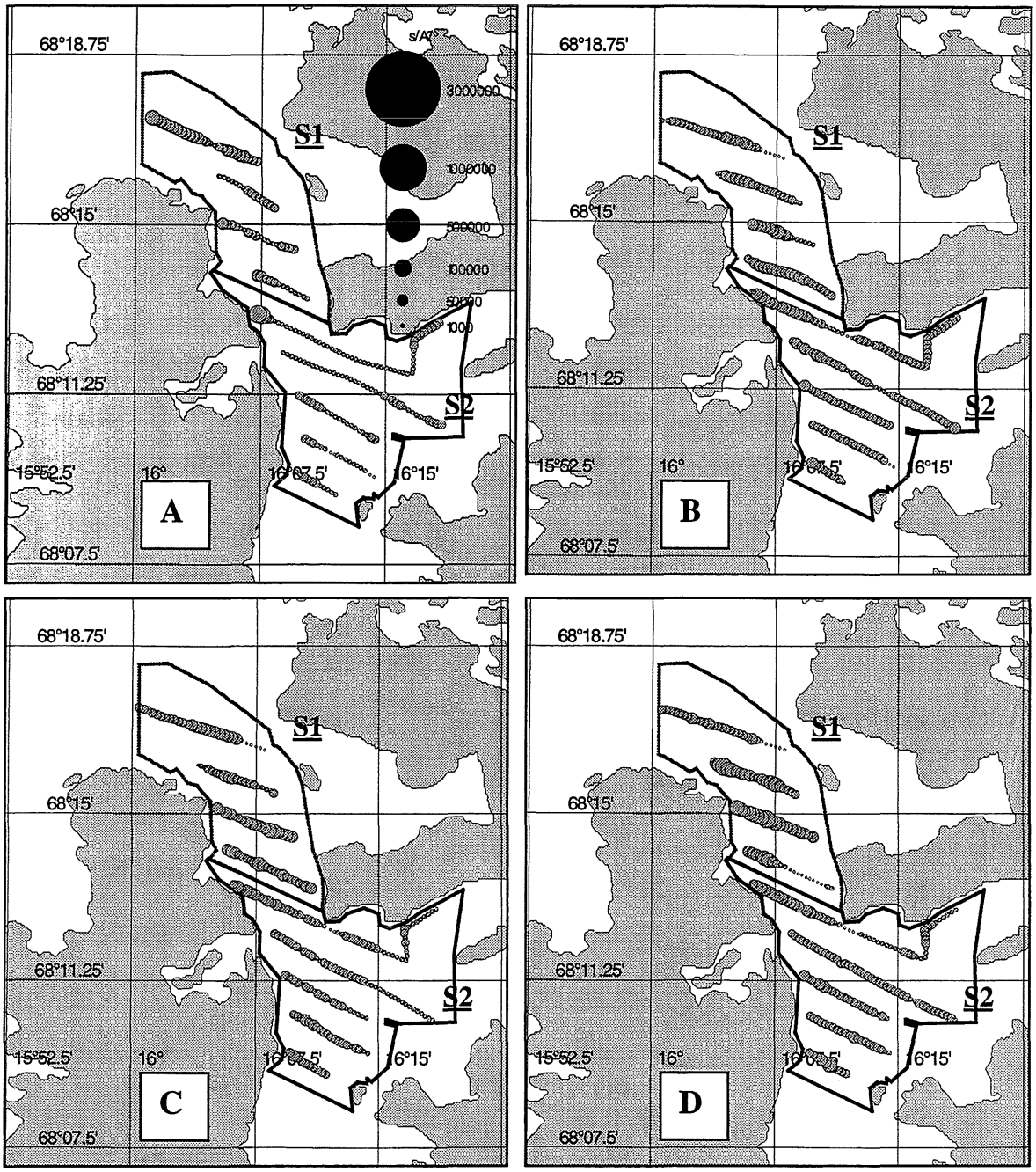

Figure 2. Acoustic density distributions of herring at the entrance to Tysfjorden during night-time according to the acoustic survey in winter 1996:

A. 8 December 1996, 0138 - 0516 UTC

B. 14 December 1996, 2044 - 15 December 1996, 0053 UTC

C. 16 December 1996, 0021 - 0348 UTC

D. 16 December 1996, 2219 - 17 December 1996, 0203 UTC

The measure of density is the area backscattering coefficient s_A, expressed in units of square meters of backscattering cross section per square nautical mile. Circle areas are proportional to the area backscattering coefficient s_A. The legend pertaining to all presented maps is shown in Panel A.

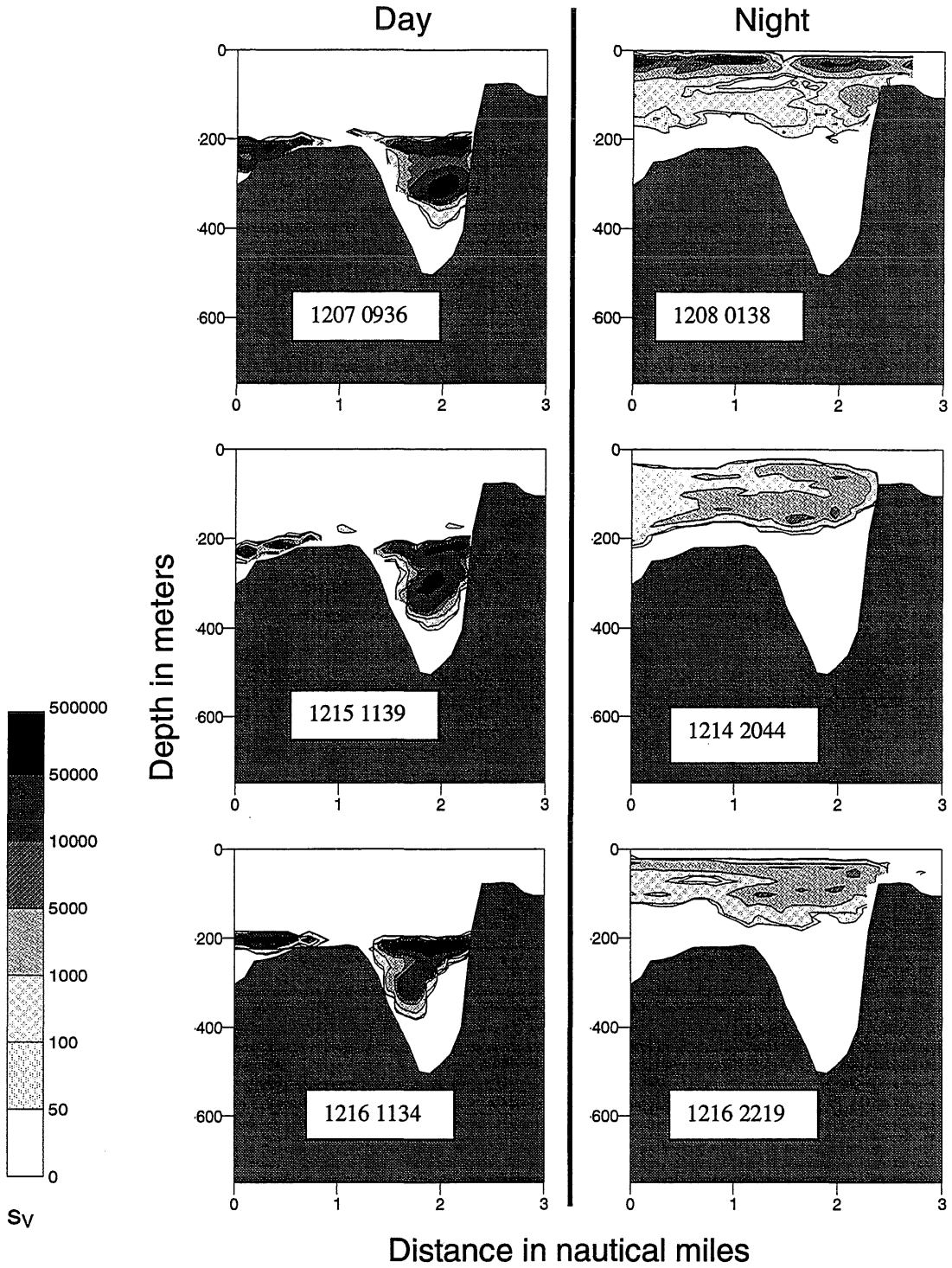

Figure 3. Comparison between daytime and nightime distributions of herring at the entrance to Tysfjorden (Transect *T1* in Figure 1A). The units of the shaded scale represent area backscattering coefficient s_A for ten-meters thick layers. Each profile is labeled by the date and hour (UTC) of the beginning of the transect.

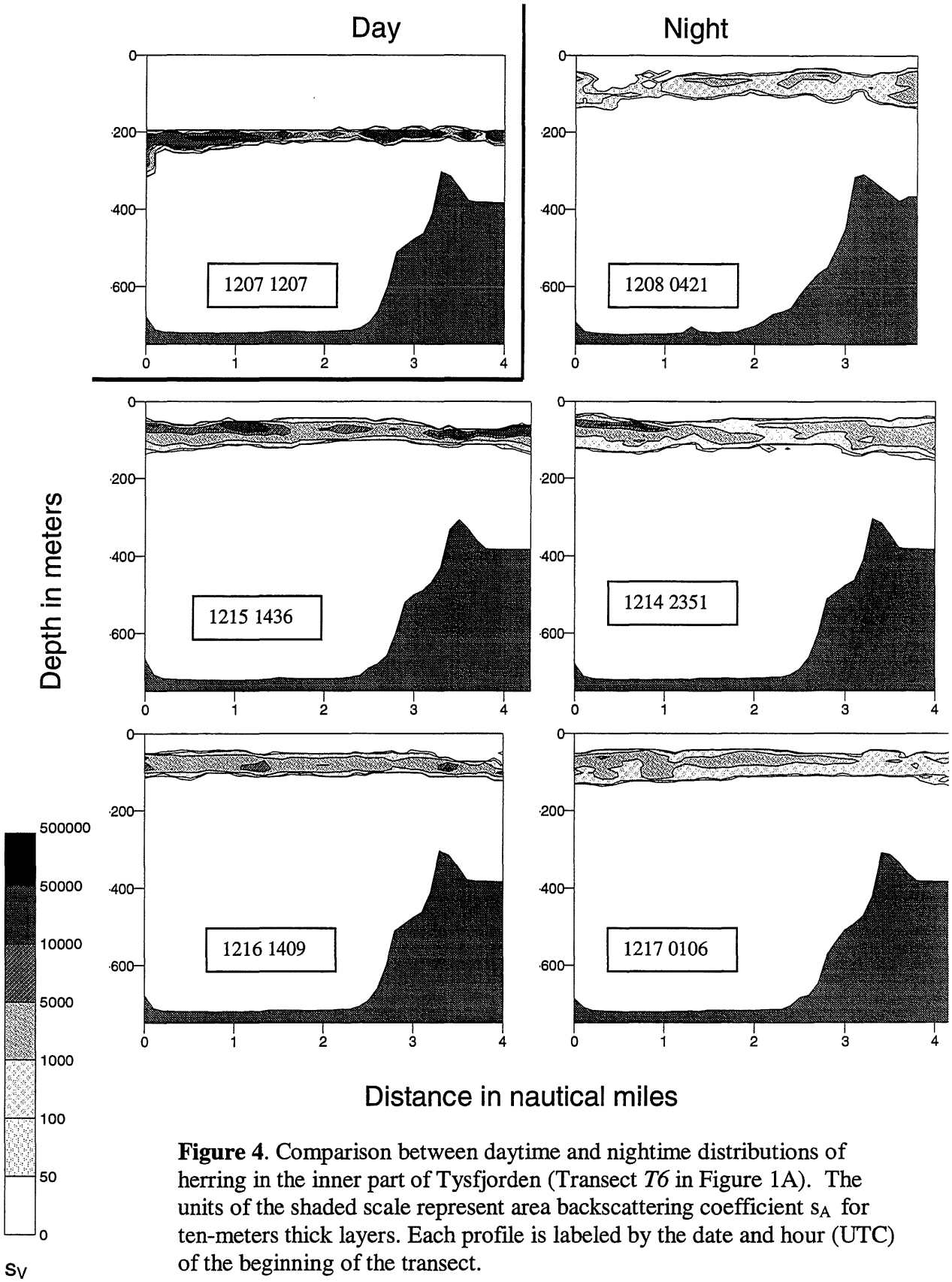

Figure 4. Comparison between daytime and nightime distributions of herring in the inner part of Tysfjorden (Transect *T6* in Figure 1A). The units of the shaded scale represent area backscattering coefficient s_A for ten-meters thick layers. Each profile is labeled by the date and hour (UTC) of the beginning of the transect.

Table 1. Summary statistics for stratum *S1* and *S2*, obtained from the 11 repetitive surveys conduced in Tysfjorden during December 1996. Day-time results are located in the upper part of the table, above the blank line. Included are the following parameters: *Av(s_A)*- mean s_A-value, *CV*- coefficient of variation and N_S - number of 0.1-nautical mile echo-integration intervals inside a stratum.

Start		*Stop*		*Stratum S1*			*Stratum S2*			*Figure*
Date	UTC	Date	UTC	Av(s_A)	CV	N_S	Av(s_A)	CV	N_S	*Ref.*
1207	0936	1207	1305	111825	3.42	75	46936	1.81	148	1A
1215	1139	1215	1535	98104	1.18	93	27678	1.19	151	1B
1216	1134	1216	1457	129296	1.14	74	39569	1.47	146	1C
1217	0750	1217	0924	91338	1.00	87	--	--	--	1D
1208	0138	1208	0516	16302	0.88	71	6102	2.32	140	2A
1208	1717	1208	2119	23700	1.49	71	7768	1.18	91	
1214	2044	1215	0053	20544	0.70	86	13464	0.63	149	2B
1216	0021	1216	0348	21113	0.69	89	9039	0.78	149	2C
1216	2219	1217	0203	29509	0.95	90	13548	0.79	152	2D
1217	2204	1218	0046	17141	1.11	86	9018	0.71	147	
1218	0113	1218	0427	18015	0.51	88	8418	0.73	142	

Table 2. Numerical values of the variogram model given by equation 1, obtained from the survey data inside stratum *S1* and *S2*. Day-time results are located in the upper part of the table.

Start		*Stop*		*Stratum S1*			*Stratum S2*			*Figure*
Date	UTC	Date	UTC	a_1	a_2	A_s	a_1	a_2	A_S	*Ref.*
1207	0936	1207	1305	0.3			0.3	1.5	0.2	1A
1215	1139	1215	1535	0.5			0.3	3.5	0.6	1B
1216	1134	1216	1457	0.7			0.8	2.8	0.5	1C
1217	0750	1217	0924	0.7			--	--	--	1D
1208	0138	1208	0516	0.6	2.8	0.4	0.3	4	0.3	2A
1208	1717	1208	2119	2.0			1.5			
1214	2044	1215	0053	0.8			1.8			2B
1216	0021	1216	0348	1.1			2.6			2C
1216	2219	1217	0203	1.2			2.4			2D
1217	2204	1218	0046	1.2			2.8			
1218	0113	1218	0427	1.1			2.3			

The two prominent and most likely contending candidates are the physical effect of depth on the swimbladder, and behavior as through avoidance-induced reaction and more general depth-related changes in orientation distribution.

The diurnal variation in acoustic backscattering from wintering herring seen in this investigation has also been detected by other authors (Huse and Kornneliussen 1995), and can have several explanations. The vertical distribution of the herring was deeper during the night than during the daytime. A decrease in acoustic backscattering during the day, due to swimbladder compression according to Boyle's law (Ona 1984, Mukai and Foote 1997), could be expected. However, this may be exceeded by more

pronounced tilt angles in deeper herring layers at night (Huse and Ona 1996), causing a reduced acoustic backscattering (Foote and Nakken 1978). Also, the shallow herring layers at night are influenced by the surveying vessel, which induces avoidance reactions in the herring (Foote 1981; Olsen et al. 1983; Olsen 1990). These avoidance reactions will modulate the herring tilt angle to reduce acoustic backscattering, as well as potentially herd the shallowly distributed herring away from the survey track. Which of the factors is more important cannot be deduced from the present material.

A further investigation of the acoustic data has been performed by means of geostatistics. Experimental variograms have been computed for each of the strata for each of the eleven survey coverages. To reduce the functions, simple models have been fit according to the equations in the methods section.

With some exceptions, the daytime and night-time distributions also show fundamentally different properties of horizontal aggregation. The daytime distributions have a consistently shorter range of aggregation than do the night-time distributions, roughly by a factor of 2-3, from about 0.3-0.7 NM to 0.8-2 NM for stratum *S1*. Similar trends are apparent in Stratum *S2*.

A single case may deserve further comment. The short-range component of the model fits using two spherical functions for the first night-time distribution shows the nugget-like influence of near-boundary patches. This is biologically consistent with earlier observations of shoreward movements of wintering herring in the same region.

As was seen in the study by Ostrowski and Foote (1996), geostatistics provides a ready means of quantifying structure. It also holds promise for automatic stratification, as to distinguish physical regions within which external phenomena may require different treatments or analyses.

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REFERENCES

Bodholt, H., Nes, H., and Solli, H. 1989. A new echo-sounder system. Proc. IOA, **11**:123-130.

Cressie, N. 1991. Statistics for spatial data. Wiley, New York. 900 pp.

Foote, K. G. 1981. Acoustic investigation of fish behaviour apropos of avoidance reaction. ICES CM 1981/B:21. 13pp. (Mimeo.).

Foote, K. G. 1990. Correcting acoustic measurements of scatterer density for extinction. J. acoust. Soc. Am. **88**: 1543-1546.

Foote, K. G., and Nakken, O. 1978. Dorsal aspect target strength functions of six fishes at two ultrasonic frequencies. Fisken Hav. Ser. B., 1978(3): 1-96.

Foote, K. G., Knudsen, H. P., Korneliussen, R. J., Nordbø, P. E., and Røang, K. 1991. Postprocessing system for echo sounder data. J. acoust. Soc. Am., **90**:37-47.

Foote, K. G., Ostrowski, M., Røttingen, I., and Slotte, A. 1997. Abundance estimation of Norwegian spring spawning herring wintering in the Vestfjord system, December 1996. ICES C.M. 1997/FF:13. 8 pp + 4 tables + 10 figs.

Huse, I. J., and Korneliussen, R. J. 1995. Diurnal variations in acoustic density measurements of wintering Norwegian spring spawning herring. ICES C.M. 1995/B:12, Ref. H. 17pp. (Mimeo.).

Huse, I. J., and Ona, E. 1996. Tilt angle distribution and swimming speed of overwintering Norwegian spring spawning herring. ICES J. mar. Sci., **53**: 863-873.

Mukai, T., and Foote, K. G. 1997. On the depth dependence of fish target strength. ICES C.M. 1997/FF:7. 15pp. (Mimeo.).

Olsen, K. 1990. Fish behaviour and acoustic sampling. Rapp. P.-v. Reun. Cons. perm. int. Explor. Mer, **189**:147-158.

Olsen, K., Angell, J., Pettersen, F., and Løvik, A. 1983. Observed fish reactions to a surveying vessel with special reference to herring, cod, capelin and polar cod. FAO Fish. Rep. **300**:131-139.

Ona, E. 1984. In situ observation of swimbladder compression in herring. ICES C.M. 1984/B:18, 15pp. (Mimeo.).

Ostrowski, M., and Foote, K. G. 1996. Acoustic portrait of herring in Vestfjord, January 1996 with geostatistical analysis. ICES C.M. 1996/H:31 12pp. (Mimeo.).

Røttingen, I., Foote, K. G., Huse, I., and Ona, E. 1994. Acoustic abundance estimation of wintering Norwegian spring spawning herring, with emphasis on methodological aspects. ICES C.M. 1994/B+D+G+H:1. 17pp. (Mimeo.).