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An evaluation of the western Newfoundland herring acoustic abundance index from 1989-1997.

by

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Abstract

A hydroacoustic survey was conducted aboard the *F.G. Creed* in the fall of 1997 as part of a fishery-independent abundance index 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) were collected from a 38 kHz transducer, as well as split-beam phase data. This survey revealed that herring concentrations were more schooled than in 1995, closer to shore, more in the upper layers, and displaced towards the north and the south where warmer waters were available at all depths. The vast majority of herring echoes (80%) were recorded north of New Ferrole (stratum 10) and along the coast towards the Strait of Belle Isle. The total combined spring and autumn stock size in 1997 (88,000 t) was relatively stable compared to the 1995 estimate (89,500 t), although the spring-spawning stock decreased by 37% and the autumn-spawning stock increased by 20% over the past two years.

Résumé

Un relevé hydroacoustique fut mené à bord du *F. G. Creed* à l'automne 1997, 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 (STD). Des données brutes de réverbération de volume (Sv) à partir d'un transducteur 38 kHz ainsi que des données de faisceaux scindés (split-beam) ont été collectées. Le relevé a démontré que les concentrations de hareng étaient plus regroupées en bancs qu'en 1995, plus près de la côte et dans les couches de surface, et distribuées vers le nord et le sud où les eaux plus chaudes étaient disponibles à toutes les profondeurs. La majorité des échos de hareng (80%) a été enregistrée au mord de New Ferolle (strate 10) et le long de la côte vers le détroit de Belle-Isle. La biomasse combinée printemps et automne de 1997 (88,000 t) est demeurée relativement stable comparée à l'estimation de 1995 (89,500 t), quoique le stock de frayeurs de printemps ait diminué de 37% et que le stock de frayeurs d'automne ait augmenté de 20 % lors des deux dernières années.

Introduction

Since 1989, the Laurentian Region of Fisheries and Oceans has conducted six 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 1997 survey and compares the results with the time series since 1991.

The hydroacoustic work for this latest survey was conducted aboard the CSS *Frederick G. Creed* from October 15 to October 31. In addition, several vessels from the west coast large purse seine fleet were directly implicated in the collection of oceanographic and biological data.

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 20 to 60 m isobaths (7200 km^2). The survey area was stratified 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). In 1997, the strata outer limits were adjusted relative to 1995 to generally correspond to the abrupt depth change (approximately the 60 m bottom depth contour) beyond which few herring have been observed in the past.

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 1 and 2 (St. Georges Bay) because of the controversy over the biomass estimate of this spawning component (McQuinn and Lefebvre, 1995b). 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 (fish on bottom) 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. to avoid dead zone problems (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 time, the seiner remained in close proximity (20-40 km) 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 such cases, biological samples were usually 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 a 38 kHz hull-mounted, split-beam transducer. 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 CH1 software (Simard *et al.* 1998) developed at the Maurice Lamontagne Institute (MLI) and translated into the Femto HDPS format for analysis. The equipment was calibrated before the survey (Table 1) using a target of known reflectivity (-33.7 dB for a 60-mm copper sphere) and following the procedures specified by Simrad (Simrad EK500 Instruction Manual). The beam pattern was also calibrated by scanning the copper sphere throughout the beam using a computer-controlled motorised positioning system (Winch) developed at MLI and by collecting and analysing the data using the Lobe beam-pattern software (Simrad EK500 Instruction Manual).

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 swimbladders 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 pelagic aggregations 10's of meters thick.

Estimates of area backscatter, stock biomass and variance were calculated following the procedures and equations recommended by the CAFSAC pelagic subcommittee (O'Boyle and Atkinson 1989). Although the application of classical statistics for a random-stratified design to a systematic-stratified survey (1995 and 1997) may lead to a bias in the strata variance estimates, the variance should theoretically be overestimated (Cochran, 1977). We therefore consider the variance estimates presented in the results section to be conservative.

The conversion of backscatter to biomass was accomplished by using target strength estimates per unit length determined from the equation suggested by Foote (1987) for clupeoids at 38 kHz:

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

and for herring at 120 kHz (Foote *et al.*, 1993):

$$TS_{cm} = 20 \log L - 73.5 \quad (2)$$

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

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

where W is the mean fish weight (kg) (Buerkle, U., pers. com.). 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.

Equations 1 and 2 are general algorithms 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 these equations should be considered as approximate. 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

In 1997, all the planned strata were sampled acoustically with the exception of stratum 4 and 7 (Port-au-Port Bay and Bay of Islands) where historically few herring have been detected. This survey revealed that herring concentrations were more schooled than in 1995, close to shore, and more in the upper layers (Figure 2). There was also a displacement towards the north and the south with respect to 1995 (McQuinn and Lefebvre, 1996), where warmer waters were available at all depths. Significant concentrations of herring schools were seen in St. George's Bay (stratum 1), and a few schools were recorded off Bay of Islands (stratum 5). However, the vast majority of herring echoes (80%) were recorded north of New Ferrole (stratum 10) and along the coast towards the Strait of Belle Isle (Table 2).

Age Composition

From the numbers-at-age data, the 1987 spring-spawning and 1986 autumn-spawning year-classes, which have dominated these stocks over the past decade, have slowly been replaced by the 1990 year-class, both spring and autumn spawning (Table 3). In 1997, the spring-spawning stock was dominated by the 1990 and 1994 year-classes, while the autumn-spawning stock was dominated by 1988, 1990 and 1993 year-classes, although there was still a large proportion of 11+ fish in the catch.

Abundance Estimates

The 1997 combined total stock biomass was estimated to be 88,000 t, comprised of 24,000 t of spring spawners and 64,000 t of autumn spawners (Table 4). The total stock size was therefore relatively stable compared to the 1995 estimate (89,500 t), although the spring-spawning stock decreased by 37% and the autumn-spawning stock increased by 20% over the past two years. In 1995, 64% of the herring biomass surveyed was in the two most northerly strata, while in 1997, 80% was in the most northerly stratum. Due to the poor performance of the transducer and the incertitude as to the proper calibration parameters (McQuinn and Lefebvre, 1995a), the data from the 1989 survey are not presented here. The biomass estimates for the 1991 and 1993 surveys have been updated from previous estimates (McQuinn and Lefebvre, 1995b) following a revision of the length/TS equation (2) used for the conversion from echo energy to biomass at 120 kHz (Foote *et al.*, 1993). These revised estimates show a constant decline in the spring-spawner biomass from 1991 to 1997, while the autumn spawners declined from 1991 to 1993, remained stable until 1995 and began to increase in 1997 (Table 4; Figure 3).

The estimates of spawning-stock biomass (mature herring only) of 65,500 t (18,000 t of spring spawners and 47,500 t of autumn spawners) was a decrease over the 1995 estimate of 85,000 t (37,000 t of spring spawners and 48,000 t of autumn spawners). The last 4 surveys have shown a constant decline in the spring-spawners spawning stock-biomass, while the autumn spawners appeared to be stable over the same time period (Figure 4).

Discussion

Abundance Estimates

The 1997 acoustic survey was the most comprehensive survey of west coast herring conducted to date. Biological sampling was improved over past years, although it was noted that the 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 absolute abundance. However, an examination of these potential biases reveals that the majority of them should result in an underestimate of stock abundance (McQuinn and Lefebvre 1996). Therefore the results of these surveys should at least be taken as minimal or relative biomass estimates, comparable from year to year. If, however, we compare the spawning-stock biomasses estimated from these acoustic surveys with the spawning-stock biomass of western Newfoundland herring estimated from the virtual population analysis (McQuinn *et al.*, 1999), we find that they are very similar (Figures 5 and 6). This may not be surprising, given that the acoustic estimates are used to calibrate the VPAs. However, when we compare the spawning-stock biomass estimates for spring spawners from the acoustic survey with the VPA estimates calibrated using the index-fisherman abundance index only (1995-1998), the annual estimates are not significantly different for any of the 4 years (Figure 7) and, for the final two years, they are for all practical purposes, identical. Although there are several potential biases with these acoustic estimates, it is likely that they are insignificant in practice given that these two independent methods (VPA using catch rate index versus the acoustic survey) yield very similar results.

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Table 1. Specifications for the SIMRAD 38 kHz split-beam tranducers from target-sphere calibration conducted before the 1997 fall herring acoustic survey.

Parameter	38 kHz
Alongship -3 dB beam width (deg):	6.86
Athwartship -3 dB beam width (deg):	6.74
Alongship offset:	-0.05
Athwartship offset:	0.01
Equivalent 2-way beam angle (dB):	-20.98
Transceiver Gain (dB)	
20 log r	27.40
40 log r	27.45

Table 2. Acoustic backscatter and biomass density per transect of herring from the 1997 fall 4R acoustic survey.

Stratum	Transect Number	Transect Length (m)	Target Strength (dB/kg)	Spring Spawners (%)	Average Sa ($/m^2$)	Biomass Density (kg/m^2)	Set Number
St. Georges S.	16	1895	-34.812	43.5	0.00000000	0.0000	
(Stratum 1)	17	2028	-34.812	43.5	0.00000000	0.0000	
	18	1009	-34.812	43.5	0.00000000	0.0000	
	19	1390	-34.812	43.5	0.00000000	0.0000	
	20	1351	-34.812	43.5	0.00000000	0.0000	
	21	2626	-34.812	43.5	0.00001156	0.0350	
	22	3090	-34.812	43.5	0.00000894	0.0271	
	23	3211	-34.812	43.5	0.00006541	0.1981	
	24	2948	-34.812	43.5	0.00000444	0.0134	
	25	3774	-34.812	43.5	0.00002938	0.0890	
	26	2882	-34.812	43.5	0.00000379	0.0115	
	27	3287	-34.812	43.5	0.00002401	0.0727	
	28	3161	-34.812	43.5	0.00000289	0.0087	
	29	3847	-34.812	43.5	0.00000138	0.0042	
	30	3106	-34.812	43.5	0.00000288	0.0087	
	31	3430	-34.812	43.5	0.00000653	0.0198	
	32	3195	-34.812	43.5	0.00000479	0.0145	
	33	5240	-34.812	43.5	0.00000045	0.0014	
	34	4865	-34.812	43.5	0.00000343	0.0104	
	35	4382	-34.812	43.5	0.00000023	0.0007	
	36	5731	-34.812	43.5	0.00000046	0.0014	
	37	5246	-34.812	43.5	0.00000032	0.0010	
	38	6788	-34.812	43.5	0.00000000	0.0000	
	39	8092	-34.812	43.5	0.00000000	0.0000	
	40	8907	-34.812	43.5	0.00000000	0.0000	
	41	10857	-34.812	43.5	0.00000000	0.0000	
	42	9060	-34.812	43.5	0.00000000	0.0000	
	43	7063	-34.812	43.5	0.00000000	0.0000	
	44	6606	-34.812	43.5	0.00000000	0.0000	
	45	6306	-34.812	43.5	0.00000000	0.0000	
	46	5492	-34.812	43.5	0.00000000	0.0000	
	47	5675	-34.812	43.5	0.00000000	0.0000	
	48	5158	-34.812	43.5	0.00000000	0.0000	
	49	6137	-34.812	43.5	0.00000000	0.0000	
	50	4771	-34.812	43.5	0.00000000	0.0000	
	51	5542	-34.812	43.5	0.00000714	0.0216	
	52	3592	-34.812	43.5	0.00000965	0.0292	
	53	5454	-34.812	43.5	0.00001804	0.0546	
	54	3985	-34.812	43.5	0.00000450	0.0136	
St. Georges N.	1	1035	-34.812	43.5	0.00000000	0.0000	
(Stratum 2)	2	1979	-34.812	43.5	0.00000000	0.0000	
	3	3538	-34.812	43.5	0.00000000	0.0000	
	4	3130	-34.812	43.5	0.00000000	0.0000	
	5	4037	-34.812	43.5	0.00000000	0.0000	
	6	4318	-34.812	43.5	0.00000000	0.0000	
	7	3910	-34.812	43.5	0.00000000	0.0000	
	8	3369	-34.812	43.5	0.00000000	0.0000	

Table 2. Acoustic backscatter and biomass density per transect of herring from the 1997 fall 4R acoustic survey.

Stratum	Transect Number	Transect Length (m)	Target Strength (dB/kg)	Spring Spawners (%)	Average Sa ($/m^2$)	Biomass Density (kg/m^2)	Set Number
	9	3238	-34.812	43.5	0.00000000	0.0000	
	10	3163	-34.812	43.5	0.00000000	0.0000	
	11	5679	-34.812	43.5	0.00000000	0.0000	
	12	5264	-34.812	43.5	0.00000000	0.0000	
	13	3142	-34.812	43.5	0.00000000	0.0000	
	14	2643	-34.812	43.5	0.00000000	0.0000	
	15	2441	-34.812	43.5	0.00000000	0.0000	
	16	4737	-34.812	43.5	0.00000000	0.0000	
	17	7169	-34.812	43.5	0.00000079	0.0024	
	18	10226	-34.812	43.5	0.00000013	0.0004	
	19	10988	-34.812	43.5	0.00000007	0.0002	
	20	9838	-34.812	43.5	0.00000000	0.0000	
	21	8555	-34.812	43.5	0.00000000	0.0000	
	22	8580	-34.812	43.5	0.00000000	0.0000	
	23	5399	-34.812	43.5	0.00000000	0.0000	
	24	5722	-34.812	43.5	0.00000000	0.0000	
	25	6143	-34.812	43.5	0.00000001	0.0000	
	26	5645	-34.812	43.5	0.00000000	0.0000	
	27	5942	-34.812	43.5	0.00000050	0.0015	
	28	4027	-34.812	43.5	0.00000013	0.0004	
	29	3472	-34.812	43.5	0.00001933	0.0585	
Port-au-Port G.	1	1255	-34.812	43.5	0.00000000	0.0000	
(Stratum 3)	2	2733	-34.812	43.5	0.00000000	0.0000	
	3	4459	-34.812	43.5	0.00000000	0.0000	
	4	4778	-34.812	43.5	0.00000000	0.0000	
	5	2149	-34.812	43.5	0.00000000	0.0000	
	6	4252	-34.812	43.5	0.00000000	0.0000	
	7	3477	-34.812	43.5	0.00000000	0.0000	
	8	11345	-34.812	43.5	0.00000000	0.0000	
	9	16604	-34.812	43.5	0.00000000	0.0000	
	10	17509	-34.812	43.5	0.00000000	0.0000	
	11	19035	-34.812	43.5	0.00000000	0.0000	
	12	19686	-34.812	43.5	0.00000000	0.0000	
	13	22801	-34.812	43.5	0.00000000	0.0000	
	14	25091	-34.812	43.5	0.00000000	0.0000	
	15	27071	-34.812	43.5	0.00000000	0.0000	
	16	27758	-34.812	43.5	0.00000000	0.0000	
	17	28541	-34.812	43.5	0.00000000	0.0000	
	18	29891	-34.812	43.5	0.00000000	0.0000	
	19	29411	-34.812	43.5	0.00000000	0.0000	
	20	30284	-34.812	43.5	0.00000000	0.0000	
	21	29478	-34.812	43.5	0.00000000	0.0000	
	22	30165	-34.812	43.5	0.00000000	0.0000	
	23	29393	-34.812	43.5	0.00000270	0.0082	704
	24	27688	-34.812	43.5	0.00000023	0.0007	
	25	18948	-34.812	43.5	0.00000000	0.0000	
	26	17207	-34.812	43.5	0.00000000	0.0000	

Table 2. Acoustic backscatter and biomass density per transect of herring from the 1997 fall 4R acoustic survey.

Stratum	Transect Number	Transect Length (m)	Target Strength (dB/kg)	Spring Spawners (%)	Average Sa (/m^2)	Biomass Density (kg/m^2)	Set Number
B. of Islands G.	1	3605	-36.072	48.7	0.00000000	0.0000	
(Stratum 5)	2	11956	-36.072	48.7	0.00000000	0.0000	
	3	19597	-36.072	48.7	0.00000004	0.0002	
	4	19286	-36.072	48.7	0.00000000	0.0000	
	5	18519	-36.072	48.7	0.00000005	0.0002	
	6	16780	-36.072	48.7	0.00000011	0.0004	
	7	15346	-36.072	48.7	0.00000010	0.0004	
	8	12922	-36.072	48.7	0.00000001	0.0000	
	9	1248	-36.072	48.7	0.00000000	0.0000	
	10	626	-36.072	48.7	0.00000000	0.0000	
	11	5006	-36.072	48.7	0.00000000	0.0000	
	12	12874	-36.072	48.7	0.00000000	0.0000	
	13	15914	-36.072	48.7	0.00000000	0.0000	
	14	17062	-36.072	48.7	0.00000067	0.0027	
	15	16715	-36.072	48.7	0.00000293	0.0118	705
	16	16920	-36.072	48.7	0.00001198	0.0485	
	17	18418	-36.072	48.7	0.00000515	0.0209	701
	18	18015	-36.072	48.7	0.00000162	0.0066	
	19	17013	-36.072	48.7	0.00000000	0.0000	
	20	15205	-36.072	48.7	0.00000099	0.0040	702
	21	6500	-36.072	48.7	0.00000087	0.0035	
Bonne Bay Bank	1	11967	-35.814	41.0	0.00000048	0.0018	
(Stratum 6)	2	11446	-35.814	41.0	0.00000037	0.0014	
	3	13035	-35.814	41.0	0.00000001	0.0000	
	4	12293	-35.814	41.0	0.00000002	0.0001	
	5	14360	-35.814	41.0	0.00000098	0.0037	
	6	15910	-35.814	41.0	0.00000011	0.0004	
	7	17823	-35.814	41.0	0.00000029	0.0011	
	8	19380	-35.814	41.0	0.00000000	0.0000	
	9	20683	-35.814	41.0	0.00000274	0.0105	
	10	19887	-35.814	41.0	0.00000001	0.0000	
	11	20183	-35.814	41.0	0.00000000	0.0000	
	12	18513	-35.814	41.0	0.00000000	0.0000	
	13	15557	-35.814	41.0	0.00000015	0.0006	
	14	14838	-35.814	41.0	0.00000000	0.0000	
	15	16341	-35.814	41.0	0.00000017	0.0006	
	16	15146	-35.814	41.0	0.00000211	0.0080	
	17	12279	-35.814	41.0	0.00000349	0.0133	
	18	12870	-35.814	41.0	0.00000208	0.0079	
	19	14065	-35.814	41.0	0.00000107	0.0041	
	20	13659	-35.814	41.0	0.00000499	0.0190	
	21	9198	-35.814	41.0	0.00000000	0.0000	
	22	8931	-35.814	41.0	0.00000065	0.0025	
	23	7270	-35.814	41.0	0.00000005	0.0002	
	24	7058	-35.814	41.0	0.00000000	0.0000	
	25	4929	-35.814	41.0	0.00000194	0.0074	
	26	5979	-35.814	41.0	0.00000070	0.0027	

Table 2. Acoustic backscatter and biomass density per transect of herring from the 1997 fall 4R acoustic survey.

Stratum	Transect Number	Transect Length (m)	Target Strength (dB/kg)	Spring Spawners (%)	Average Sa ($/m^2$)	Biomass Density (kg/m^2)	Set Number
	27	5208	-35.814	41.0	0.00000000	0.0000	
	28	5808	-35.814	41.0	0.00000000	0.0000	
	29	5442	-35.814	41.0	0.00000000	0.0000	
	30	4300	-35.814	41.0	0.00000000	0.0000	
	31	3366	-35.814	41.0	0.00000000	0.0000	
	32	3216	-35.814	41.0	0.00000035	0.0013	
	33	3225	-35.814	41.0	0.00000288	0.0110	
	34	3181	-35.814	41.0	0.00000000	0.0000	
	35	4021	-35.814	41.0	0.00000000	0.0000	
Bonne Bay	1	1991	-35.814	41.0	0.00000000	0.0000	
(Stratum 8)	2	2152	-35.814	41.0	0.00000000	0.0000	
	3	2031	-35.814	41.0	0.00000032	0.0012	703
	4	2415	-35.814	41.0	0.00000000	0.0000	
	5	4707	-35.814	41.0	0.00000103	0.0039	
	6	3290	-35.814	41.0	0.00000000	0.0000	
	7	2480	-35.814	41.0	0.00000000	0.0000	
	8	3705	-35.814	41.0	0.00000000	0.0000	
Table Point	1	9794	-35.814	41.0	0.00000009	0.0003	
(Stratum 9)	2	9490	-35.814	41.0	0.00000002	0.0001	
	3	10438	-35.814	41.0	0.00000000	0.0000	
	4	10187	-35.814	41.0	0.00000032	0.0012	
	5	10515	-35.814	41.0	0.00000000	0.0000	
	6	9450	-35.814	41.0	0.00000006	0.0002	
	7	9854	-35.814	41.0	0.00000006	0.0002	
	8	8658	-35.814	41.0	0.00000000	0.0000	
	9	7708	-35.814	41.0	0.00000000	0.0000	
	10	7563	-35.814	41.0	0.00000002	0.0001	
	11	7523	-35.814	41.0	0.00000000	0.0000	
	12	7107	-35.814	41.0	0.00000001	0.0000	
	13	7283	-35.814	41.0	0.00000000	0.0000	
	14	5984	-35.814	41.0	0.00000000	0.0000	
	15	6493	-35.814	41.0	0.00000000	0.0000	
	16	8017	-35.814	41.0	0.00000000	0.0000	
	17	9303	-35.814	41.0	0.00000000	0.0000	
	18	9450	-35.814	41.0	0.00000000	0.0000	
	19	8180	-35.814	41.0	0.00000000	0.0000	
	20	8907	-35.814	41.0	0.00000000	0.0000	
	21	7119	-35.814	41.0	0.00000000	0.0000	
	22	10765	-35.814	41.0	0.00000009	0.0004	
	23	7306	-35.814	41.0	0.00000231	0.0088	
	24	2520	-35.814	41.0	0.00000000	0.0000	
St. John Bay	1	2584	-35.845	22.6	0.00001389	0.0534	
(Stratum 10)	2	4277	-35.845	22.6	0.00000265	0.0102	310
	3	7654	-35.845	22.6	0.00000000	0.0000	
	4	12850	-35.845	22.6	0.00000000	0.0000	
	5	20098	-35.845	22.6	0.00000753	0.0289	313
	6	7090	-35.845	22.6	0.00000429	0.0165	

Table 2. Acoustic backscatter and biomass density per transect of herring from the 1997 fall 4R acoustic survey.

Stratum	Transect Number	Transect Length (m)	Target Strength (dB/kg)	Spring Spawners (%)	Average Sa (/m^2)	Biomass Density (kg/m^2)	Set Number
	7	23645	-35.845	22.6	0.00000106	0.0041	
	8	21398	-35.845	22.6	0.00000451	0.0173	
	9	18372	-35.845	22.6	0.00000480	0.0184	
	10	16493	-35.845	22.6	0.00000040	0.0015	
	11	13016	-35.845	22.6	0.00000006	0.0002	
	12	14265	-35.845	22.6	0.00000288	0.0111	
	13	20729	-35.845	22.6	0.00001259	0.0484	
	14	25124	-35.845	22.6	0.00000006	0.0002	
	15	29848	-35.845	22.6	0.00001023	0.0393	
	16	27969	-35.845	22.6	0.00002367	0.0909	
	17	28103	-35.845	22.6	0.00001919	0.0737	
	18	29460	-35.845	22.6	0.00000816	0.0314	
	19	29597	-35.845	22.6	0.00001620	0.0622	
	20	30439	-35.845	22.6	0.00000857	0.0329	
	21	28639	-35.845	22.6	0.00002224	0.0854	
	22	27297	-35.845	22.6	0.00001227	0.0471	
	23	8121	-35.845	22.6	0.00001866	0.0717	
	24	2899	-35.845	22.6	0.00000000	0.0000	
	25	2545	-35.845	22.6	0.00000683	0.0262	

Table 3. Numbers at age ($x10^3$) for spring- and autumn-spawning herring estimated from the biennial acoustic survey in NAFO division 4R from 1991 to 1997.

SPRING-SPAWNERS

	1991	1993	1995	1997
2	5252	15591	1000	4053
3	14241	36865	4627	31460
4	78462	32008	5587	2199
5	216	26686	32838	4280
6	13484	41341	12184	7656
7	43972	1567	6786	17319
8	26318	6965	18560	3093
9	48683	6965	5301	236
10	8773	5398	12356	9335
11	44080	12879	14334	2317
2+	283480	186265	113573	81946

AUTUMN-SPAWNERS

	1991	1993	1995	1997
2	0	3054	0	3893
3	8841	42610	7365	18723
4	37546	25955	15411	31975
5	29664	33590	59905	12201
6	12515	14213	12296	10703
7	4207	36785	20719	69137
8	12515	9533	8609	5732
9	16616	5601	16702	10951
10	4101	8996	5713	1180
11	106938	31228	36515	36947
2+	232942	211566	183236	201440

Table 4. Acoustic backscatter, biomass and variance per strata from the west coast of Newfoundland biennial fall herring acoustic survey, 1991-1997.

1991

Stratum Name	Stratum No.	Stratum Area (km^2)	No. of Transects	Average Distance (m)	Mean TS (dB)	Sa - Area Scattering (sr) Mean (sr/m^2)	Var	S.E.	Total Scattering (m^2/sr)	Biomass Density (kg/m^2)	Biomass Density (t/stratum) Total	Var	S.E.	C.V.	Spring Spawners (% by wt.)	Spring Spawner Biomass	Autumn Spawner Biomass
St. Georges S.	1																
St. Georges N.	2																
Port-au-Port G.	3																
Port-au-Port	4	437.4	6	10518.7	-38.19	0.00E+00	0.00E+00	0.00E+00	0.0	0.00000	0	0.00E+00				0	0
B. of Islands G.	5	707.6	11	11898.6	-38.19	1.44E-06	1.98E-12	1.41E-06	1016.8	0.00946	6697	4.30E+07	6559	97.9	55.0	3683	3014
Bonne Bay Bank	6	682.5	29	12992.7	-38.19	3.85E-05	1.05E-09	3.25E-05	26307.3	0.25388	173267	2.13E+10	145932	84.2	55.0	95297	77970
Bay of Islands	7	295.7	6	14526.2	-38.19	6.71E-07	4.79E-13	6.92E-07	198.4	0.00442	1307	1.82E+06	1348	103.1	55.0	719	588
Bonne Bay	8	53.2	14	2158.5	-37.60	8.47E-06	6.22E-11	7.89E-06	451.1	0.04874	2595	5.84E+06	2416	93.1	66.2	1718	877
Table Point	9																
St. John Bay	10	1640.3	21	14503.1	-37.60	0.00E+00	0.00E+00	0.00E+00	0.0	0.00000	0	0.00E+00				0	0
	Total	3816.8	87	11410.7					27973.6	0.04817	183866	2.13E+10	146106	79.5	55.2	101417	82449

1993

Stratum Name	Stratum No.	Stratum Area (km^2)	No. of Transects	Average Distance (m)	Mean TS (dB)	Sa - Area Scattering (sr) Mean (sr/m^2)	Var	S.E.	Total Scattering (m^2/sr)	Biomass Density (kg/m^2)	Biomass Density (t/stratum) Total	Var	S.E.	C.V.	Spring Spawners (% by wt.)	Spring Spawner Biomass	Autumn Spawner Biomass
St. Georges S.	1	1157.4	17	10929.8	-36.71	2.89E-07	7.69E-14	2.77E-07	333.9	0.00135	1566	2.27E+06	1505	96.1	49.7	778	788
St. Georges N.	2	665.8	10	10732.0	-36.71	0.00E+00	0.00E+00	0.00E+00	0.0	0.00000	0	0.00E+00	0	0.0		0	0
Port-au-Port G.	3	850.6	13	11531.0	-36.71	1.10E-06	5.89E-13	7.67E-07	933.6	0.00515	4379	9.38E+06	3062	69.9	49.7	2176	2203
Port-au-Port	4	437.4	11	7524.4	-36.71	6.48E-09	4.14E-17	6.43E-09	2.8	0.00003	13	1.74E+02	13	99.3	49.7	7	7
B. of Islands G.	5	707.6	16	10237.8	-36.71	4.44E-06	2.52E-12	1.59E-06	3141.8	0.02083	14737	2.78E+07	5270	35.8	49.7	7324	7413
Bonne Bay Bk.	6	1035.5	44	10350.2	-37.68	1.28E-05	6.98E-12	2.64E-06	13206.5	0.07470	77354	2.34E+08	15300	19.8	49.6	38337	39017
Bay of Islands	7	295.7	4	14401.7	-36.71	1.81E-06	3.00E-12	1.73E-06	534.2	0.00847	2506	5.77E+06	2403	95.9	49.7	1245	1260
Bonne Bay	8	53.2	11	2200.5	-37.43	9.62E-07	3.14E-13	5.61E-07	51.2	0.00532	283	2.72E+04	165	58.3	44.0	125	159
Table Point	9																
St. John Bay	10																
	Total	5203.3	126	9736.7					18204.0	0.01938	100839	2.79E+08	16713	16.6	49.6	49993	50846

1995

Stratum Name	Stratum No.	Stratum Area (km^2)	No. of Transects	Average Distance (m)	Mean TS (dB)	Sa - Area Scattering (sr) Mean (sr/m^2)	Var	S.E.	Total Scattering (m^2/sr)	Biomass Density (kg/m^2)	Biomass Density (t/stratum) Total	Var	S.E.	C.V.	Spring Spawners (% by wt.)	Spring Spawner Biomass	Autumn Spawner Biomass
St. Georges S.	1	1156.7	14	10952.6	-35.94	0.00E+00	0.00E+00	0.00E+00	0.0	0.00000	0	0.00E+00	0	0.0		0	0
St. Georges N.	2	666.5	8	10911.8	-35.94	0.00E+00	0.00E+00	0.00E+00	0.0	0.00000	0	0.00E+00	0	0.0		0	0
Port-au-Port G.	3	866.8	10	11557.3	-36.01	1.89E-06	2.22E-12	1.49E-06	1640.6	0.00756	6552	2.66E+07	5162	78.8	70.0	4586	1965
Port-au-Port	4																
B. of Islands G.	5	766.3	25	11957.9	-36.06	3.19E-06	1.91E-12	1.38E-06	2447.9	0.01290	9885	1.82E+07	4262	43.1	53.7	5312	4573
Bonne Bay Bank	6	1044.5	33	12481.3	-36.14	3.41E-06	5.88E-13	7.67E-07	3563.3	0.01403	14658	1.08E+07	3294	22.5	39.0	5717	8942
Bay of Islands	7	296.6	10	10005.6	-36.16	0.00E+00	0.00E+00	0.00E+00	0.0	0.00000	0	0.00E+00	0	0.0		0	0
Bonne Bay	8	53.0	9	2404.3	-36.18	2.24E-07	2.58E-14	1.61E-07	11.9	0.00093	49	1.34E+03	37	74.5	79.2	39	10
Table Point	9	487.1	11	9065.9	-36.17	2.11E-06	1.46E-12	1.21E-06	1029.0	0.00874	4257	5.97E+06	2444	57.4	38.8	1650	2607
St. John Bay	10	1786.5	20	17441.1	-36.19	7.29E-06	1.63E-11	4.04E-06	13028.9	0.03031	54149	9.00E+08	30005	55.4	38.5	20847	33301
	Total	7124.0	140	10753.1					21721.6	0.01257	89550	9.62E+08	31015	34.6	42.6	38151	51398

1997

Stratum Name	Stratum No.	Stratum Area (km^2)	No. of Transects	Average Distance (m)	Mean TS (dB)	Sa - Area Scattering (sr) Mean (sr/m^2)	Var	S.E.	Total Scattering (m^2/sr)	Biomass Density (kg/m^2)	Biomass Density (t/stratum) Total	Var	S.E.	C.V.	Spring Spawners (% by wt.)	Spring Spawner Biomass	Autumn Spawner Biomass
St. Georges S.	1	310.5	39	4645.6	-34.81	5.51E-06	2.45E-12	1.57E-06	1712.0	0.01670	5184	3.49E+06	1869	36.0	43.5	2255	2929
St. Georges N.	2	293.2	29	5080.2	-34.81	7.02E-07	2.18E-13	4.67E-07	205.8	0.00213	623	2.93E+05	541	86.8	43.5	271	352
Port-au-Port G.	3	1293.0	26	18500.4	-34.81	2.35E-07	2.62E-14	1.62E-07	304.0	0.00071	921	6.98E+05	836	90.8	43.5	400	520
Port-au-Port	4																
B. of Islands G.	5	841.5	21	13310.8	-36.07	1.95E-06	5.80E-13	7.62E-07	1640.0	0.00789	6638	1.15E+07	3398	51.2	48.7	3233	3406
Bonne Bay Bank	6	1166.4	35	11181.8	-35.81	1.04E-06	6.06E-14	2.46E-07	1212.1	0.00396	4623	2.01E+06	1418	30.7	41.0	1895	2727
Bay of Islands	7																
Bonne Bay	8	53.2	8	2846.4	-35.81	3.17E-07	3.47E-14	1.86E-07	16.9	0.00121	64	2.58E+03	51	78.9	41.0	26	38
Table Point	9	574.8	24	8317.3	-35.81	1.56E-07	7.36E-15	8.58E-08	89.4	0.00059	341	6.07E+04	246	72.2	41.0	140	201
St. John Bay	10	1419.7	25	18100.5	-35.85	1.28E-05	3.19E-12	1.79E-06	18105.2	0.04899	69556	1.59E+08	12599	18.1	22.6	15720	53836
	Total	6660.2	207	10412.1					23285.3	0.01321	87951	1.77E+08	13298	15.1	27.2	23941	64010

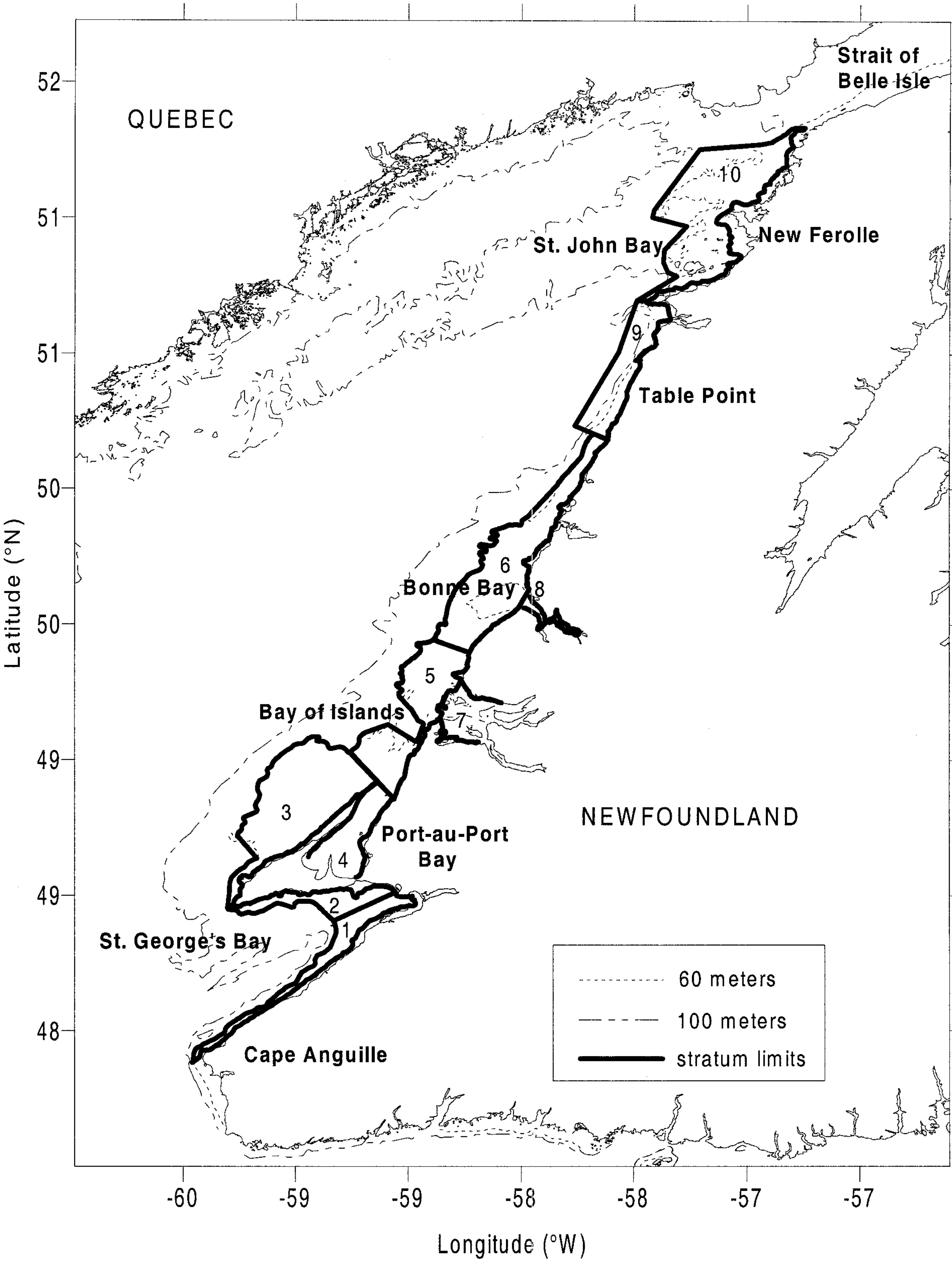

Figure 1. The west coast of Newfoundland showing the strata limits for the 1997 fall acoustic survey.

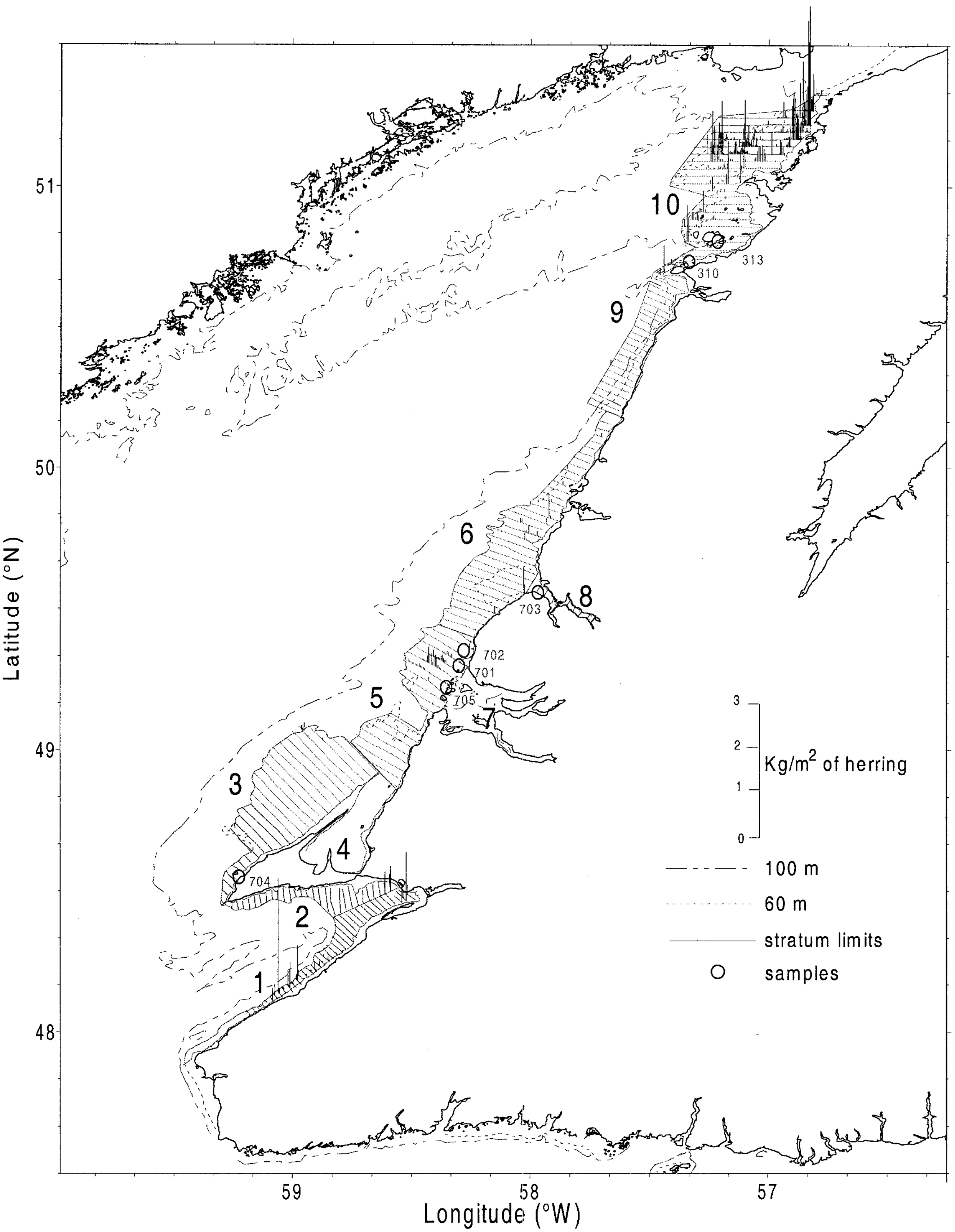

Figure 2. Distribution of herring density (kg/m^2) along the west coast of Newfoundland in October, 1997 (stratum numbers and completed transects are indicated).

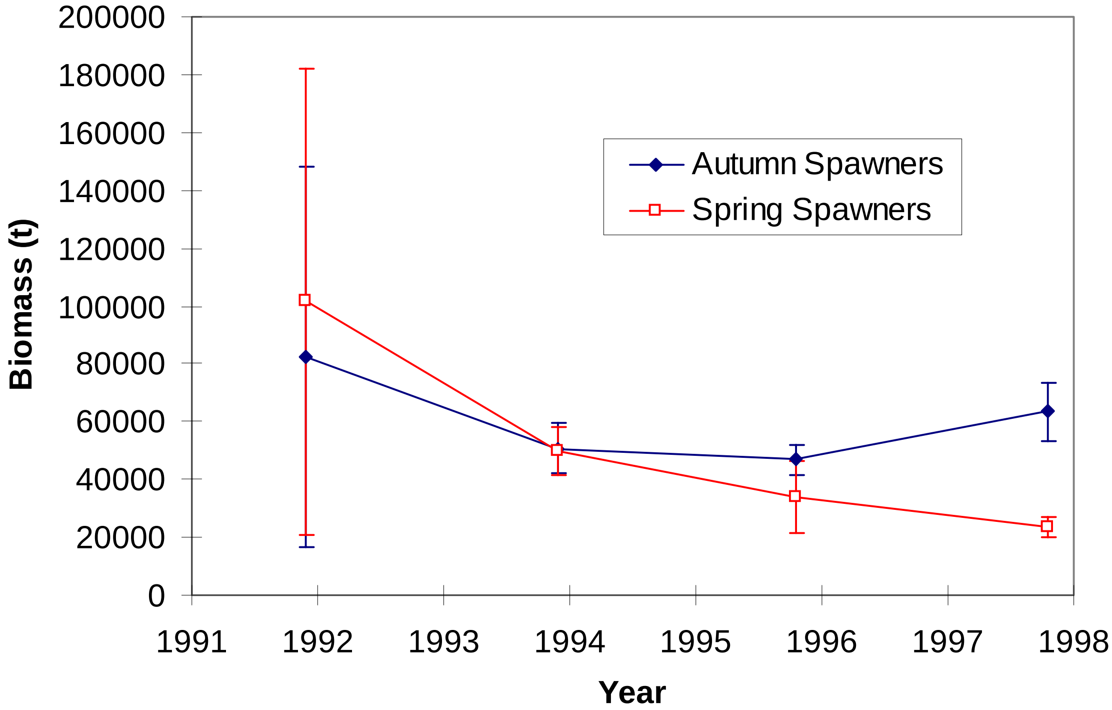

Figure 3. Total stock biomass and standard error estimates of spring- and autumn-spawning herring in NAFO division 4R from 1991 to 1997 from the biennial acoustic survey.

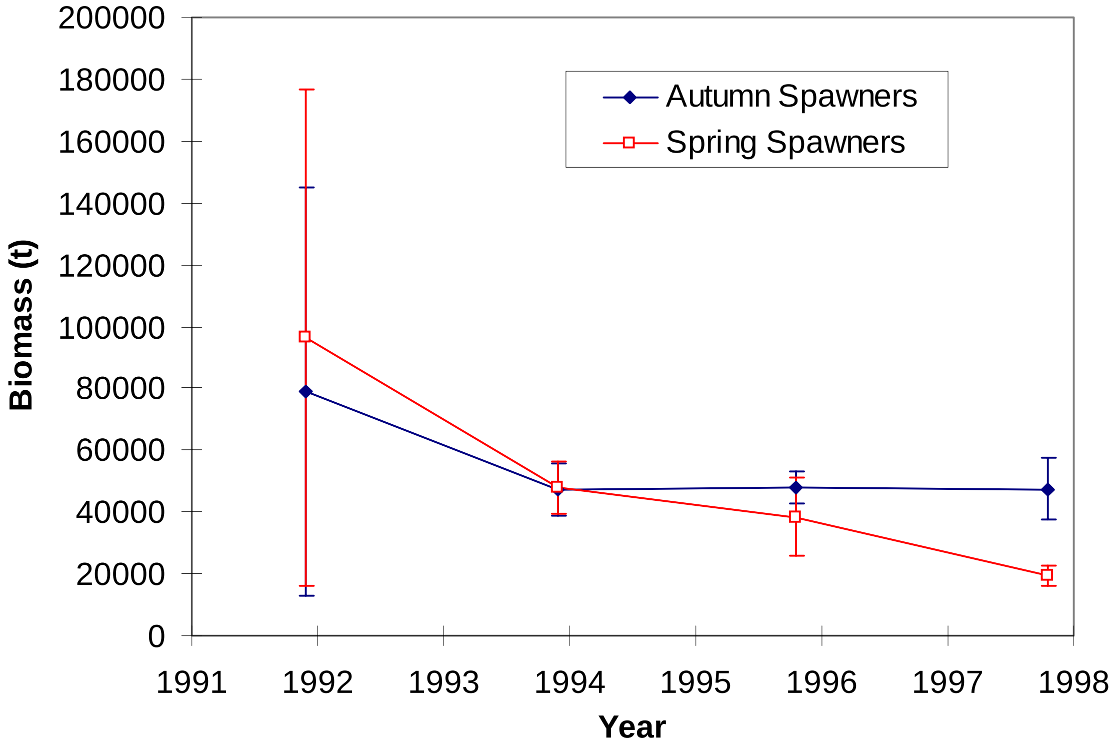

Figure 4. Spawning-stock biomass and standard error estimates of spring- and autumn-spawning herring in NAFO division 4R from 1991 to 1997 from the biennial acoustic survey.

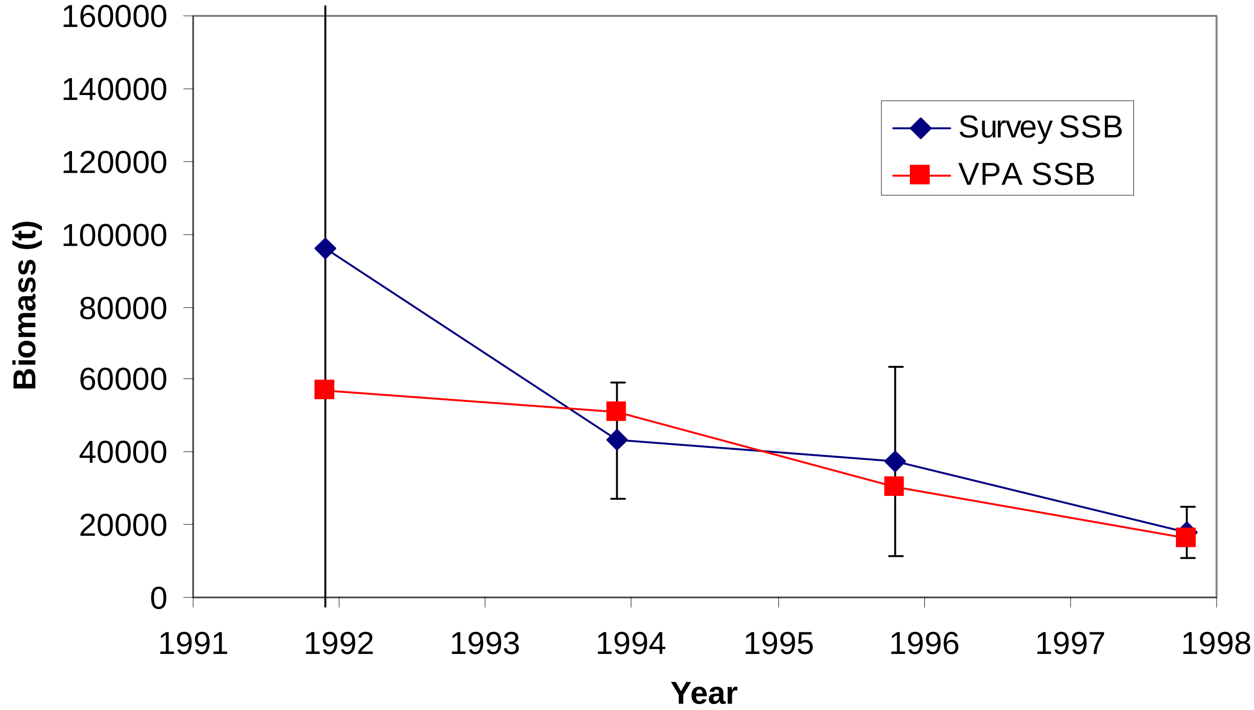

Figure 5. Spawning-stock biomass and 95% confidence interval estimates of spring-spawning herring in NAFO division 4R from 1991 to 1997 from the biennial acoustic survey compared to the virtual population analysis.

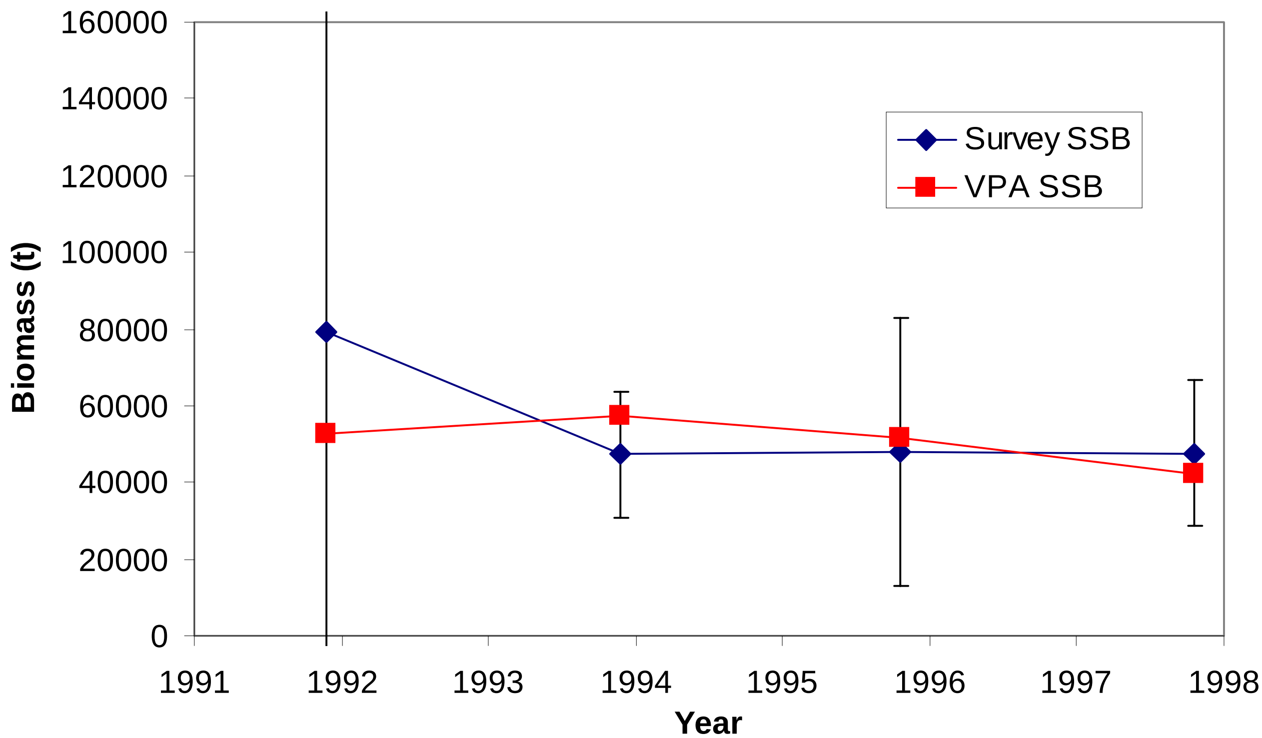

Figure 6. Spawning-stock biomass and 95% confidence interval estimates of autumn-spawning herring in NAFO division 4R from 1991 to 1997 from the biennial acoustic survey compared to the virtual population analysis.

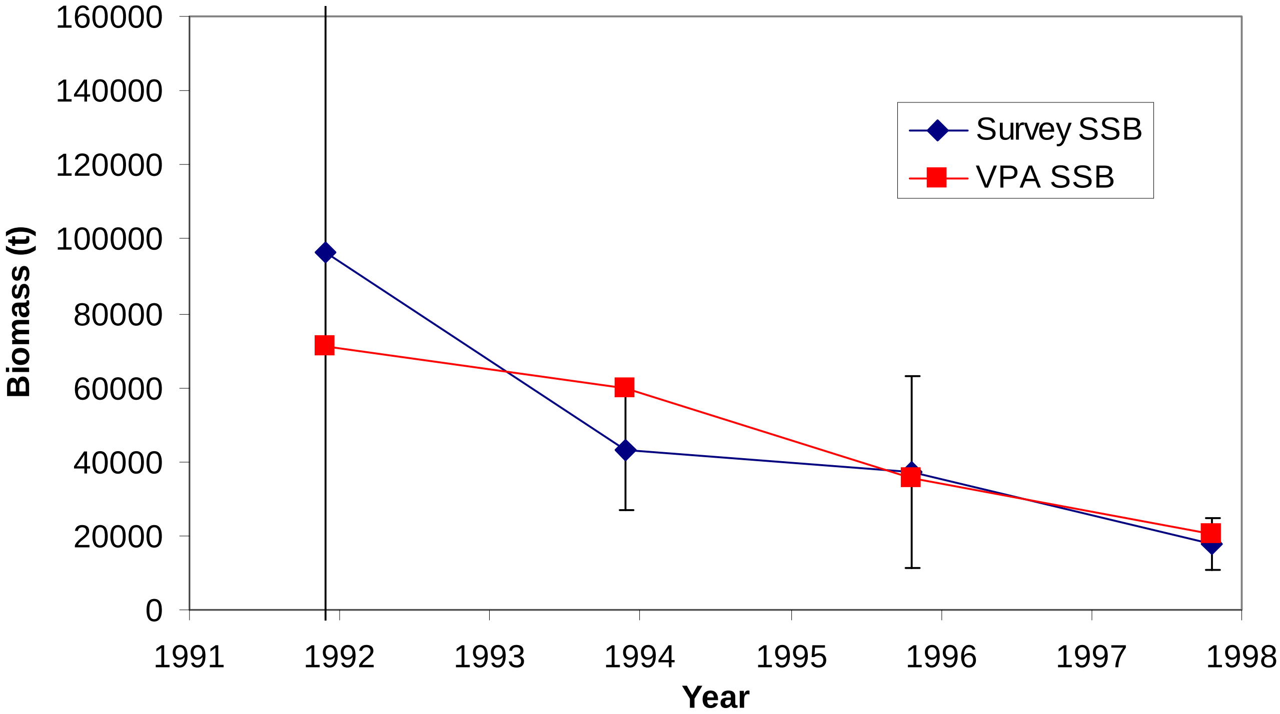

Figure 7. Spawning-stock biomass estimates of spring-spawning herring in NAFO division 4R from 1991 to 1997 from the biennial acoustic survey compared to the virtual population analysis (Index-Fisherman CPUE only).