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An evaluation of the acoustic backscatter of western Newfoundland herring with a comparison of classical statistics and geostatistics for the estimation of variance

by

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Abstract

A hydroacoustic survey was conducted aboard the *F.G. Creed* in the fall of 1995 as part of a fishery-independent index of abundance for the west coast of Newfoundland herring stocks. Systematic-parallel transects were chosen along the coast and were surveyed during night-time hours. Biological sampling was accomplished in collaboration with the western Newfoundland large purse seine fleet, which also took temperature, salinity and depth (STD) profiles. Raw volume backscatter data (Sv) from both 38 and 120 kHz transducers, as well as split-beam phase data were collected. The variances of the abundance estimates were estimated by two procedures: (1) using classical statistics and (2) using geostatistics (1-D transitive and 2-D intrinsic kridging). The survey revealed that herring concentrations were spread out along the bottom throughout several strata, similar to the distribution found in 1993. The most important concentration, over 1/3 of the total biomass, was found off New Ferrole (stratum 10). The biomass was estimated at 84,000 t, made up of 38,000 t of spring spawners and 46,000 t of autumn spawners. Using classical statistics, the coefficient of variation (CV) on the biomass estimates ranged from 22.4 to 84.5 % by strata. The estimated CV was significantly reduced using 1-D kridging, resulting in an overall CV for all strata of 16.6 %. The estimated CV of 23.9 % for stratum 10 using the 2-D kridging was also substantially lower than both the 1-D kridging (37.3 %) and the classical statistics (59.6 %).

Résumé

Un relevé hydroacoustique fut mené à bord du *F. G. Creed* à l'automne 1995, afin de produire un indice d'abondance indépendant de la pêcherie, pour les stocks de hareng de la côte Ouest de Terre-Neuve. Des transects parallèles ont été choisis de façon systématique le long de la côte et furent sondés durant la nuit. L'échantillonnage biologique fut accompli en collaboration avec la flotte des grands senneurs de l'ouest de Terre-Neuve, qui a aussi enregistré des profils de température, salinité et profondeur. Des données brutes de réverbération de volume (Sv) à partir de deux transducteurs (38 et 120 kHz) ainsi que des données de faisceaux scindés (split-beam) ont été collectées. Les variances des estimations d'abondance furent évaluées en utilisant deux procédures: (1) les statistiques classiques et (2) les géostatistiques (krigeage transitive 1-D et intrinsèque 2-D). Le relevé a démontré que les concentrations de hareng sont réparties sur le fond le long de la côte, de façon similaire à la distribution retrouvée en 1993. La concentration la plus importante, au-delà du 1/3 de la biomasse totale, fut retrouvée au large de New-Ferolle (strate 10). La biomasse fut estimée à 84,000 t, constituée de 38,000 t de frayeurs de printemps et 46,000 t de frayeurs d'automne. Utilisant les statistiques classiques, le coefficient de variation (CV) de l'estimation de biomasse s'est étendu de 22,4 à 84,5 % par strate. Pour toutes les strates, le CV estimé fut significativement réduit en utilisant le krigeage 1-D, résultant en un CV global de 16,6 %. Le CV estimé de 23,9 % pour la strate 10 en utilisant le krigeage 2-D, fut aussi substantiellement plus bas que les CV du krigeage 1-D (37,3 %) et des statistiques classiques (59,6 %).

Introduction

Since 1989, the Quebec Region of Fisheries and Oceans has conducted five hydroacoustic surveys of the herring along the west coast of Newfoundland (NAFO division 4R). The objective of this series of surveys is to develop a fishery-independent index of stock abundance for these herring stocks. This document summarises the results from the 1995 survey and discusses the accuracy and precision of the biomass estimates.

The hydroacoustic work for this survey was conducted aboard the NSC *Frederick G. Creed* from October 20 to November 2. In addition, several vessels from the west coast large purse seine fleet were directly implicated in the collection of survey data. As the Department does not presently operate a research vessel capable of adequately sampling herring given the physical conditions encountered along the west coast of Newfoundland at this time of year, the co-operation of the purse seine captains and crews was essential in the successful execution of this survey.

Material and Methods

Study Area and Design

The survey was intended to cover the entire west coast of Newfoundland (Figure 1) from Cape Anguille to the southern end of the Strait of Belle Isle within the 10 to 100 m isobaths (7200 km^2). The survey area was stratified (Figure 2) based on the major physical features (large bays) and on data on herring distribution obtained from the commercial fishery and past surveys (McQuinn and Lefebvre, 1995a). Historical fishing patterns suggest that in the late fall/early winter, the herring move to the nearshore to concentrate in large, relatively stationary schools in and around several of these bays (McQuinn and Lefebvre, 1995b). The outer limits of the strata were drawn to correspond generally to the shelf break between approximately 60 to 100 m bottom depth, beyond which few herring have been observed in the past. Only Port au Port Bay (strata 4) was not surveyed.

The orientation of the transects within each stratum was determined by drawing a baseline parallel to the coastline and selecting transects perpendicular to the line. Systematic-parallel transects were then chosen by dividing the baseline into 200 m wide units, and selecting equidistant lines among the units (Figure 2). Sampling density was designed to be more intensive in strata of suspected high fish density (5,6,8). The strata were rated either 1, 2 or 3 according to the proposed sampling intensity: strata with a rating of 2 and 3 had one half and one third, respectively, the sampling intensity of strata with a 1 rating. The total number of transects was determined by the available ship time minus 30% for down-time (poor weather, equipment failure, etc.). The transects were run during night-time hours only (17:00-07:00) to avoid day-night differences in fish availability and horizontal orientation (tilt angle). Past experience has shown that at this time of the year herring are more likely to rise off the bottom at night and to form into more or less concentrated schools, thus reducing their distribution near the sea floor where they are less distinguishable from the bottom echo, i.e. the dead zone (Mitson,1983).

Biological sampling was accomplished in collaboration with the western Newfoundland large purse seine fleet. A scientific staff was invited aboard each of four purse seiners over the two week period of the survey to take temperature, salinity and depth (STD) profiles and to collect biological samples while the staff aboard the *F.G. Creed* collected the acoustic data. The STD and sampling equipment was installed aboard each fishing vessel for a three- to four-day period. During this period, the seiner remained in close proximity (1-2 hours) to the acoustic vessel and conducted regular STD profiles. When significant quantities of fish were detected by the acoustic vessel, the seiner proceeded to the position of the school to make a set for species and size composition determinations. At times, the research purse seiner was unable to make a successful set on detected fish schools. However, in most cases, biological samples were obtained from other purse seiners, including vessels from the small purse seine fleet (< 20 m), which were fishing in close proximity.

Equipment

The echosounder used was the Simrad EK500 which powered both 38 and 120 kHz hull-mounted, split-beam transducers. Raw volume backscatter data (Sv) from both transducer frequencies, as well as split-beam phase data were stored on a Pentium PC in real-time using the Sonde software developed at the Maurice Lamontagne Institute (MLI). Sv data from the 38 kHz transducer was also stored on disk by the Femto hydroacoustic data processing system (HDPS) software. The equipment was calibrated before the survey (Table 1) using copper spheres of known target strength (60 and 23 mm for the 38 and 120 kHz transducers, respectively) and following the procedures specified by Simrad (Simrad EK500 Instruction Manual). The copper spheres were each centred in their respective beams using a computer-controlled motorized positioning system developed at MLI.

Data Analyses

Recorded echoes were edited using the Femto HDPS software to eliminate backscatter other than from herring schools (e.g. surface noise, bottom signal, other species, etc.). The species composition of some schools was unconfirmed by biological sampling because we were unable to catch them with the purse seine or there was no fishing activity in the area. In these cases, gross form and density were considered to judge whether or not they were to be included in the analyses. Most fish schools recorded were considered to be herring as very few other fish species with swim bladders were in the survey area at that time of year. Herring schools in the late fall show a relatively limited range of characteristic forms, from candle shaped, to dense domes on the bottom, to large aggregations 10's of meters thick. Although mackerel was present in the southern strata during the survey, they were not considered to add an important bias in the total backscatter due to their small target strength relative to herring (-52.8 dB versus -36.0 dB). In addition, backscatter from mackerel was relatively easy to remove from the echograms as the mackerel formations in general did not resemble herring schools and no mackerel were captured in our research sets.

Estimates of area backscatter and stock biomass were calculated following the procedures and equations recommended by the CAFSAC pelagic subcommittee (O'Boyle and Atkinson 1989). However, the variances of the abundance estimates were estimated by two procedures: (1) using classical statistics as outlined by O'Boyle and Atkinson (1989) and (2) using geostatistics (1-D transitive and 2-D intrinsic kridging) following the methods of Petitgas (1993). Although the application of classical statistics to a systematic-stratified survey design may lead to a bias in the strata variance estimates, the calculations were made none-the-less to compare with the geostatistical methods. The 1-D kridging method used biomass density estimates summed along each transect and calculated experimental variograms from these cumulated data. The 2-D method used individual density values along the transects, averaged into 250 m elementary sampling distance units (ESDU).

The conversion of backscatter to biomass was accomplished using target strength estimates per unit length determined from the equation suggested by Foote (1987) for clupeoids:

$$TS_{cm} = 20 \log L - 71.9 \qquad (1)$$

where L is the mean total fish length (cm), and converted to target strength per unit weight:

$$TS_{kg} = TS_{cm} + 10 \log W^{-1}$$

where W is the mean fish weight (kg). The mean lengths and weights were calculated for each transect from the samples most closely associated with each school. Total biomass of spring and autumn spawners was calculated using an estimate of the percent weight of each spawning stock corresponding to each sample (Table 2).

Equation 1 is a general algorithm applicable for all clupeoids but does not consider the effects of several factors such as fish behaviour (e.g. tilt angle), physiology and depth on the parameters (Ona 1990). As such, the TS values estimated from this equation should be considered as approximations. Although certain measures were taken to reduce interannual variability in TS (surveying at night only, conducting the survey at the same time of year), there may still be inherent biases from the general formula due to the local conditions in 4R which affect the aforementioned factors.

Results

Distribution

The 1995 herring acoustic survey revealed that herring concentrations were spread out along the bottom throughout several strata (Figure 3), similar to the distribution found in 1993 (McQuinn and Lefebvre, 1995a). Few herring were seen in the southern strata, i.e. St. George's Bay, although some fishing activity was occurring in these strata during the survey, and some herring backscatter was observed in between survey transects. Significant concentrations were recorded off Long Point (stratum 3), south of Bear Head and off Bay of Islands (stratum 5), along Bonne Bay Bank (stratum 6), west of Table Point (stratum 9) and in St. John Bay (stratum 10). However, the most important concentration, over 1/3 of the total biomass (Table 3), was found off New Ferrole (stratum 10) at the outer end of two predetermined transects (Figure 4). As is the general practice, recording of backscatter was extended to the end of the concentration. These fish were concentrated in a 5 to 10 m layer along the bottom over 8 km (Figure 5).

Size Composition

From the length frequency data, the large 1987 spring-spawning and 1986 autumn-spawning year-classes, observed in the Bonne Bay - Bay of Islands area (4Rb/4Rc) since 1990, have slowly been replaced by the 1989 and 1990 year-classes. The spring-spawning stock is now dominated by the 1987 and 1989 year-classes, although the 1980-1982 year-classes are still strong in the northern areas (Figure 6). In 1995, the autumn-spawning stock was comprised of numerous year-classes (1979, 1986, 1988 and 1990), although the relative strength of each varied over the survey area, with a tendency towards larger individuals towards the north (Figure 7).

Abundance Estimates

The calculated 1995 acoustic biomass estimate of 84,000 t, made up of 38,000 t of spring spawners and 46,000 t of autumn spawners (Table 4), was an increase over the 1993 estimate of 66,000 t (31,000 t of spring spawners and 35,000 t of autumn spawners). However, the 1993 estimate was considered to be low as (a) two northern strata were not surveyed due to bad weather, while fishing activity at that time confirmed the presence of herring schools in these strata and (b) some herring backscatter was not recorded due to the failure of the acquisition software to correctly save the data files (McQuinn and Lefebvre, 1995a). In 1995, 64 % of the herring biomass surveyed was in the two northern strata. The distribution of herring in the remaining strata was similar from 1993 to 1995, even though the survey was conducted three weeks earlier in 1995.

Variance Estimates

Using classical statistics, the coefficient of variation (CV) on the biomass estimates ranged from 22.4 to 84.5 % by strata (Table 4). The overall CV was 36.7 %. These estimates do not assume any spatial structure in the distribution of herring backscatter within a strata and do not take into account the spatial autocorrelation often found in herring acoustic biomass surveys (Petitgas 1993, Simmonds and Fryer, 1996). 1-D kridging was therefore applied to these data to reduce the estimated variances by modelling the spatial autocorrelation. Covariograms were calculated (Figure 8) for the five most important strata (3,5,6,9, and 10) and variance estimates were produced from these models (Table 5). In all cases, the estimated CV was significantly reduced, resulting in a CV of 16.6 % on the overall biomass estimate.

Although the 1-D method was able to significantly increase the measured precision of the biomass estimates, it does not consider the spatial autocorrelation along the transects. Therefore, the 2-D kridging method was also attempted on these data. This method calculated variograms using the biomass density estimates from each ESDU, therefore incorporating the 2-D spatial information in the variogram model. However, the inconvenience of this method lies in the difficulty in modelling these highly skewed data (Figure 9). The experimental variograms were not well behaved, mainly due to the low frequency occurrence of very large density estimates, common to many acoustic datasets. Experimental variograms can be calculated from truncated datasets (Simard *et al.* 1993), where a few extreme values representing most of the data variance are eliminated (Figure 10). However, the problems associated with the application of the resulting variogram models in the estimation of the overall variance are not trivial. In the case of 1995 acoustic survey, only the data from stratum 10 allowed the calculation of a experimental variogram from the untruncated dataset. The resulting CV estimate of 23.9 % (versus 37.3 % with 1-D kridging and 59.6 % with classical statistics) demonstrated that additional gains in precision can be made using the 2-D spatial information (Table 6).

Discussion

Abundance Estimates:

The 1995 acoustic survey was the most comprehensive survey of west coast herring conducted to date. All the planned strata were covered with the exception of stratum 4 (Port-au-Port Bay) where historically few herring have been detected. Biological sampling was improved over past years, although it was noted that purse seines were limited by adverse fishing conditions (e.g. high winds, fish on bottom, fish not schooled, etc.) and could not always fish on significant concentrations of herring. In addition, large areas of thinly distributed herring were not sampled, and although this did not represent a large percentage of the total area backscatter, confirmation of species and length composition was not possible for these echoes. In this respect, a pelagic trawl would be the fishing gear of choice.

Biases associated with the detection of acoustic backscatter and its conversion to biomass tends to limit confidence in acoustic survey estimates as absolute measures of abundance. However, an examination of these potential biases reveals that the majority of them should result in an underestimate of stock abundance (Table 7). In particular, (a) the fact that significant amounts of herring were found outside the original survey area suggests the possibility that other unsurveyed concentrations were also present elsewhere, (b) the general target-strength formula used for this survey is representative for day-time distributions of fish tilt angles, and may be a significant overestimate for the actual night-time fish tilt angles of this survey, thereby significantly underestimating the biomass (Buerkle, 1983; Buerkle 1990) and (c) several concentrations were detected close to bottom and thus some herring were undoubtedly in the bottom dead zone (Mitson, 1983). Other source of bias are also possible, although their impact in this case should be relatively minor. For these reasons, the biomass estimates presented here are considered to be minimal estimates and should be comparable from year to year.

The 1995 acoustic survey estimated a spring-spawning minimum stock biomass of approximately 37,000 t along the west coast of Newfoundland. In 1993, the acoustic survey found 31,000 t of spring spawners. However as stated earlier, this latter survey undoubtedly underestimated a significant portion of the stock since commercial catch data showed that both spring- and autumn-spawning herring were present in these two unsurveyed northern strata. The 1995 survey also estimated the minimum autumn stock biomass at 46,000 t. The majority of these herring were located in the northern strata, which normally are not heavily fished at this time of the year. These herring were not formed into schools, but rather were in a relatively thick, dense layer close to the bottom. Although the 1993 estimate was considerably lower (35,000 t), the missed northern strata in this survey may well account for the difference.

Size composition data showed that recruiting year-classes eventually congregate in the middle strata (Bonne Bay/Bay of Islands areas) following the pattern seen in previous surveys (McQuinn and Lefebvre 1995b). There was also a general tendency for a higher proportion of autumn spawners to be found towards the north, again are seen in previous years (McQuinn and Lefebvre 1995a).

The large concentration of herring found outside of the planned survey area illustrated the importance of accurately determining the area of stock distribution. This concentration represented approximately 38% of the total biomass estimate and having missed it would have dramatically changed our view of the stock abundance. This is an area which has not often been surveyed in the past because of difficult weather conditions in late November-early December when previous surveys have been conducted (McQuinn and Lefebvre, 1995a). Moving the survey to October has improved this situation, however, it is clear that additional strata must be included in the offshore area of this northern zone. This may not be a general problem with the outer limit of the more southerly strata as the seaward extent of most herring concentrations consistently ends at the shelf break and herring are rarely found beyond 60-70 meters bottom depth i.e. below the thermocline. In the Strait of Belle Isle however, the shelf is extended towards the north shore of Quebec, which appears to offer suitable habitat for herring at this time of year. The herring we encountered in this area may well be migrating from the north shore to the west coast and the Esquiman Channel in the late fall (McQuinn and Lefebvre, 1995a). This underlines the necessity to continue explorations outside the survey area as a measure to ensure that the bulk of the these herring stocks is being assessed by this survey.

Variance Estimates:

Increasingly, geostatistical techniques are being applied to hydroacoustic data for biomass and variance estimation (Simard *et al.* 1993, Petitgas 1993, Simmonds and Fryer, 1996). The present study has shown the advantages of considering the spatial autocorrelation, either in 1-dimentional or 2-dimentional space, when estimating the biomass variance. A simple inspection of the spatial distribution of herring backscatter in western Newfoundland (Figure 3) reveals that there are patterns to their distribution which can be exploited for the estimation of the variance. The comparisons made between classical statistics and geostatistics in the present paper show clearly that the estimated variance can be significatly reduced using either the 1-D and 2-D kridging methods. The advantages of the 1-D method lies in its simplicity and in the smoothing of the data distribution, producing relatively well behaved covariograms. However, as techniques for treating highly skewed data are developed, the 2-D kridging method will undoubtedly allow for even greater improvement in our estimates of precision.

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Table 1. Specifications for the SIMRAD 38 and 120 kHz split-beam tranducers from target-sphere calibrations conducted before the 1995 fall herring acoustic survey.

Parameter	38 kHz	120 kHz
-3 dB beam width (deg):	6.9	7.5
Longitudinal offset:	0.00	0.15
Transversal offset:	0.00	-0.07
Equivalent 2-way beam angle (dB):	-20.9	-20.6
Transceiver Gain (dB)		
20 log r	27.8	24.6
40 log r	27.8	24.6

Table 2. Percent spring spawners by weight from the biological samples collected during the 1995 fall herring acoustic survey (stratum number in brackets).

Stratum	% Spring Spawners
St. John Bay (10)	42.2
Bonne Bay Bank (6)	39.0
Bonne Bay (8)	79.2
Bay of Islands (7)	64.2
Port-au-Port Gulf (3)	70.0
Bay St. George South (1)	54.8

Table 3. Acoustic backscatter and biomass of herring per transect for the 1995 fall herring acoustic survey.

Stratum	Transect Number	Transect Length (km)	Target Strength (dB/kg)	Average Sa (/m²)	Biomass Density (Kg/m²)	Set Number
St. Georges S.	21	15.843	-35.75	0.00000000	0.0000	
(Stratum 1)	23	15.167	-35.75	0.00000000	0.0000	
	25	14.704	-35.75	0.00000000	0.0000	
	27	13.181	-35.75	0.00000000	0.0000	
	29	13.580	-35.75	0.00000000	0.0000	
	31	12.472	-35.75	0.00000000	0.0000	
	33	12.523	-35.75	0.00000000	0.0000	
	35	11.673	-35.75	0.00000000	0.0000	
	37	10.404	-35.75	0.00000000	0.0000	
	39	9.766	-35.75	0.00000000	0.0000	
	41	7.113	-35.75	0.00000000	0.0000	
	43	4.551	-35.75	0.00000000	0.0000	
	45	5.282	-35.75	0.00000000	0.0000	
	47	7.078	-35.75	0.00000000	0.0000	
St. Georges N.	63	14.208	-35.75	0.00000000	0.0000	
(Stratum 2)	61	14.952	-35.75	0.00000000	0.0000	
	59	15.787	-35.75	0.00000000	0.0000	
	57	12.535	-35.75	0.00000000	0.0000	
	55	11.247	-35.75	0.00000000	0.0000	
	53	9.865	-35.75	0.00000000	0.0000	
	51	6.932	-35.75	0.00000000	0.0000	
	49	1.770	-35.75	0.00000000	0.0000	
Port-au-Port	19	12.933	-36.01	0.00000000	0.0000	
(Stratum 3)	17	11.675	-36.01	0.00000014	0.0006	
	15	8.323	-36.01	0.00000000	0.0000	
	13	8.179	-36.01	0.00000000	0.0000	
	11	11.927	-36.01	0.00000000	0.0000	
	9	13.817	-36.01	0.00000074	0.0029	
	7	12.443	-36.01	0.00000000	0.0000	
	5	11.304	-36.01	0.00000120	0.0048	551
	3	12.542	-36.01	0.00001409	0.0563	
	1	12.431	-36.01	0.00000016	0.0006	
Bay of Islands -	90	13.413	-36.01	0.00000015	0.0006	
Gulf side	92	13.514	-36.01	0.00002752	0.1099	
(Stratum 5)	94	18.347	-36.01	0.00000325	0.0130	
	96	16.328	-36.01	0.00000357	0.0143	
	98	13.663	-36.01	0.00000349	0.0139	
	100	14.181	-36.01	0.00000102	0.0041	
	102	13.253	-36.01	0.00000013	0.0005	
	104	13.303	-36.01	0.00000000	0.0000	
	106	13.278	-36.01	0.00000000	0.0000	
	108	12.847	-36.01	0.00000000	0.0000	
	110	8.639	-36.14	0.00000000	0.0000	
	112	9.145	-36.14	0.00000000	0.0000	
	114	10.392	-36.14	0.00000000	0.0000	
	116	11.086	-36.14	0.00000000	0.0000	
	118	8.088	-36.14	0.00002616	0.1076	
	120	7.981	-36.14	0.00000278	0.0114	

Table 3.(con't)

Stratum	Transect Number	Transect Length (km)	Target Strength (dB/kg)	Average Sa (/m²)	Biomass Density (Kg/m²)	Set Number
	122	7.479	-36.14	0.00000117	0.0048	
	124	8.997	-36.14	0.00000319	0.0131	
	126	14.312	-36.14	0.00000000	0.0000	
	128	11.903	-36.14	0.00000000	0.0000	
	129	12.254	-36.14	0.00000000	0.0000	
	131	12.496	-36.14	0.00000331	0.0136	
	154	12.518	-36.14	0.00000019	0.0008	
	152	11.606	-36.14	0.00000139	0.0057	
	150	9.925	-36.14	0.00000046	0.0019	
Bonne Bay Bank	155	9.999	-36.14	0.00000005	0.0002	
(Stratum 6)	157	10.207	-36.14	0.00000000	0.0000	
	159	11.064	-36.14	0.00000040	0.0016	
	161	12.172	-36.14	0.00001731	0.0712	554
	163	13.099	-36.14	0.00000315	0.0129	702
	165	16.942	-36.14	0.00000179	0.0074	
	167	17.697	-36.14	0.00000134	0.0055	
	169	19.445	-36.14	0.00001472	0.0606	
	171	19.890	-36.14	0.00000327	0.0135	
	173	21.092	-36.14	0.00000205	0.0084	
	175	19.836	-36.14	0.00000391	0.0161	
	177	18.967	-36.14	0.00000105	0.0043	
	179	18.014	-36.14	0.00000098	0.0040	
	181	16.258	-36.14	0.00000526	0.0216	
	183	14.341	-36.14	0.00000272	0.0112	
	185	14.355	-36.14	0.00000231	0.0095	
	187	12.253	-36.14	0.00000774	0.0319	
	189	12.056	-36.14	0.00000040	0.0016	
	191	10.994	-36.14	0.00000268	0.0110	
	193	10.354	-36.14	0.00000423	0.0174	
	195	10.338	-36.14	0.00000217	0.0089	
	197	11.811	-36.14	0.00000077	0.0032	
	198	10.627	-36.14	0.00000134	0.0055	
	200	9.934	-36.14	0.00000093	0.0038	
	202	9.596	-36.14	0.00000100	0.0041	
	204	9.145	-36.14	0.00000171	0.0070	
	206	8.278	-36.14	0.00000354	0.0146	
	208	5.977	-36.14	0.00000190	0.0078	
	210	7.747	-36.14	0.00000112	0.0046	
	212	7.227	-36.14	0.00000402	0.0165	
	214	8.122	-36.14	0.00000284	0.0117	
	216	7.094	-36.14	0.00000533	0.0219	
	218	6.947	-36.14	0.00000489	0.0201	
Bay of Islands	76	15.980	-36.16	0.00000000	0.0000	
(Stratum 7)	74	14.126	-36.16	0.00000000	0.0000	
	72	18.244	-36.16	0.00000000	0.0000	
	78	18.924	-36.16	0.00000000	0.0000	
	80	15.681	-36.16	0.00000000	0.0000	
	84	17.100	-36.16	0.00000000	0.0000	550

Table 3.(con't)

Stratum	Transect Number	Transect Length (km)	Target Strength (dB/kg)	Average Sa (/m²)	Biomass Density (Kg/m²)	Set Number
Bonne Bay	149	1.488	-36.17	0.00000000	0.0000	
(Stratum 8)	147	1.719	-36.17	0.00000000	0.0000	
	145	1.810	-36.17	0.00000000	0.0000	
	143	2.325	-36.17	0.00000027	0.0011	
	141	0.675	-36.17	0.00000000	0.0000	
	139	3.283	-36.17	0.00000000	0.0000	
	137	2.867	-36.17	0.00000000	0.0000	
	135	3.336	-36.17	0.00000000	0.0000	
	133	4.134	-36.17	0.00000094	0.0039	319
Table Point	220	10.421	-36.14	0.00000161	0.0066	
(Stratum 9)	222	11.105	-36.14	0.00000072	0.0030	
	285	10.939	-36.14	0.00000427	0.0176	
	283	10.542	-36.14	0.00000007	0.0003	
	281	9.964	-36.14	0.00000000	0.0000	
	279	9.985	-36.14	0.00000000	0.0000	
	277	10.028	-36.14	0.00000057	0.0024	
	275	7.517	-36.14	0.00001559	0.0641	
	273	6.921	-36.14	0.00000021	0.0009	
	269	5.286	-36.14	0.00000000	0.0000	
	267	7.016	-36.14	0.00000000	0.0000	
St. John Bay	265	13.793	-36.14	0.00000000	0.0000	
(Stratum 10)	263	15.116	-36.14	0.00000000	0.0000	
	261	22.070	-36.14	0.00000000	0.0000	
	259	21.745	-36.14	0.00000028	0.0011	
	246	18.397	-36.14	0.00000233	0.0096	
	244	12.548	-36.14	0.00000000	0.0000	
	255	26.286	-36.14	0.00001183	0.0486	320
	257	13.773	-36.14	0.00000187	0.0077	326
	251	26.736	-36.14	0.00000014	0.0006	
	248	23.214	-36.14	0.00000226	0.0093	
	242	17.764	-36.14	0.00000270	0.0111	
	240	13.282	-36.14	0.00000148	0.0061	
	238	10.122	-36.14	0.00000038	0.0016	
	236	28.768	-36.14	0.00000754	0.0310	
	234	27.326	-36.14	0.00005494	0.2258	
	232	14.976	-36.14	0.00000358	0.0147	
	230	15.259	-36.14	0.00000621	0.0255	
	228	11.768	-36.14	0.00000000	0.0000	
	226	10.070	-36.14	0.00000007	0.0003	
	224	8.619	-36.14	0.00000000	0.0000	

Table 4. Acoustic backscatter, biomass and variance (classical statistics) per strata from the 1995 fall herring acoustic survey.

Stratum Name	Stratum No.	Stratum Area (Km^2)	No. of Transects	Mean TS (dB)	Sa Wt. Mean ($/m^2$)	Sa Var	Sa S.E.	Total Scattering (m^2/sr)	Biomass Density (kg/m^2)	Biomass (t/stratum) Total	Biomass (t/stratum) Var	Biomass (t/stratum) S.E.	Biomass (t/stratum) C.V.
St. Georges S.	1	1156.68	14	-35.752	0	0	0	0	0	0	0	0	0
St. Georges N.	2	666.54	8	-35.752	0	0	0	0	0	0	0	0	0
Port-au-Port G.	3	866.77	10	-36.014	1.7664E-06	2.23E-12	1.49E-06	1531.052	0.0070548	6114.907	26667654	5164.073	84.451
Port-au-Port	4	0	0		-	-	-	-	-	-	-	-	-
B. of Islands G.	5	766.27	25	-36.062	2.9814E-06	1.91E-12	1.38E-06	2284.525	0.0120397	9225.626	18139768	4259.081	46.166
Bonne Bay Bank	6	1044.52	33	-36.142	3.4115E-06	5.88E-13	7.67E-07	3563.339	0.0140327	14657.41	10848466	3293.701	22.471
Bay of Islands	7	296.55	10	-36.160	0	0	0	0	0	0	0	0	0
Bonne Bay	8	53.01	9	-36.175	2.0902E-07	2.61E-14	1.62E-07	11.07995	0.0008663	45.9238	1345.9643	36.68739	79.888
Table Point	9	487.14	11	-36.140	1.9714E-06	1.45E-12	1.21E-06	960.3311	0.0081059	3948.729	5829248.3	2414.384	61.143
St. John Bay	10	1786.49	20	-36.139	6.8062E-06	1.64E-11	4.05E-06	12159.27	0.0279774	49981.29	886597673	29775.79	59.574
	Total	7123.97	140					20509.59	0.0117875	83973.88	948084156	30790.98	36.667
	Spring									37998.58			
	Autumn									45975.30			

Table 5. Acoustic backscatter, biomass and variance (1-D kridging) per strata from the 1995 fall herring acoustic survey.

Stratum Name	Stratum No.	Stratum Area (Km^2)	No. of Transects	Average Distance (m)	Intertransect Distance (nm)	Biomass Density (kg/m^2)	Biomass (t/stratum) Total	Biomass (t/stratum) Var	Biomass (t/stratum) S.E.	Biomass (t/stratum) Q	Biomass (t/stratum) C.V.
St. Georges S.	1	1156.68	14	10539.4164		0	0	0	0	0	0
St. Georges N.	2	666.54	8	14483.3149		0	0	0	0	0	0
Port-au-Port G.	3	866.77	9	9896.5203	4	7.25E-03	6282.22	8.32E-03	0.091211	0.2609225	34.957
Port-au-Port	4	-	-	-		-	-	-	-	-	-
B. of Islands G.	5	766.27	25	14375.4231	1.25	1.26E-02	9662.39	8.82E-03	0.093914	0.3940513	23.833
Bonne Bay Bank	6	1044.52	33	7421.00333	1.25	1.33E-02	13923.73	3.17E-03	0.05627	0.5498736	10.233
Bay of Islands	7	296.55	10	9270.8011		0	0	0	0	0	0
Bonne Bay	8	53.01	9	16749.4893	1.17	-	-	-	-	-	-
Table Point	9	487.14	9	17861.3255	2.5	0.0105256	5127.44	5.05E-03	0.071043	0.236826	29.998
St. John Bay	10	1786.49	16	8618.628	2.55	2.46E-02	43878.80	0.140106	0.374308	1.0021077	37.352
	Total	7123.97	137	12135.1024			78874.58	0.165459	0.406767	2.4437811	16.645

Table 6. Statistics pertaining to 2-D kridging by strata on herring acoustic backscatter from the 1995 fall acoustic survey.

Stratum	N Total	N Pos.	Max Value	n Trunc.	Percent of Variance	Mean	Estimator Variance	C.V.	Estimation variance	C.V.
5	708	177	37.76	3	65.1	0.2543	1.97329	-	0.0026298	
6	1395	435	62.62	2	78.0	0.3111	0.91706	-	0.0010723	
9	346	28	17.96	3	96.9	0.0408	0.03577	-	-	
10	1311	320	57.43	0	0	0.7005	15.76981	566.9	0.0280723	23.92

Table 7. Possible sources of bias and their relative affect (direction and importance) on the biomass estimate.

Possible bias	Under-estimation	Over-estimation	Relative importance
Population area not entirely surveyed	✓		high
Actual TS less than assumed TS	✓		high
Fish in dead zone close to bottom	✓		high
Missed schools in thinly populated strata	✓		medium
Shadowing in dense concentrations	✓		medium
Missed strata	✓		low
Vessel avoidance	✓		?
Other species included in backscatter		✓	low
Schools surveyed more than once		✓	low

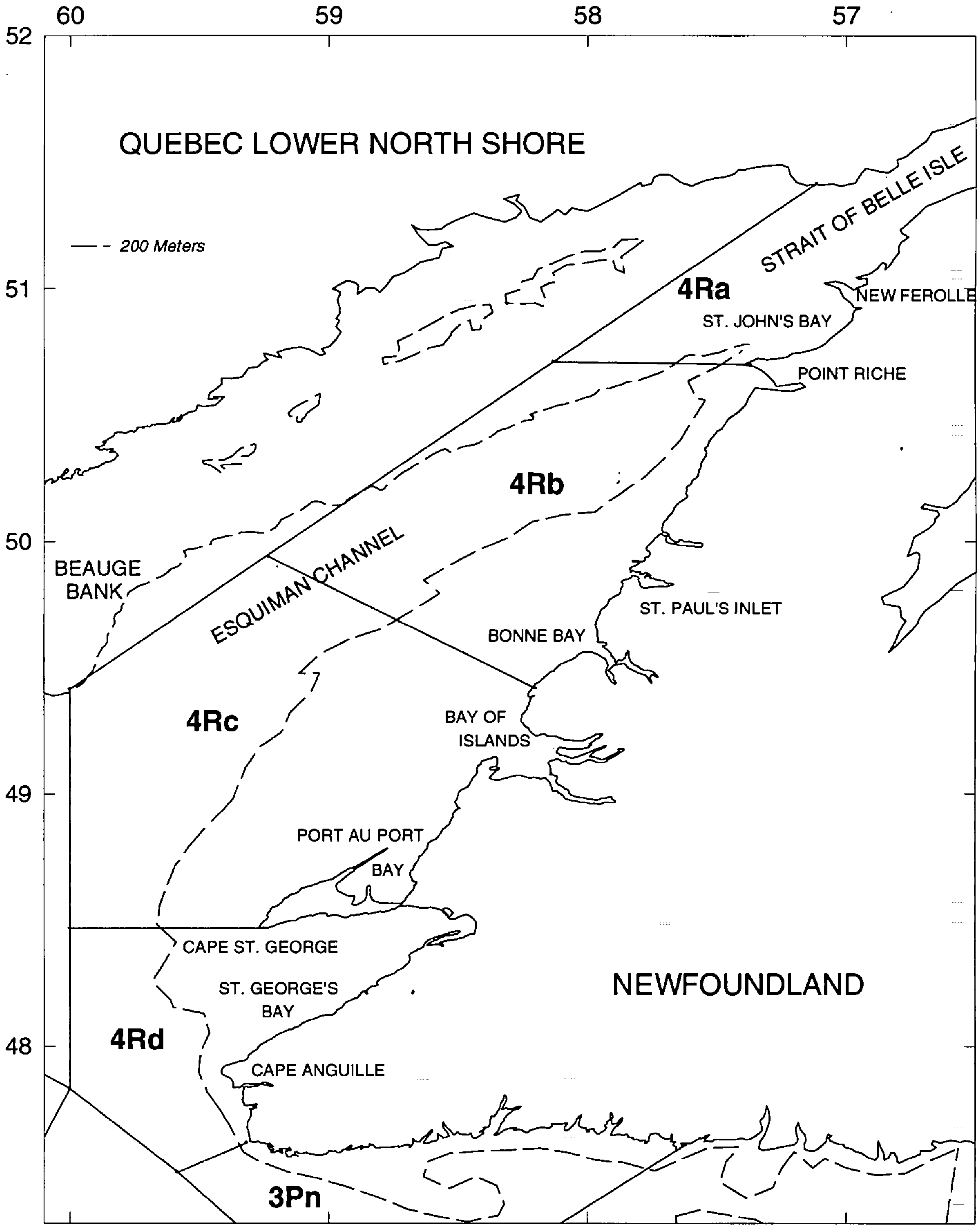

Figure 1. West coast of Newfoundland unit areas.

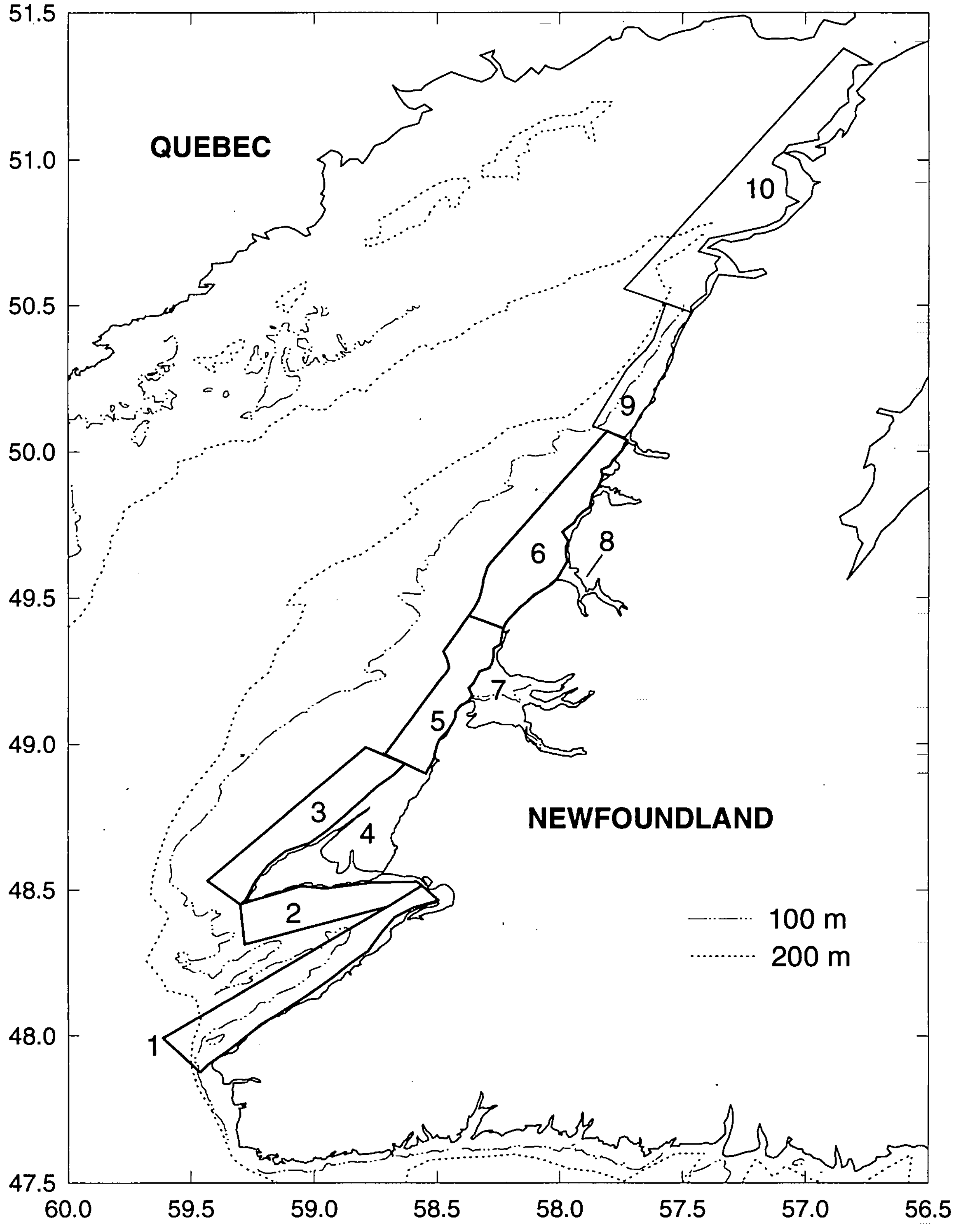

Figure 2. Locations of strata for the 1995 fall acoustic survey.

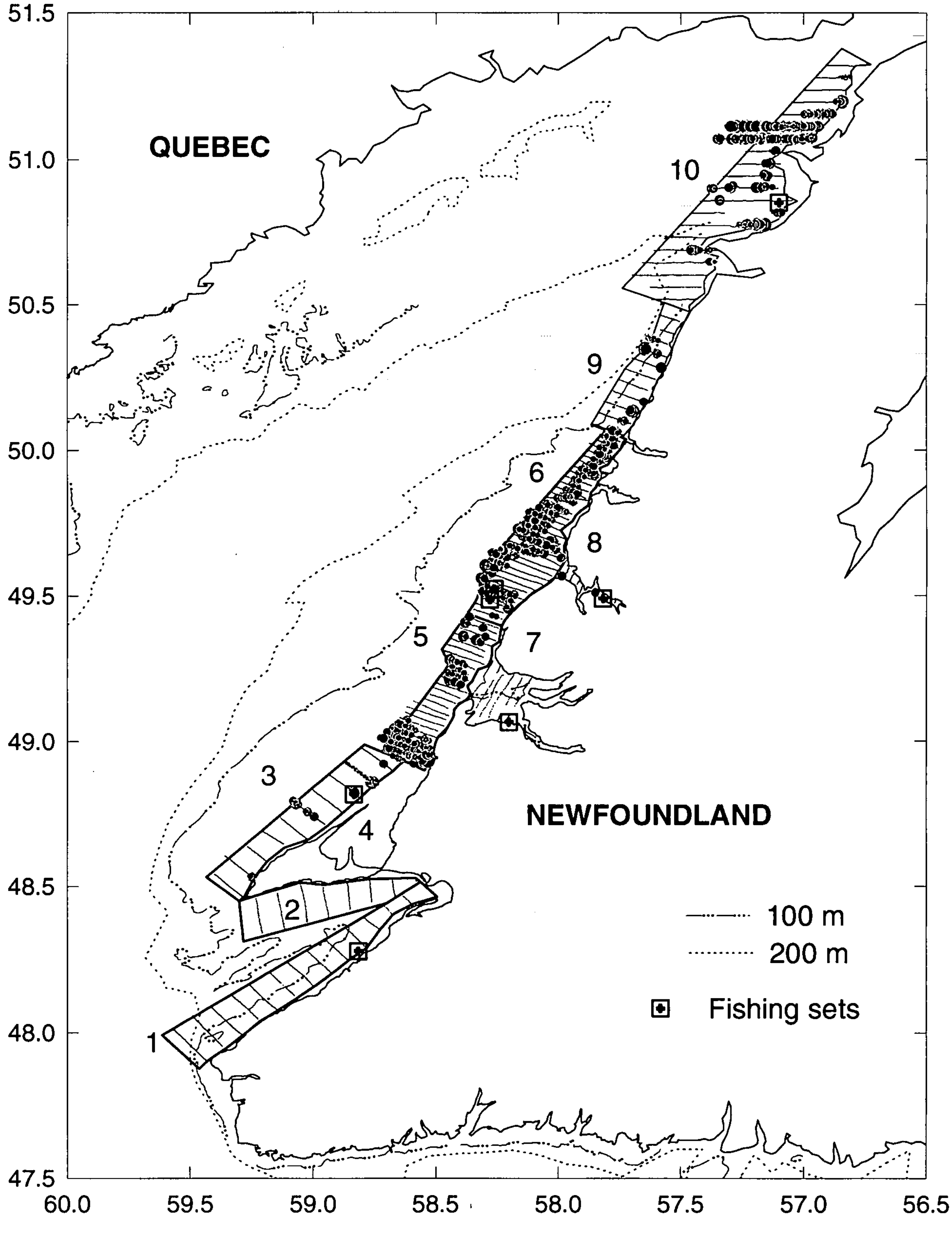

Figure 3. Locations of survey transects, herring acoustic echos (log scale) and fishing sets from the 1995 fall acoustic survey.

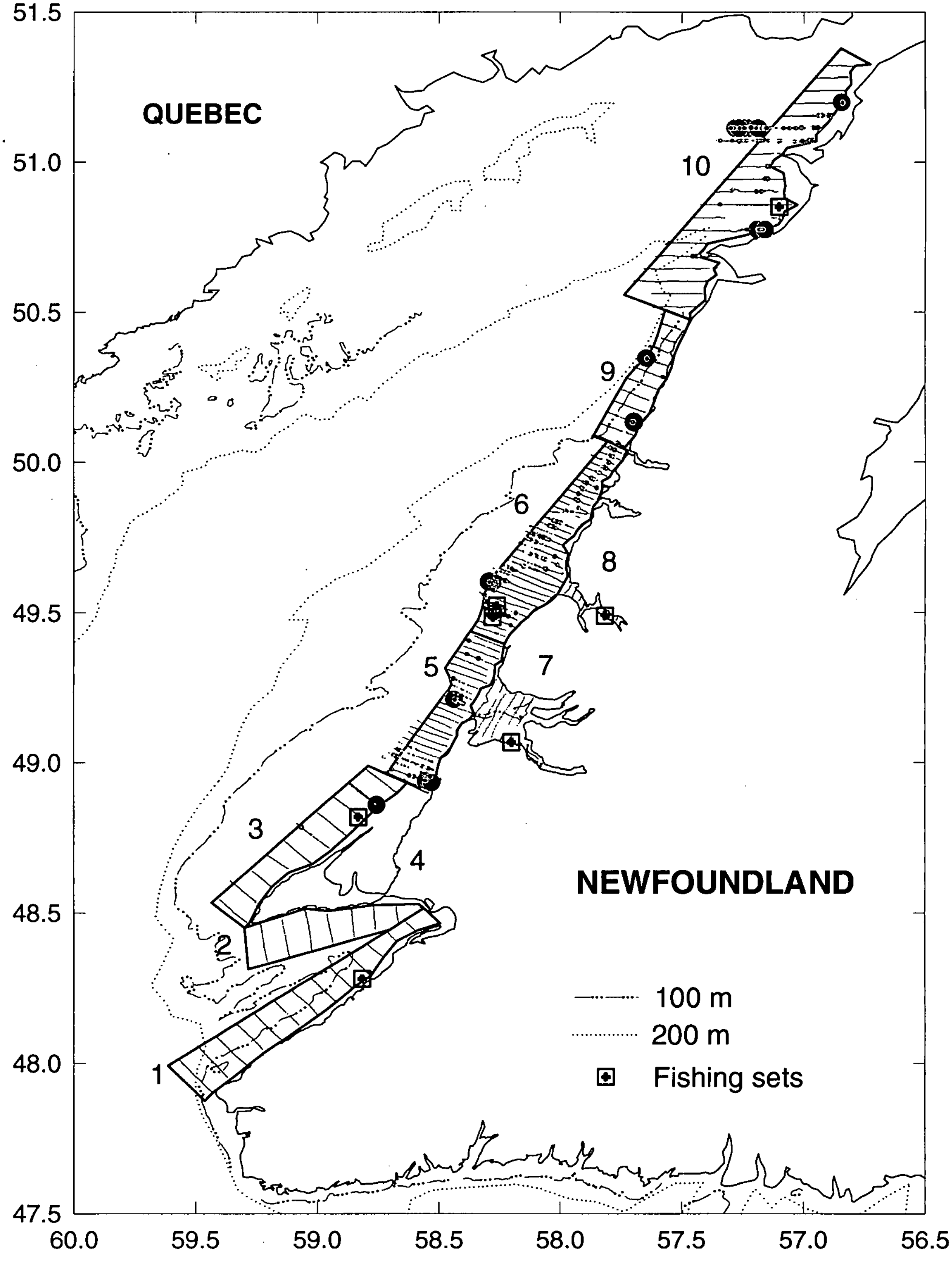

Figure 4. Locations of survey transects, herring acoustic echos (proportional circles) and fishing sets from the 1995 fall acoustic survey.

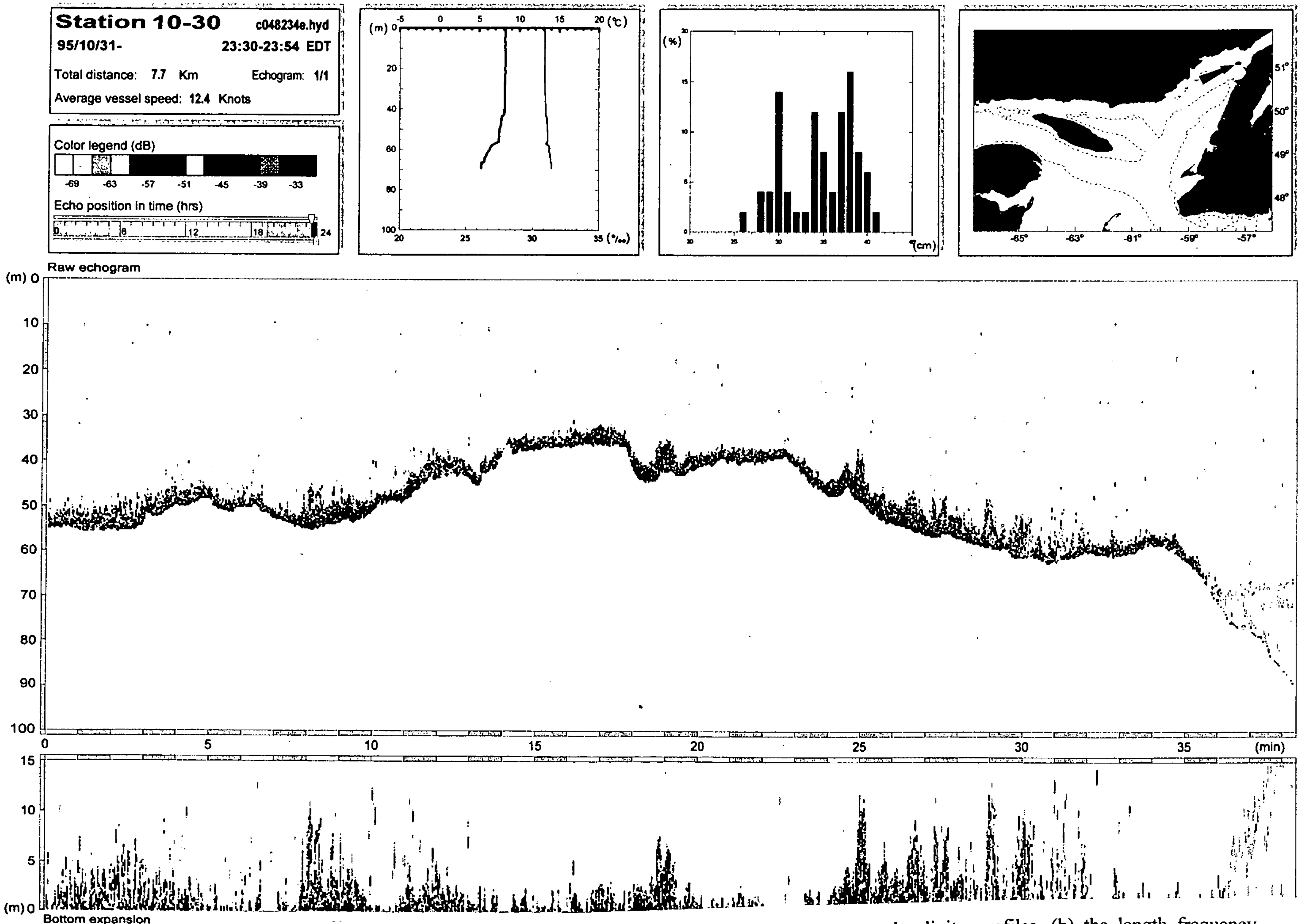

Figure 5. Echogram of herring concentration in stratum 10. Indicated are (a) the temperature and salinity profiles, (b) the length frequency distribution, (c) the position of the transect in time and space, and (d) a bottom expansion of the first 15 m.

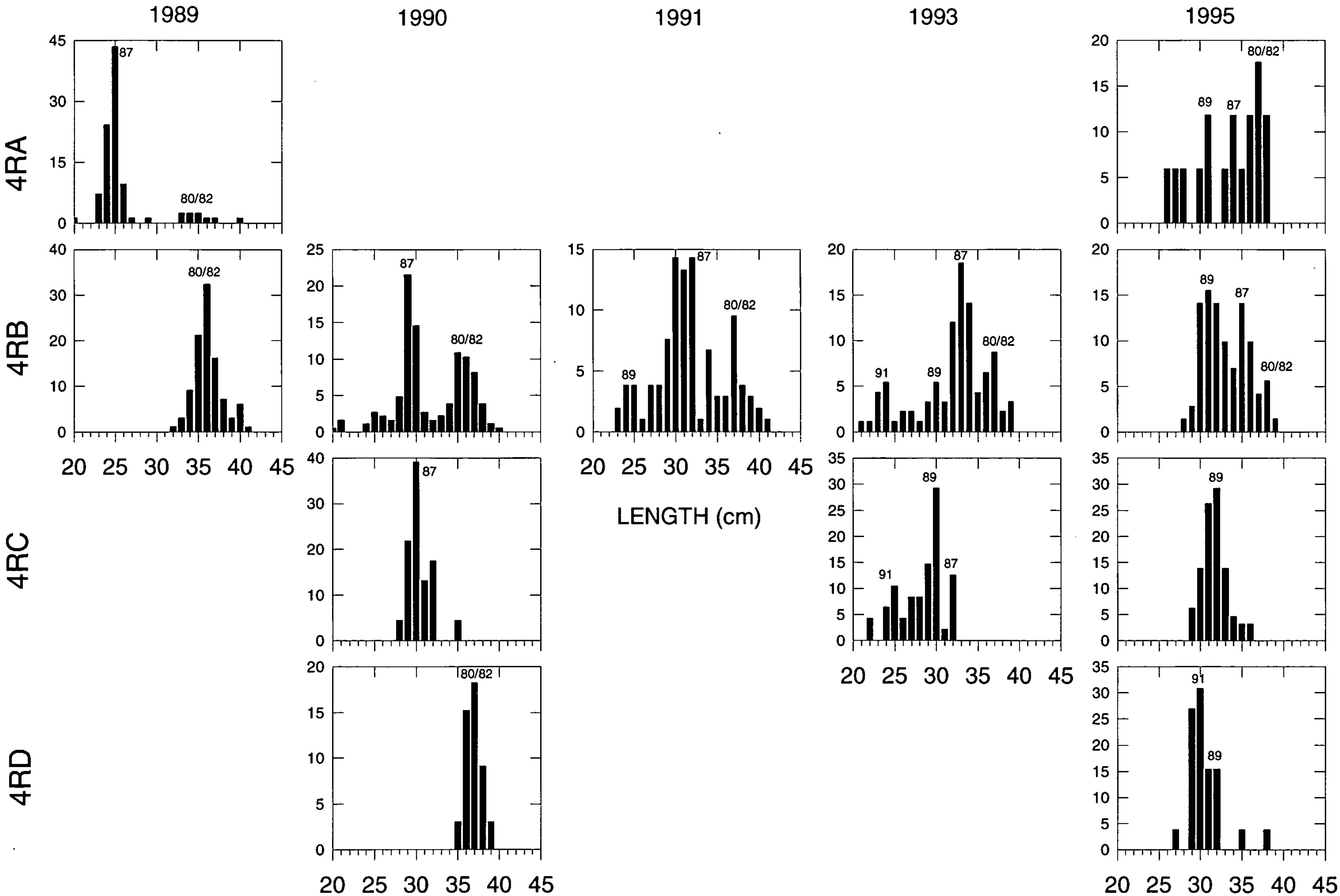

Figure 6. Length frequency distributions of spring-spawning herring caught during the late fall hydroacoustic surveys in subareas 4Ra to 4Rd from 1989 to 1995 (major year-classes are indicated).

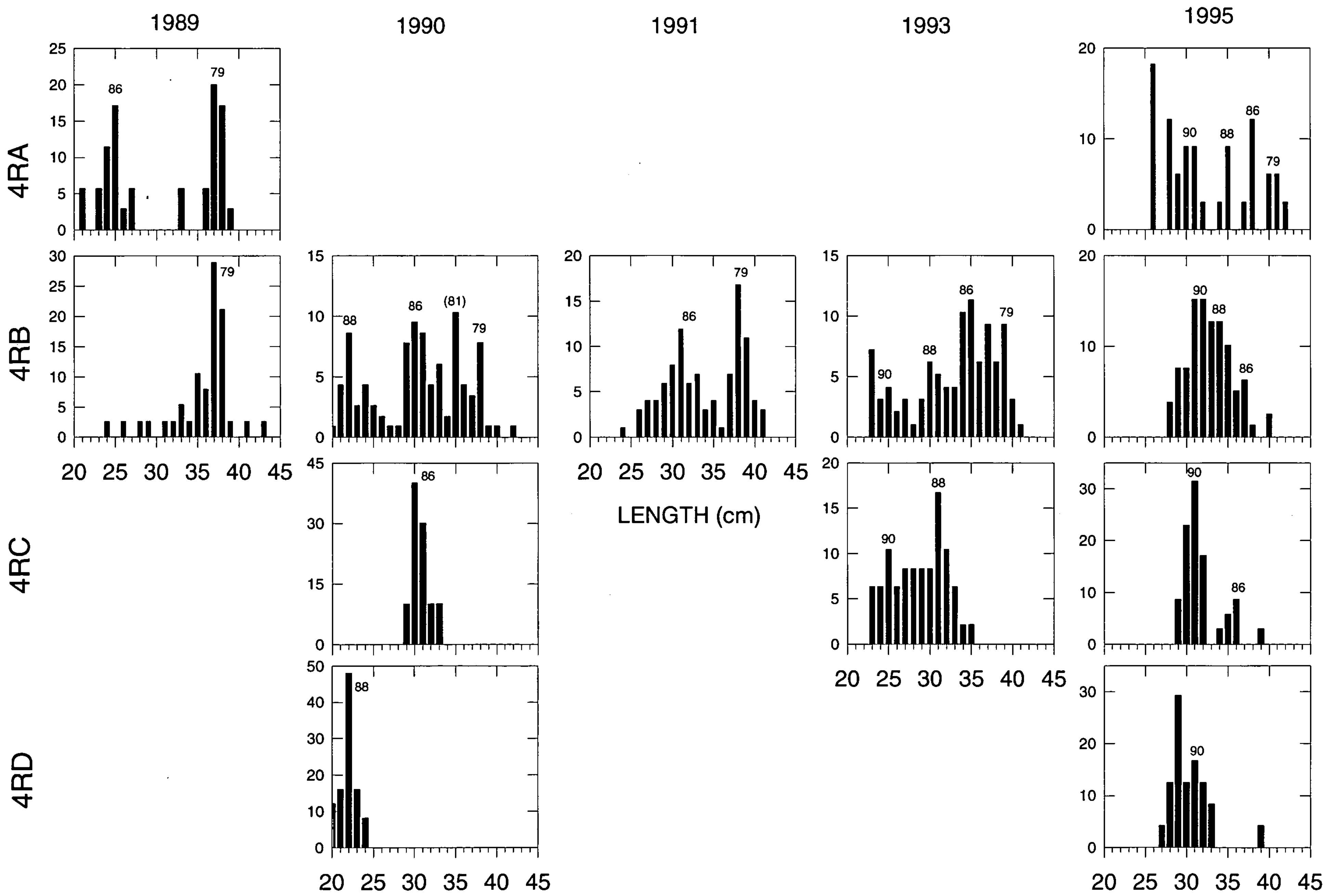

Figure 7. Length frequency distributions of autumn-spawning herring caught during the late fall hydoacoustic surveys in subareas 4Ra to 4Rd from 1989 to 1995 (major year-classes are indicated).

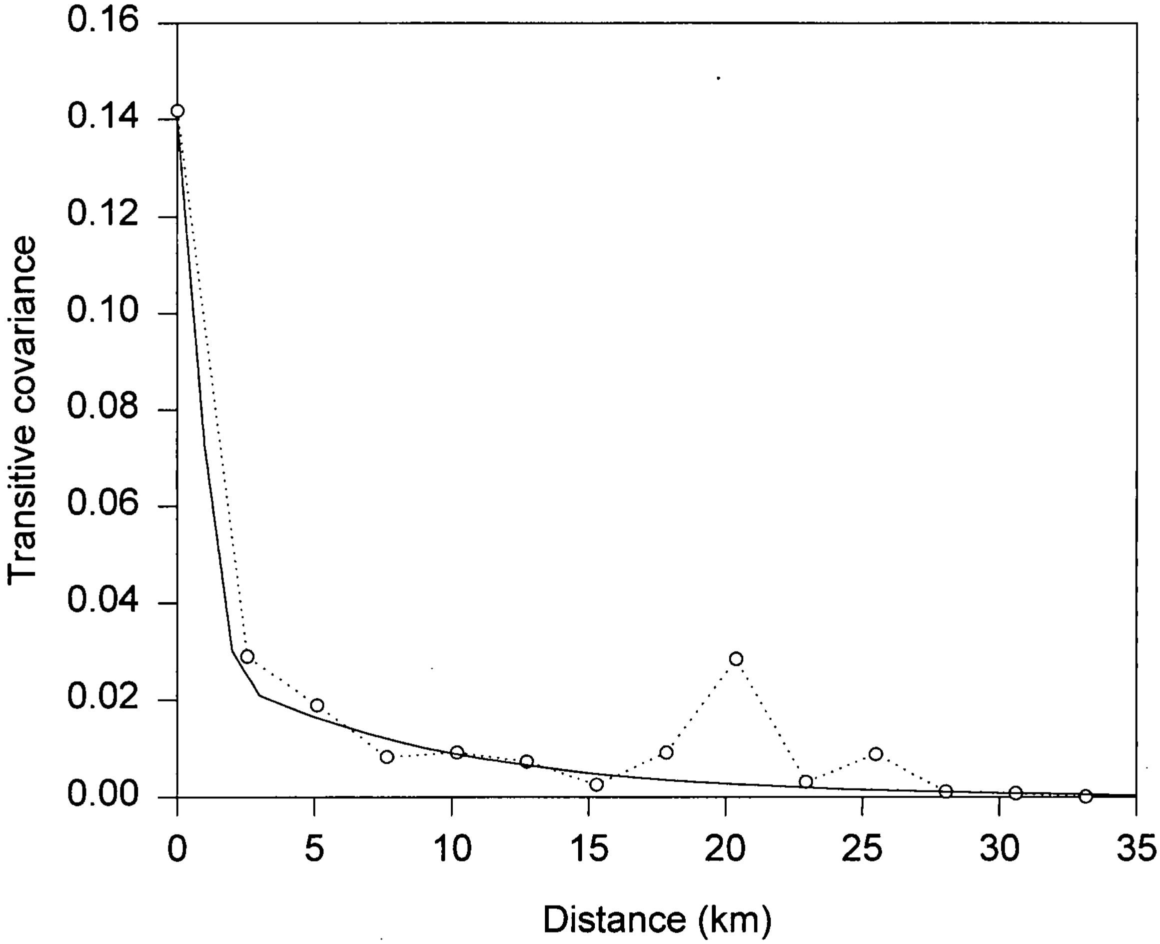

Figure 8. Experimental 1-D transitive covariogram of the cumulated echoes for stratum 10. The fitted model is g(h)=spherical(sill=0.14;range=3 km)+exponential(sill=.03;practical range=25 km).

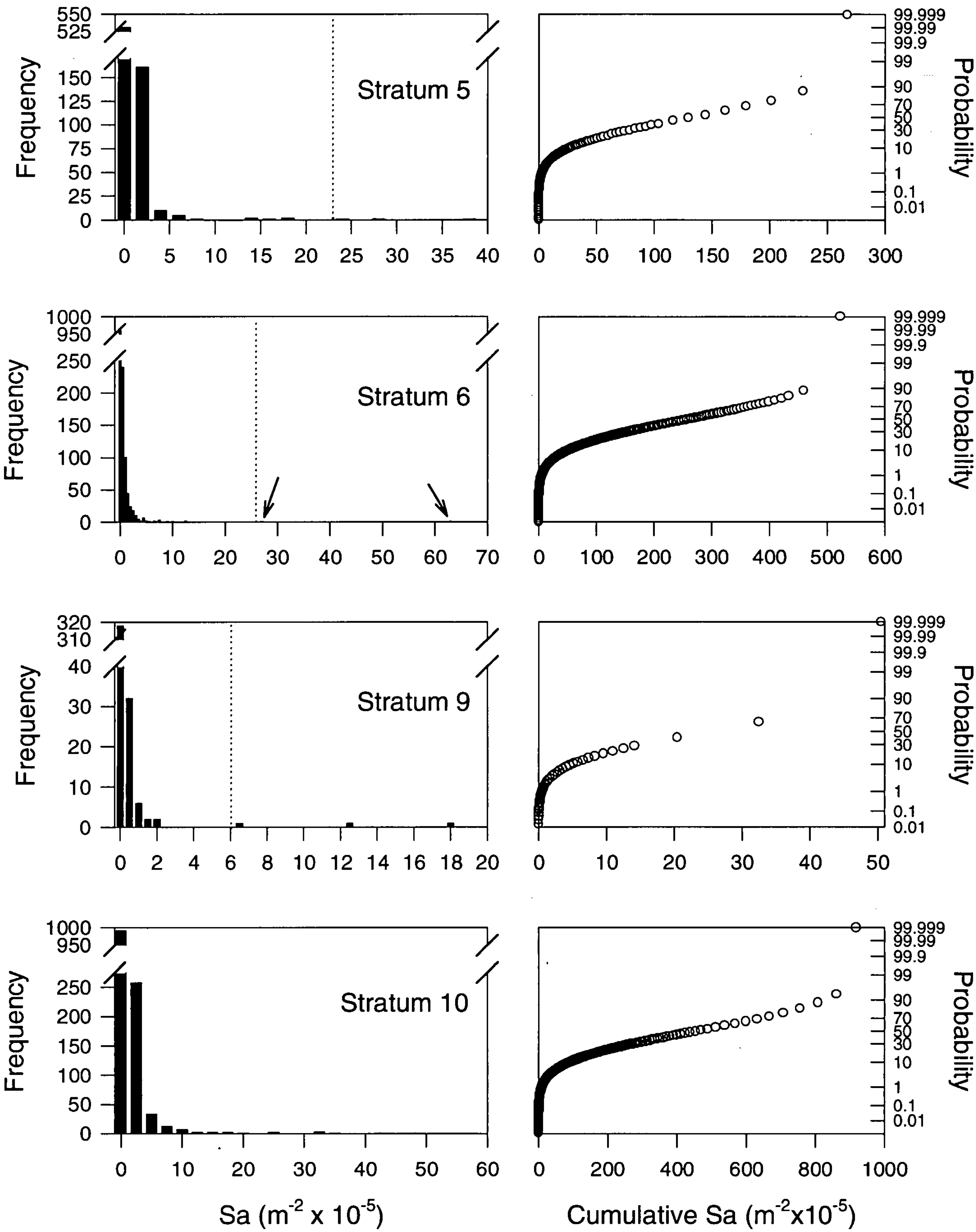

Figure 9. Histogran of Sa values (showing truncated data for strata 5,6 and 9) and cumulative frequency distributions of ESDU of 250 m.

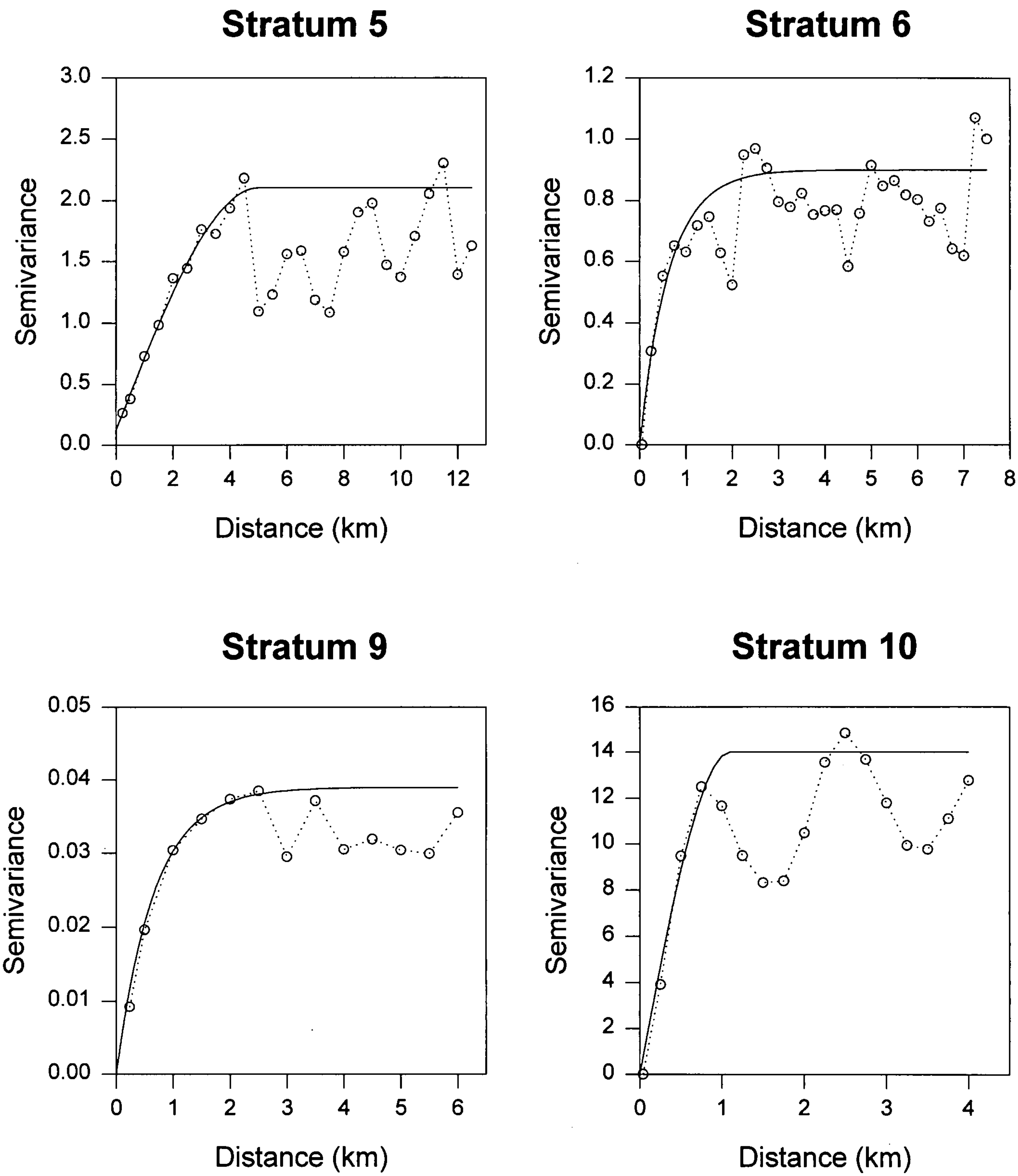

Figure 10. Experimental variograms of truncated data (Strata 5,6 and 9) and untruncated data (strata 10) and fitted models.