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An acoustic-trawl survey of offshore over-wintering northern cod, February-March 2008

Relevé acoustique des voies migratoires hivernales de la morue franche, février et mars 2008

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ABSTRACT

An acoustic-trawl survey was conducted during the winter 2008 off eastern Newfoundland and southern Labrador (47^o to 54^{o}N), in NAFO Div. 2J3KL. Survey goals included assessing the distribution, the abundance and the biological characteristics of northern cod (*Gadus morhua*) overwintering on the outer shelf and upper slope. As observed during the 2007 winter survey, cod were found highly aggregated primarily in the region adjacent to the Bonavista Corridor (NAFO Div. 3K) and to a lesser extent in the inner region of Hawke Channel (NAFO Div. 2J). However, major differences in abundance, distribution and behavioral patterns were observed in 2008, notably in the Bonavista Corridor. The detected biomass (-/+ 95% CI) in 3K amounted to 101,162 t (94,272-108,050 t), of which > 90% was located within an area of 18.5 x 37 km at depths <400 m in the Bonavista Corridor, including a spawning component of 43,000 t (37,000-50,000 t). Aggregations ranged from demersal layers (5-25 m from the seafloor) to vertical columns (up to 100 m from the seafloor), the latter typically associated with cod courtship and spawning behavior. Aggregations also displayed marked diel migrations; in 2007 cod were found only demersally and no diel migrations were observed. Catch data indicated that most fish ranged between 35-65 cm in length (4-7 years-old). Approximately 45% of the sampled fish were mature or maturing. The biomass estimates in 2J amounted to 4,760 t (4,596-4,924 t), with 771 t (758-784 t) in 3L (mostly of fish <35 cm and immature and/or maturing; target areas in 3L were not completed surveyed). When compared to the 2007 survey, the results of this study indicate that the biomass estimate of cod overwintering offshore in 3K has increased several fold, age and length structures have expanded; and behavioral and distribution changes related to spawning and migratory cycles are now evident.

RÉSUMÉ

Un relevé acoustique au chalut de fond a été réalisé au cours de l’hiver 2008 à l’est de Terre-Neuve et au sud du Labrador (de 47 ^{o} à 54 ^{o}N), à OPANO, div. 2J,3KL. Le relevé visait l’évaluation de la distribution, de l’abondance et des caractéristiques biologiques de la morue franche (*Gadus morhua*) hivernant sur la plate-forme externe et sur la pente supérieure. Comme en 2007, nous avons constaté que la morue était fortement concentrée d’abord dans la région adjacente au corridor de Bonavista (OPANO, div. 3KL) et, dans une moindre mesure, dans la région intérieure du chenal Hawke (OPANO, div. 2J). Cependant, d’importantes différences ont été observées en 2008 en ce qui concerne l’abondance, la distribution et les modèles de comportement, surtout dans le corridor de Bonavista. La biomasse détectée (-/+ 95 % CI) en 3K s’élevait à 101 162 t (94 272 -108 050 t), dont > 90 % était située dans un périmètre de 18,5 x 37 km à des profondeurs <400 m dans le corridor de Bonavista, y compris une composante de reproducteurs de 43 000 t (37 000 -50 000 t). Les concentrations variaient de couches de fond (de 5 à 25 m du fond marin) à des colonnes verticales (jusqu’à 100 m du fond marin); cette dernière occurrence étant typiquement associée au comportement de parade nuptiale et de frai. Les regroupements présentaient des migrations journalières importantes; en 2007, la morue ne se trouvait qu’en couches de fond et aucune migration journalière n’a été observée. Les données sur les prises indiquent que la plupart des poissons étaient d’une longueur de 35 à 65 cm (4-7 ans). Environ 45 % des poissons échantillonnés étaient matures ou presque. Les estimations de la biomasse en 2J s'élevaient à 4 760 t (4 596 -4 924 t), dont 771 t (758-784 t) en 3L (surtout des poissons de <35 cm et immatures ou matures; les zones ciblées en 3L n'ont pas été sondées en totalité). En comparaison au relevé de 2007, les résultats de cette étude indiquent que l'estimation de la biomasse de la morue franche hivernant en 3K s'est multipliée, que les structures d'âge et de taille ont augmenté; les changements de comportement et de distribution afférents aux cycles de reproduction et de migration sont désormais clairement établis.

INTRODUCTION

This report presents the results of an acoustic-trawl survey for northern cod conducted between February 25 and March 9, 2008. The survey objectives were to estimate the abundance, the distribution and biological characteristics of cod overwintering on the outer shelf and upper slope, from the northern Grand Bank to southern Labrador (47^o to 54^oN), in NAFO Div. 2J3KL (Fig. 1). The survey also supported a tagging and telemetry program aimed at studying cod movements on the shelf.

MATERIAL AND METHODS

The survey was conducted aboard the CCGS Teleost. The vessel was equipped with a calibrated Simrad EK 500 echosounder with a hull-mounted 38 kHz transducer (Simrad ES38-B, 7.1^o beam width). The area surveyed and acoustic sampling design were similar to those from the 2007 survey (Mello and Rose 2008), except in NAFO Div. 3L. In 3L the survey covered about 70% of the area surveyed in 2007. This was due to a time limitation imposed by heavy sea-ice conditions (and reduced vessel speed) encountered earlier when surveying in 2J and 3K. Echosounder measurements were recorded 24 hours/day. The vessel steamed at 3 to 8 knots and followed a triangular track along the shelf break (Fig. 1), covering the depth range known to hold most cod aggregations at this time of the year (Kulka et al. 1995; Wroblewski et al. 1995).

Fishing tows were conducted with a Campelen trawl within and around detected fish aggregations and in areas of low or no acoustic signal. Tow duration varied from 5 to 15 minutes at a speed of 3 knots. Catch data were used to verify the species contributing to the acoustic signal and to obtain measurements of cod length, weight, age, sex and maturity stage. Stomachs were also collected for future diet analysis.

At each tow location, the temperature of the water column was profiled using a trawl-mounted CTD (Seabird 19), and the time, depth, light level, wind direction and force were recorded (Table 1). Metrics of the trawl geometry (doorspread, headrope and footrope depth, and clearance from seafloor) were measured continuously using trawl-mounted sensors (Scanmar, Scantech Group). Constant wire tension was controlled by an auto-trawl system, maintaining optimal trawl position. Together, these systems were used to maintain trawl symmetry, compensating for seafloor slope and oblique water flow (Stauffer 2004).

The acoustic echograms were edited manually and integrated using Echoview software (SonarData Pty Ltd) to estimate the area backscattering coefficient or *ABC* (m^2/m^2) for each integration bin or elementary distance sampling unit (*EDSU* = 100 m long by 25 m deep) along the survey track. Seafloor depth was estimated for each ping as the depth of the maximum volume-backscattering strength (*Sv*; dB), backstepped to -48 dB. Seafloor depths were corrected for the transducer depth. Echotraces (e.g. echo shapes and colours) and target strengths (*TS*) of single fish were used to separate the *Sv* from cod from that of the seafloor and other fish species. *ABC* attributed to cod (cod_{ABC}) was converted to areal fish densities (kg/m^2) as $AD = cod_{ABC} / 10^{TS/10}$, using a mass-based *TS* equation (Rose 2003): TS (dB/kg) = $-11.26 \log (LT) - 13.67$, where *LT* is mean total length (cm). Density estimates were corrected for potential biases associated with the acoustic dead zone using a theoretical method as proposed by Ona and Mitson (1996), and spatial correlation. The latter was modeled as auto-correlation using geostatistical analysis and incorporated into the estimation procedure.

Estimates of fish density were calculated using three different approaches. First, fish density and the corresponding SE surfaces were calculated for each NAFO Division using ordinary kriging as an interpolation method. ArcGis software was used for the variogram modeling and kriging. Cross-validation was used to assess the accuracy and precision of the model predictions prior to producing the final surfaces. The calculated statistics include the regression lines using the observed and predicted density values (line of 'best fit'), and the mean error distribution. In 3K, the sensitivity of fish density estimation was investigated in more detail, because of the detection in 2008 of unusually dense aggregations of cod found in the Bonavista Corridor (Fig. 1), and concerns regarding the violation of the assumption of spatial stationarity (isotropy) and the estimation of variogram models (Rivoirard et al. 2000). The analysis consisted of estimating variogram models with different values for range, sill and nugget, and then identifying the model with the smallest nugget effect (small scale variability in fish density that is not described by the variogram model). Next, an abundance index g (the mean fish density of the interpolated surface) was estimated using the model with the smallest nugget effect (g_{nug}) and compared with the abundance index from the 'best fit' model (g_{best}). In each NAFO Division, an estimate of cod biomass was obtained by multiplying g_{nug} and g_{best} by the surveyed area, except in 3L, where the biomass was estimate for an area 30% larger than the area actually surveyed in 2008, and equivalent (standardized) to the area surveyed in 2007.

To achieve a more precise estimate of cod biomass within the aggregation zone in the Bonavista Corridor, a second geostatistical analysis was conducted separately at a much smaller spatial scale. GS+ software was used for the variogram modeling and kriging. The analysis was performed on a subset of the data (n = 5,336 fish density measurements) recorded around the area of the aggregations and including several haphazardly directed transects on which data were collected while conducting the tagging and telemetry program. Biomass estimates were obtained by multiplying the geostatistical mean density by the area occupied by the aggregations. The spawning biomass was calculated based on sampling done for maturity in the Bonavista Corridor (less than 2% of cod sampled for maturity were from remaining areas in 3K).

The third analysis was conducted with the same dataset from the aggregations found in the Bonavista Corridor using bootstrapping. In this technique, all observations from the original sample were pooled and sampled randomly with replacement to obtain a bootstrap dataset with the same number of observations (i.e. n = 5,336). This was repeated 1000 times to develop a series of bootstrap samples. The mean fish density was calculated for each replicate sample. The overall mean fish density (g_{boot}) and SD were estimated using the distribution of the 1000 replicates. Sensitivity to autocorrelation was tested using the same bootstrapping method, but using a sub-sample of n = 1,000 instead. Biomass estimates were calculated as previously. In all cases, -/+ 95% confidence intervals (CI) of biomass estimates were calculated.

Further details on survey design and the acoustic and geostatistical methods used in this study can be found in Mello and Rose (2008).

RESULTS

THE FULL SURVEY

Acoustic transects in NAFO Div. 2J3KL covered a total distance of 1,850 km (Fig. 1). Surveyed depths ranged from 184 to 583 m, but mostly from 280 to 440 m (Fig. 2). The median depths were 344 m (2J), 357 m (3K) and 298 m (3L).

The CTD casts recorded at tow stations show a stratified water column with a cold upper layer, varying from -1.8 to -0.9^{o}C at the surface and from -1.8 to 3.4^{o}C at the thermocline depth (50-209 m), followed by an increase in temperature with depth, reaching 3.8^{o}C at depths > 250 m (Fig. 3).

A total of 14 tows (11 on the seafloor and 3 in the demersal zone) were conducted in the study area (12 tows in 3K and 1 tow in each 2J and 3L) at depths ranging from 248 to 497 m (Table 1). As observed in 2007, the largest catches occurred in the Bonavista Corridor. However, the catch per tow in 2008 was much higher (> 560 kg in 6 of 14 nominal tows, i.e. not standardized for time) than in the previous year, and with most fish caught in shallower water (330-380 m). In 2007 a catch > 560 kg (1 of 25 nominal tows) occurred at depths of 400-430 m. Catches from the 2008 survey in 2J and 3L were considerably smaller (17-21 kg) than those from 3K, and those from the 2007 survey in the same areas (25-108 kg). Although both surveys overlap in time (the 2007 survey was conducted from February 28 to March 19) and space, any interpretation regarding trends in cod density in 2J and 3L based on catch data alone is currently limited due of the small number of fishing tows conducted in both 2007 (2 tows in 2J and 6 in 3L) and 2008. Notwithstanding, the available catch information was very useful in helping to interpret the acoustic signal in those areas.

Biological samples from catch were mostly from 3K and included 5,826 measurements of cod length, maturity stage and sex, 276 weight measurements, and aging from otolith readings of 287 fish (3K only). As observed in 2007, cod caught in 2J and 3L were generally small (<35 cm, modal length = 26 cm in both areas), immature and maturing fish (Mat P, Mat AP). The largest fish (all from 3L) ranged from 43 to 66 cm (Fig. 4 and Table 2). In 3K a bimodal distribution of larger (36-51 cm in 2007; 40-56 cm in 2008) and immature (females) or maturing (males) fish was observed. It is also noticeable that up to 22% of the males and 14% of the females were in spawning or spent condition at the time of the survey, contrasting with the findings from the previous year, when 97% of the fish (both sexes) were either immature or maturing (Mello and Rose, 2008). The age structure of cod expanded in 3K, with mostly 4-7 and even some older fish represented in the samples, whereas most fish sampled in 2007 were 3-5 years old (Fig. 5).

The analysis of the acoustic data indicates that most cod_{ABC} (proxy for fish density) was detected at depths ranging between 450-510 m (2J), 330-390 m (3K), and 260-410 m (3L) (Fig. 6). The depth distribution of cod_{ABC} remained largely unchanged in 2J, when compared to results from the previous year, but noticeable changes were observed in 3K and 3L in 2008, with most acoustic signal observed in shallower water (cod_{ABC} depth distribution ranged between 350-550 m in 2007) and narrower depth layer (within a 200 m layer in 2007 and 60 m in 2008).

Spatial correlation was confirmed in acoustic data. Spherical models with a nugget term provided the best fit to empirical variograms (Fig. 7). The variogram range indicated auto-correlation at scales up to 39 km (2J), 28 km (3K) and 30 km (3L); variogram sill varied from 2.92 to 5.96 $(fish/m^2)^2$ and the nugget from 0.23 to 0.81 $(fish/m^2)^2$. The latter indicating unresolved spatial variability in data of 15% (2J), 14% (3K) and 8% (3L) at scales <*EDSU* (Table 3). The cross-validation analysis suggests that the models used provide accurate predictions, as indicated by the close correspondence between the regression lines based on measured and predicted values; and that the estimates are unbiased, as the regression lines for error plots (measured and predicted) are close to zero in all cases (Fig. 8). The sensitivity analysis resulted in a theoretical variogram model for 3K with a range of 9.6 km, a sill of 4.36 $(fish/m^2)^2$ and no nugget effect (Fig. 9), as well as relatively accurate and unbiased estimates of fish density (Fig.10); g_{nug} was 14% smaller than g_{best} but the SD was 23% smaller in the former and was assumed to be the best estimator for cod density in 3K.

For the second consecutive year, the prediction maps of cod density show that the highest values were found in 3K, followed by the inner region of Hawke Channel in 2J (Fig. 11). However, in 2008 density estimates in 3K were much higher (0.1 to 3.0 kg/m^2) than those from the previous year (0.002 to 0.01 kg/m^2), whereas density levels in 2007 and 2008 remained similar in both 2J (0.0001 to 0.0003 kg/m^2) and 3L (<0.0001 kg/m^2). The prediction map of SE estimation in 2J3KL exhibited mostly low values, indicating that the kriging models used had good predictive capability (Fig.12). High SE values tended to be limited to high-density areas and along the boundaries of the estimated map, as the result of the highly skewed distribution of acoustic samples used for kriging in the former, and the smaller number of samples in the latter.

The abundance index was highest in 3K, with a mean value of 0.006 kg/m^2, while in 2J the index increased slightly in relation to the 2007 estimates to 3.5 x 10^{-4} kg/m^2, but declined in 3L to 3 x 10^{-5} kg/m^2 (Table 4). These estimates include average dead zone positive corrections of 29% (2J), 22% (3K) and 25% (3L). Cod biomass estimates (-/+ 95% CI) within the surveyed areas ranged from 101,162 t (94,272-108,050 t) in 3K to 4,760 t (4,596-4,924 t) in 2J and 771 t (758-784 t) in 3L.

THE BONAVISTA CORRIDOR AGGREGATION

Most of the cod observed acoustically and caught during fishing tows (10 of 12 tows and 98% of the catch) came from fish located during the survey in the Bonavista Corridor (3K) around latitude 49.9-50.2 N and longitude 50.3-50.6 W (Fig. 13), within an area of 18.5 x 37 km and depths <400 m. Aggregations ranged from extensive demersal layers of fish ranging upwards from the seafloor 5-25 m to vertical columns ranging up to 100 m from the seafloor, and displaying marked diel migrations (Fig. 14). Densities reached up to 7 kg/m^2. Catch data indicated that most fish ranged between 35 and 65 cm in length (4-7 years old) and about 45% maturing. A lesser proportion was in spawning condition or spent.

The geostatistical analysis indicated spatial correlation at scales up to about 2.8 km but with a relatively large “nugget” effect (Figs. 15 and 16). Resultant smoothing through kriging led to a reduction in extreme values. The geostatistical mean density was 0.041 kg/m^2 and the area occupied by cod aggregations in the Bonavista Corridor was 2.37 x 10^9 m^2. The overall biomass estimates (-/+ 95% CI) amounted to 97,000 t (82,000-112,000 t), and the spawning component amounted to 43,000 t (37,000-50,000 t). The estimates include dead zone corrections ranging from 10 to 15%. Biomass estimates based on bootstrapping were not significantly different ($P > 0.05$) from the estimates obtained through geostatistical analysis using either all available data or the sub-sample dataset. In both cases, the estimated biomass was approximately 89,000 t, but as expected the precision of the estimate (-/+ 95% CI) was higher for the full dataset analysis (81,000-98,000 t) when compared to the results from the subset data analysis (73,000-110,000 t).

DISCUSSION

Cod were detected in two main locations during the 2007-2008 winter surveys; primarily in the Bonavista Corridor (3K), in the same area where large cod aggregations were last observed in the early 1990s (Rose 1993), and to a lesser extent in a region centered in Hawke Channel (2J). Traditionally, cod have been observed in these locations in winter and spring (Rojo 1958; Ruivo and Quartin 1958; Rose 2007), and according to the results of the acoustic-trawl surveys, they continue to be primary locations for cod during the post-moratorium period.

In 2008, the detected biomass of cod overwintering in 3K approached 100,000 t, of which > 90% was located in a small area (685 km^2) in the Bonavista Corridor at depths <400 m, including a spawning component of 43,000 t. Alternative bootstrapping estimates of cod biomass in the same area produced similar results as those obtained using geostatistics, including comparable levels of precision of estimates. In this study, the high resolution of the acoustic coverage generated a large number of fish density measurements (and a systematic-like sampling grid) covering the area where the aggregations were detected. In this case, the impact of biases like autocorrelation on abundance estimates will probably be low, as supported by the results of the bootstrapping and geostatistical analyses.

Of note, in 2008 fish aggregated off the seafloor within dense layers and columns up to 100 m high, as has been observed in at least three other stocks (Ouellet et al. 1997; Lawson and Rose, 2000; Rose, 2007), but not for offshore northern cod since 1992. Such pelagic distribution is indicative of cod courtship and spawning behavior (Rose 1993). As recently as the 2007 winter survey, cod were found to be more dispersed (densities <0.01 kg/m^2) in the demersal zone (depth <25 m from the seafloor) during both day and night periods and in deeper waters (450-550 m). Also in 2007, the fish caught were smaller and younger than those sampled in 2008.

Biomass estimates in 2J varied to a lesser extent, increasing by about 20%, from close to 4,000 t in 2007 to 5,000 t in 2008. The aggregations detected in Hawke Channel in both years were found at depths raging between 400-500 m and exhibited similar spatial patterns to those observed in the Bonavista Corridor in 2007 (i.e. demersal layer-like distribution and no diel migration). In 3L biomass estimates declined between 2007 and 2008, from 2,600 t to less than 1,000 t, but the 2008 estimates are likely inaccurate, due to reduced area coverage. The biological characteristics of male and female cod found in 2J and 3L were for the most part similar in both years, with the predominance of small and immature fish.

One benefit of the present acoustic method is that it enables an absolute estimate of biomass within the surveyed area. As the spatial coverage of the survey was limited (although designed to cover the expected distribution of any over-wintering and pre-spawning cod aggregations on the outer shelf), the biomass estimates should be regarded as minimum estimates for the stock. The 2008 survey suggests that biomass of cod overwintering offshore has increased several fold in recent years and experienced age (and length) structure changes with an increased frequency of older fish, thus indicating a decline in mortality rates that may have limited any rebuilding for over a decade (Fudge and Rose 2008). There are also indications of behavioral and distribution changes related to spawning (and possibly migratory cycles, see DFO, 2009), as for the first time since the moratorium, there is evidence of relatively large pre-spawning and spawning aggregations displaying what might be termed “normal” seasonal behavior (e.g., dense spawning columns).

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Table 1. Tow station information and cod catch recorded during a combined acoustic-trawl survey off Newfoundland and Labrador during the winter 2008. Wind force is according to the Beaufort scale. NST = Newfoundland Standard Time (-3:30 hours GMT). Superscript * indicates off the bottom tows.

Tow no.	Date	Time (NST)		Tow depth	Light	Wind		Catch kg (number)		
		start	end	(m)	level	force (km/h)	direction	2J	3K	3L
1	28-Feb	8:09	8:24	497	overcast	12-19	W		3 (9)	
2	1-Mar	17:21	17:35	390	dusk & dawn	20-28	W	21 (114)		
3	3-Mar	6:42	6:55	444	overcast	20-28	SW		85 (122)	
4	4-Mar	20:29	20:39	342	dark	20-28	W		997 (821)	
5	4-Mar	18:07	18:12	330	overcast	50-61	S		4 (2)	
6*	5-Mar	10:18	10:33	248	overcast	62-74	NW		0	
7	5-Mar	12:01	12:14	343	bright & hazy	62-74	W		568 (828)	
8*	5-Mar	13:50	14:21	328	bright	39-49	W		27 (17)	
9	5-Mar	15:43	15:58	341	bright	39-49	NW		672 (884)	
10*	6-Mar	9:34	9:40	375	overcast	62-74	S		11 (14)	
11	6-Mar	18:40	18:42	352	overcast	50-61	W		3721 (1654)	
12	6-Mar	22:07	22:10	357	overcast	62-74	SW		561 (525)	
13	7-Mar	17:21	18:01	328	dusk & dawn	29-38	W		870 (799)	
14	8-Mar	22:38	22:53	347	dark	6-11	SW			17 (39)

Table 2. Maturity stages of cod sampled during the 2008 winter survey in NAFO Divisions 2J3KL according to the visual classification criteria provided by Morrison (1990).

Sex	Maturity	NAFO		
		2J	3K	3L
Male	Immature	55	224	14
	Spent L		1	
	Mat P		233	1
	Partly spent		29	1
	Spent P		23	
	Spent P with milt		35	
	Spent P Mat N with milt in test		27	
	Spent P Mat N with milt	5	12	
	Mat N		2	
Female	Immature	53	431	20
	Spent L		1	
	Mat AP	1	170	2
	Mat BP			1
	Partly spent		5	
	Spent P		70	
	Mat at Present		20	
	Mat AN		1	
	Spent L Mat AP		1	

Table 3. Variogram model parameters computed for the acoustic cod density estimates from the 2008 winter survey in NAFO Divisions 2J3KL.

NAFO	Sill $(Fish/m^2)^2$	Range major (km)	Range minor (km)	Nugget $(Fish/m^2)^2$	Anisotropy direction (^{o})	Lag size (km)	Number of lags
2J	3.17	39	33	0.47	315	4.4	9
3K	5.96	28	19	0.81	54	2.2	10
3L	2.92	30	13	0.23	90	2.2	12

Table 4. Cod density indices (g_{best} in 2J and 3L, g_{nug} in 3K) and biomass estimates for the areas surveyed during the 2007 and 2008 winter acoustic-trawl surveys in NAFO Divisions 2J3KL.

Year	NAFO	Mean Fish Density (SD) (kg/m^2)	Area ($x\ 10^{10}\ m^2$)	Biomass (t)	-95% CI (t)	+95% CI (t)
2007	2J	0.0003 (0.0004)	1.36	4,085	3,999	4,161
	3K	0.001 (0.002)	1.68	16,831	16,204	17,395
	3L	0.0001 (0.0002)	2.57	2,574	2,488	2,652
2008	2J	0.00035 (0.0008)	1.36	4,760	4,596	4,924
	3K	0.00602 (0.0231)	1.68	101,162	94,272	108,050
	3L	0.00003 (0.00003)	2.57	771	758	784

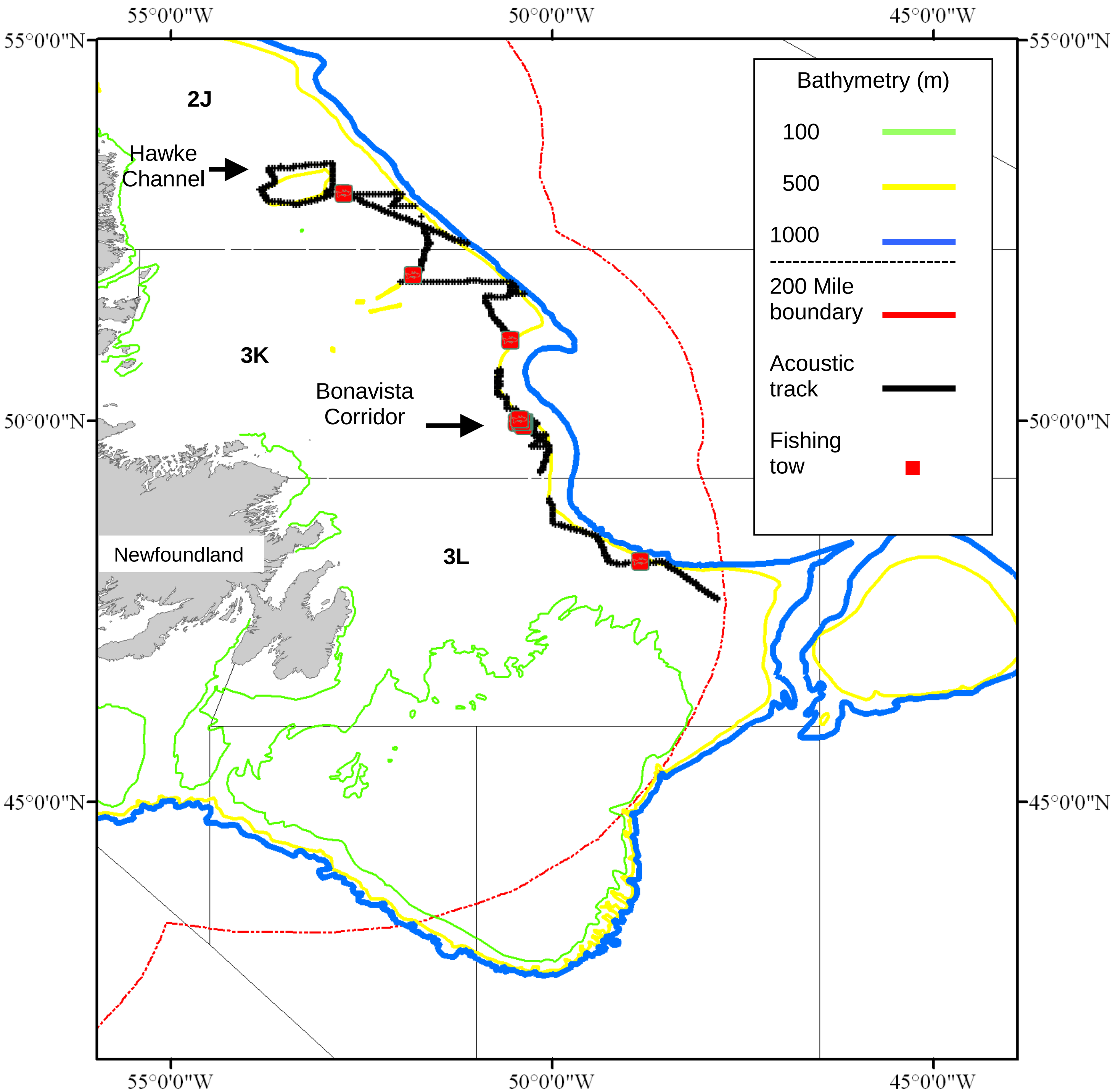


Figure 1. Northeast coast of North America showing the acoustic transects (black doted lines), the bathymetry and fishing tow stations (red squares) of the winter 2008 acoustic-trawl survey off Newfoundland and Labrador (NAFO Divisions 2J3KL).

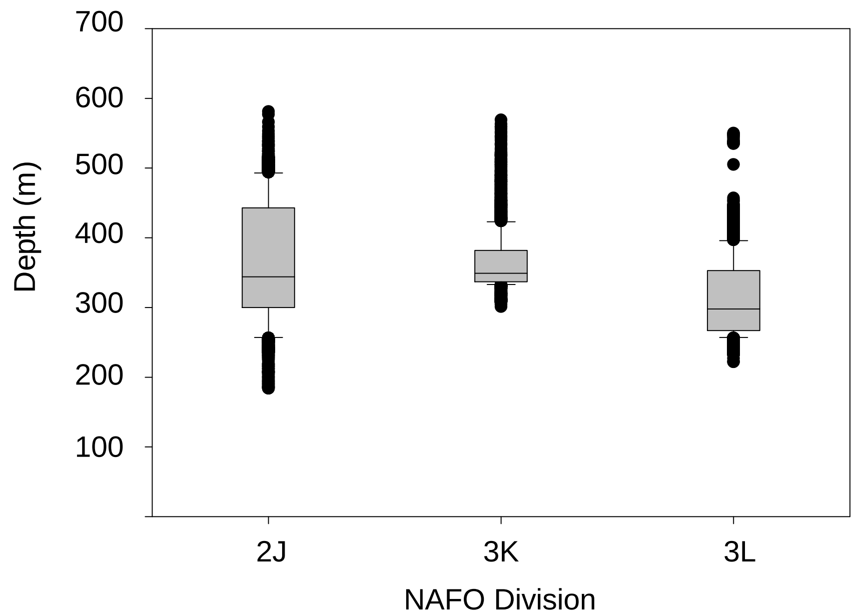


Figure 2. Depth range of acoustic transects during the 2008 winter survey. The box-plot graph shows the 25th and 75th percentiles (box lower and upper limits), the median (line inside the box), and the 10th and 90th percentiles (lower and upper limits of T-bars), with values beyond this range represented by black dots.

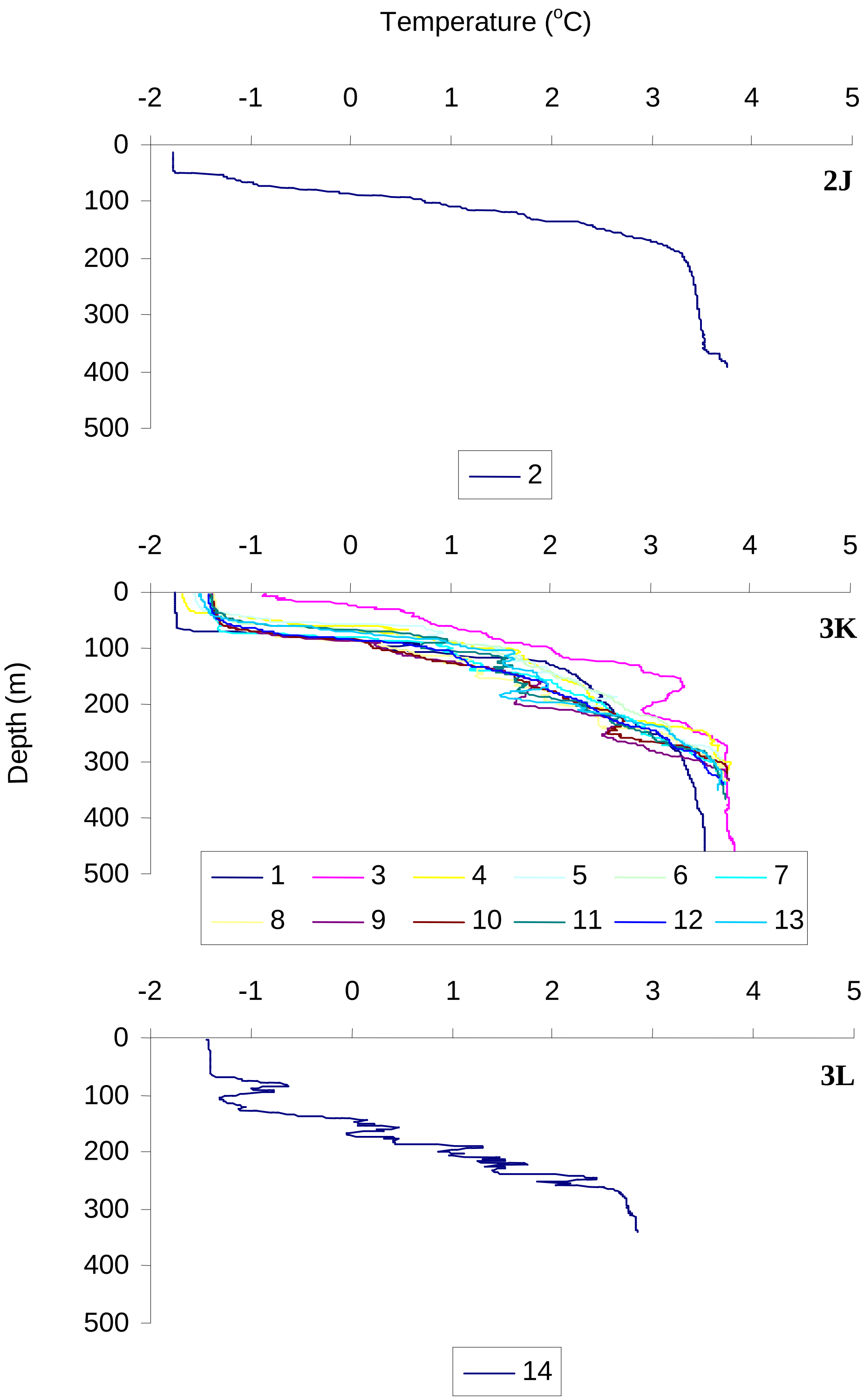


Figure 3.Profile of the water column temperature at tow stations (#1-14) recorded during the 2008 winter acoustic-trawl survey in NAFO Divisions 2J3KL.

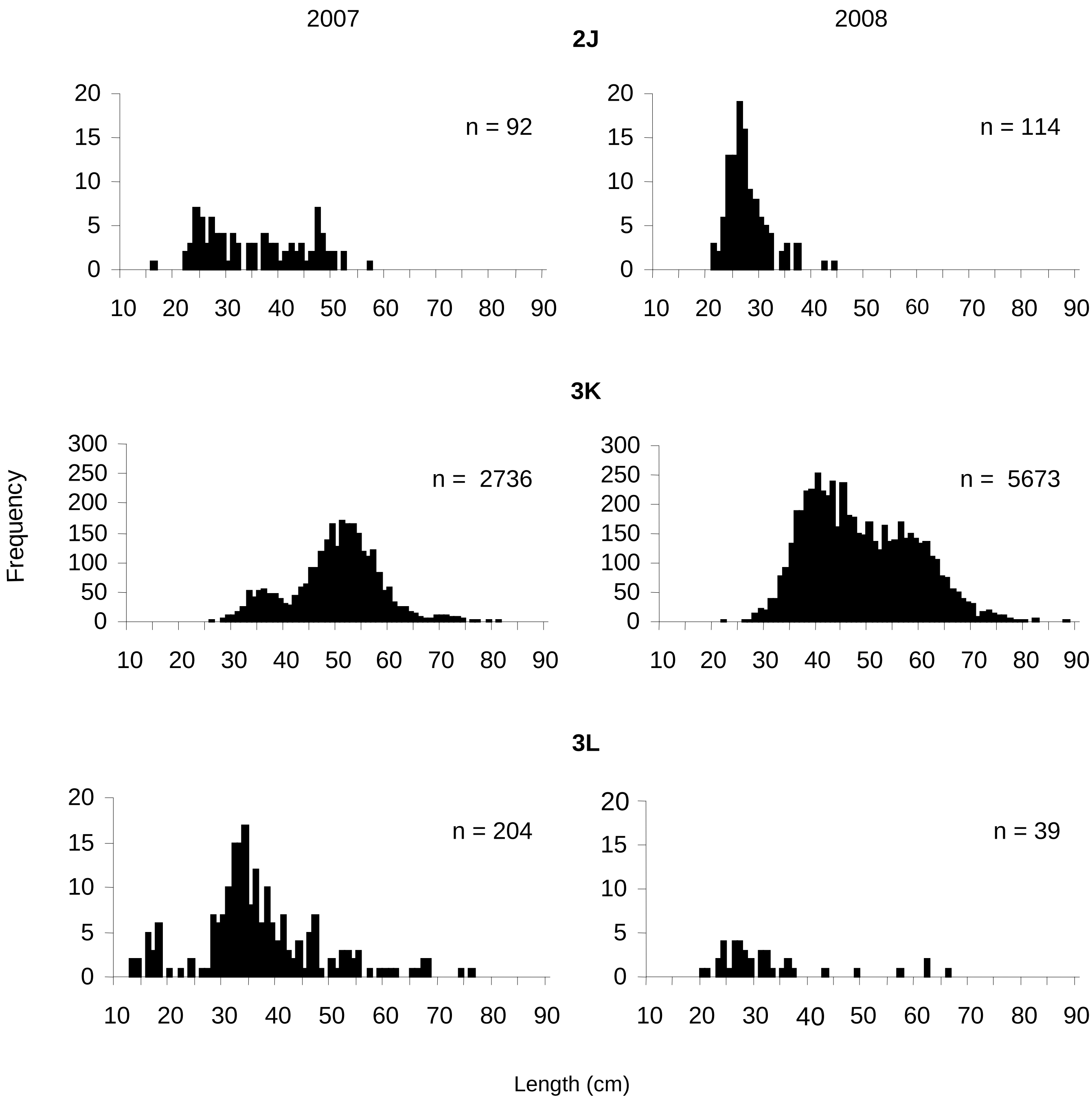


Figure 4. Length frequency distribution of cod caught during the 2007 and 2008 winter acoustic-trawl surveys in NAFO Divisions 2J3KL.

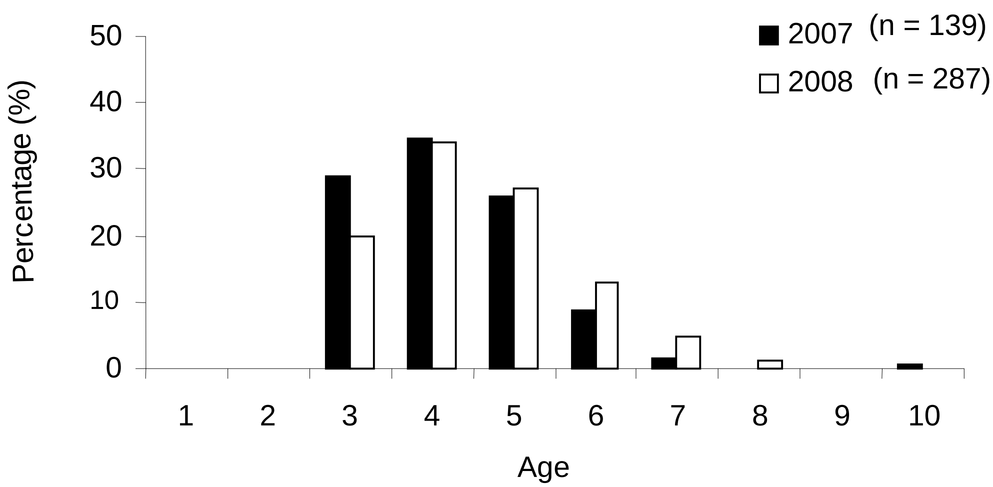


Figure 5. Age frequency distribution of cod caught during the 2007 and 2008 winter acoustic-trawl surveys in NAFO Division 3K (no otoliths were sampled in 2J and 3L in 2008). Age determination was obtained through otolith reading by DFO-NAFC personnel.

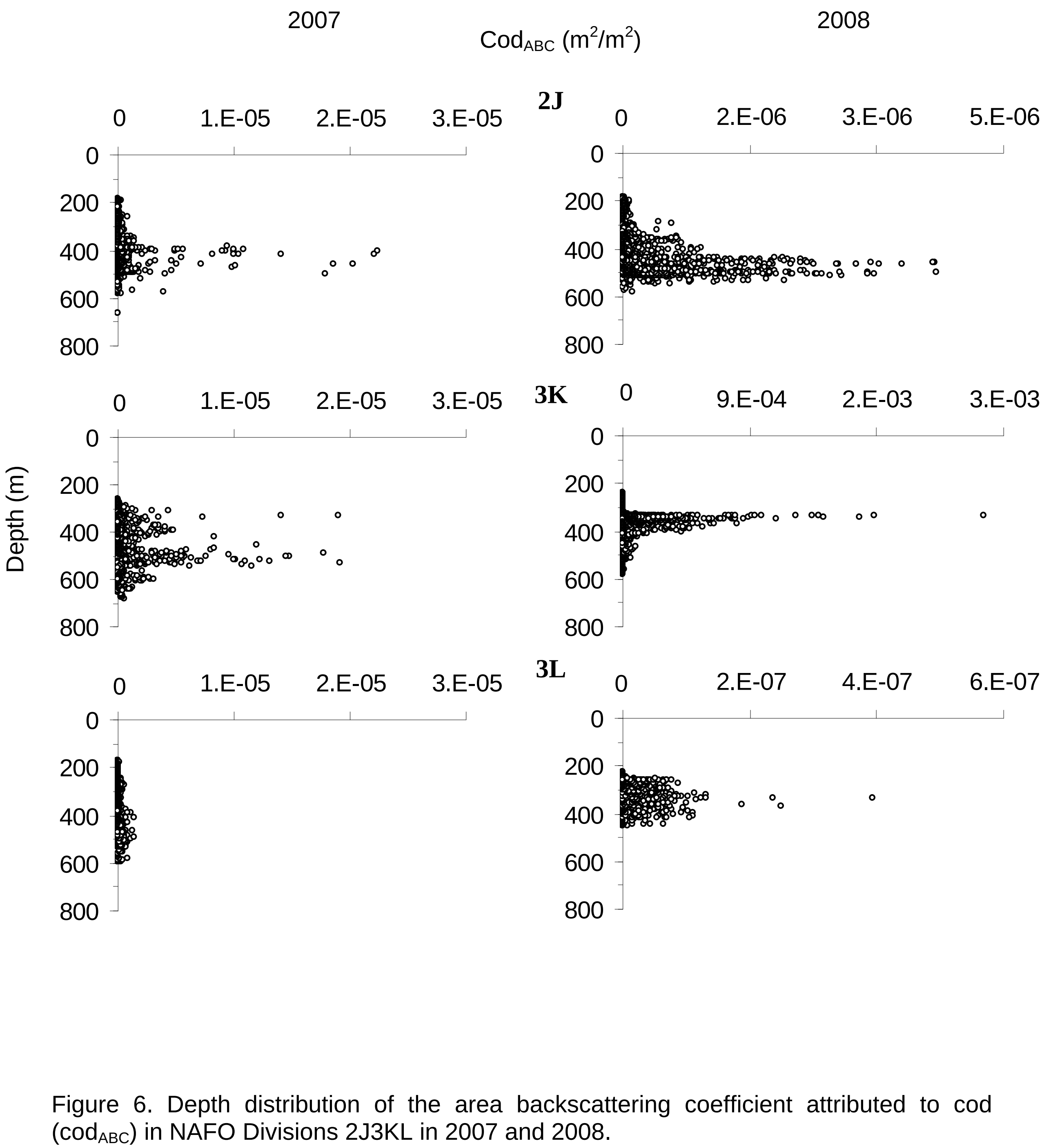


Figure 6. Depth distribution of the area backscattering coefficient attributed to cod (cod_{ABC}) in NAFO Divisions 2J3KL in 2007 and 2008.

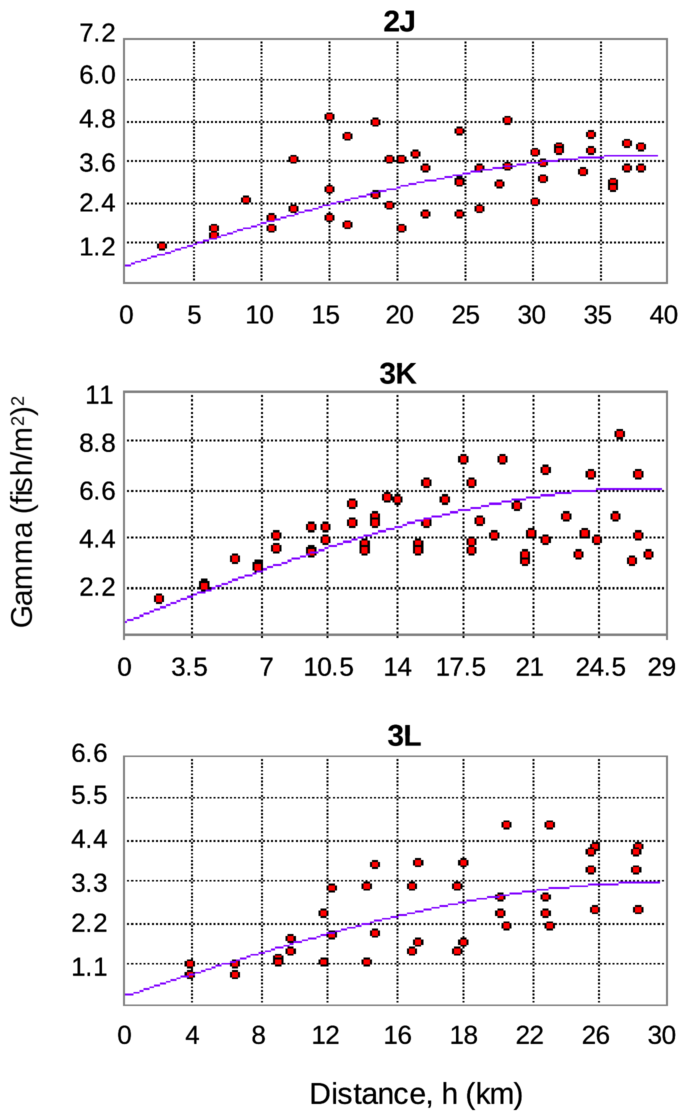


Figure 7. Empirical (dot) and theoretical (line) variogram models computed for the main direction of anisotropy (see Table 3) of acoustic cod density estimates in NAFO Divisions 2J3KL during the winter 2008. Distance h is the scalar distance between two measurements.

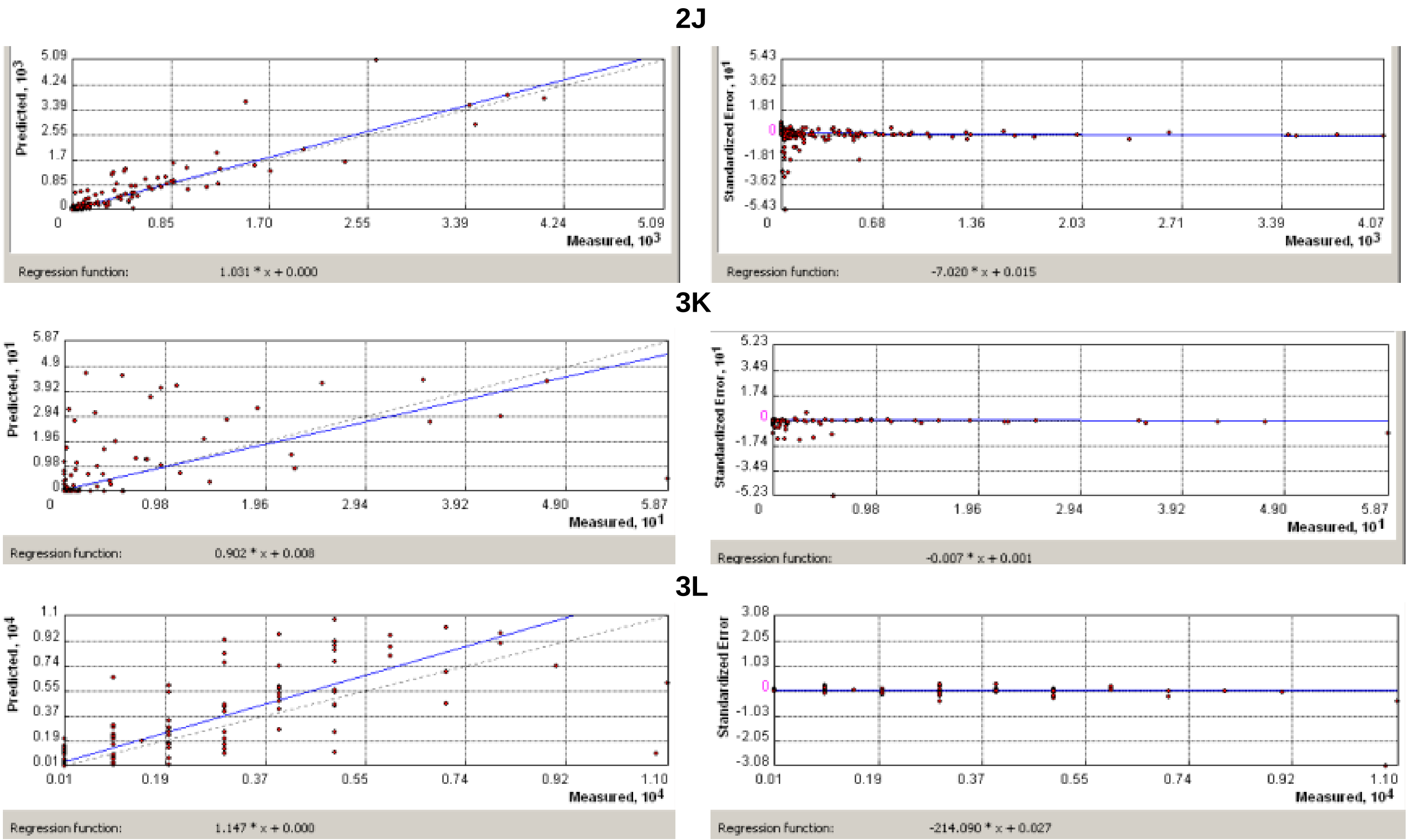


Figure 8. Results from the cross-validation analysis used to develop models for predicting cod density (left panels) and SE maps (right panels) in NAFO Divisions 2J3KL during the winter 2008. The dashed and blue lines are regression lines using measured and predicted values, respectively.

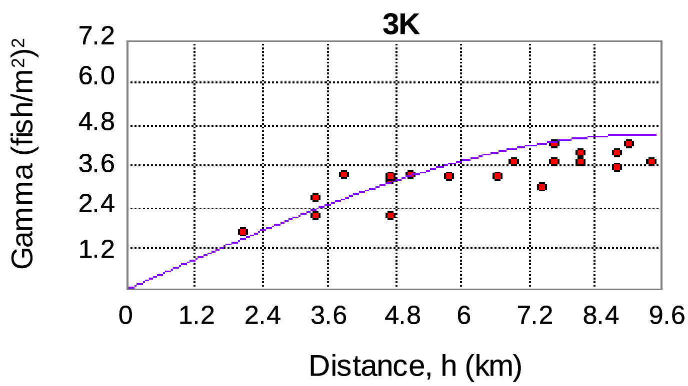


Figure 9. Empirical (dot) and theoretical (line) variogram model without a nugget effect computed for the main direction of anisotropy (72°) of acoustic cod density estimates in NAFO Division 3K during the winter 2008. Distance h (1.2 km) is scalar distance between two measurements.

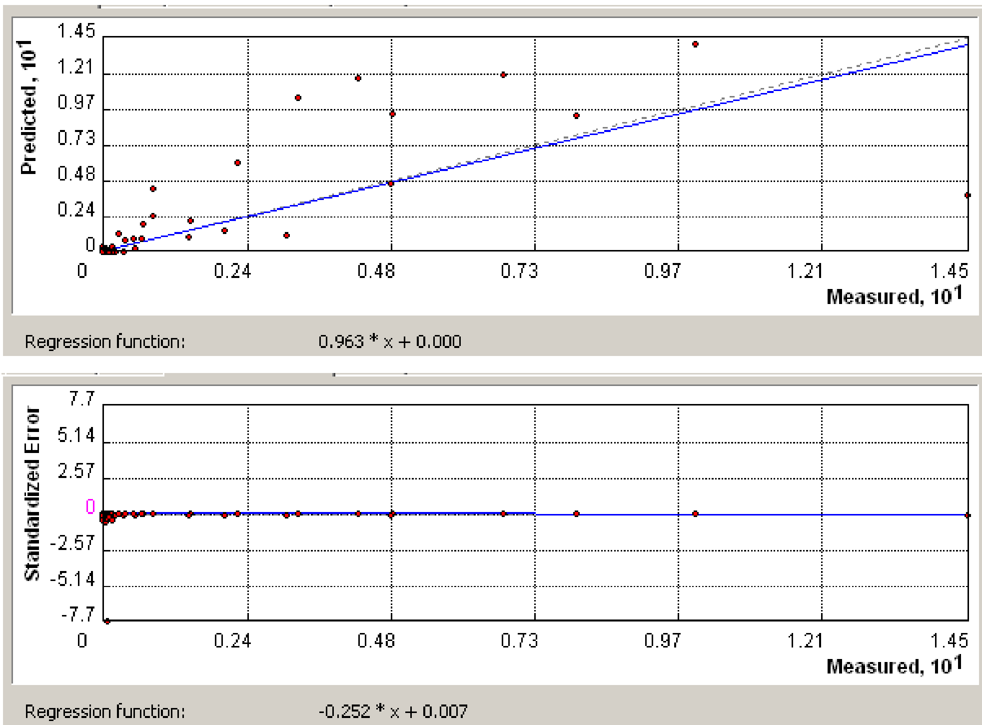


Figure 10. Results from the cross-validation analysis used to develop a model without a nugget effect for predicting cod density (upper panel) and SE maps (lower panel) in NAFO Division 3K during the winter 2008. The dashed and blue lines are regression lines using measured and predicted values, respectively.

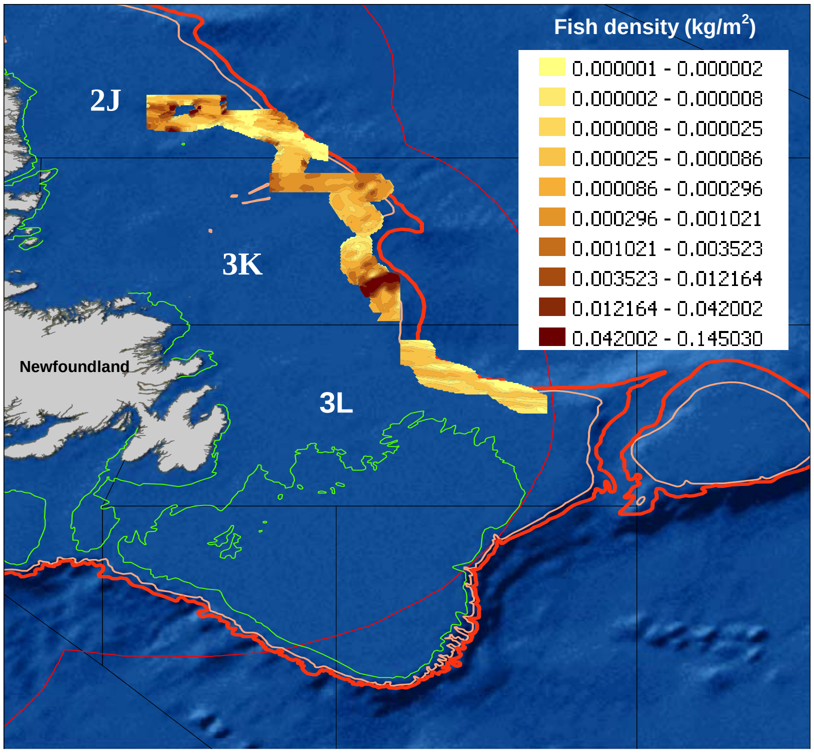


Figure 11. Prediction map of cod density (kg/m^2) along the outer shelf and upper slope from the northern Grand Bank to southern Labrador in NAFO Divisions 2J3KL during the winter 2008.

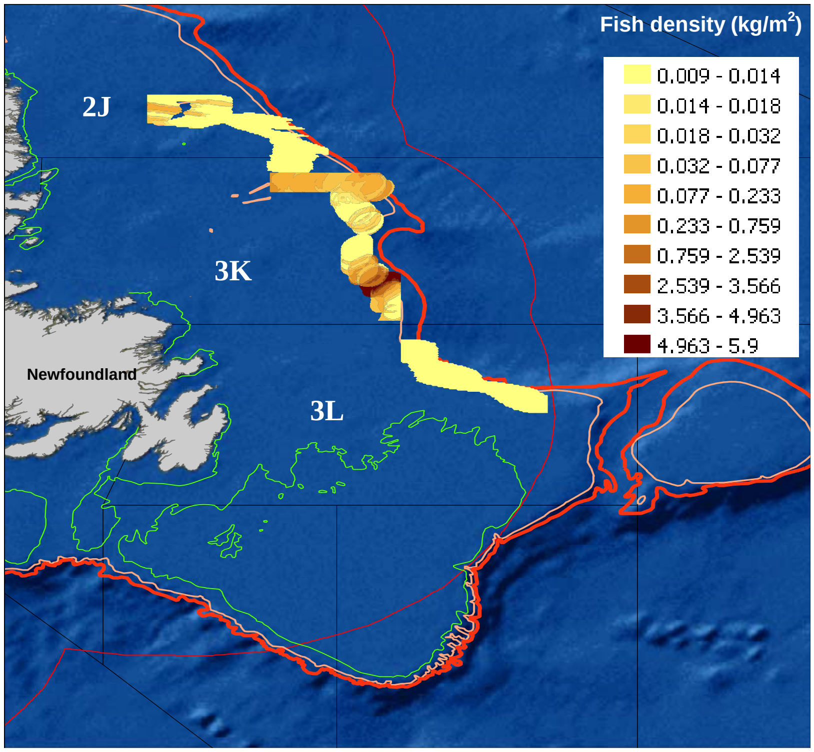


Figure 12. Prediction map of SE (kg/m^2) along the outer shelf and upper slope from the northern Grand Bank to southern Labrador in NAFO Divisions 2J3KL during the winter 2008.

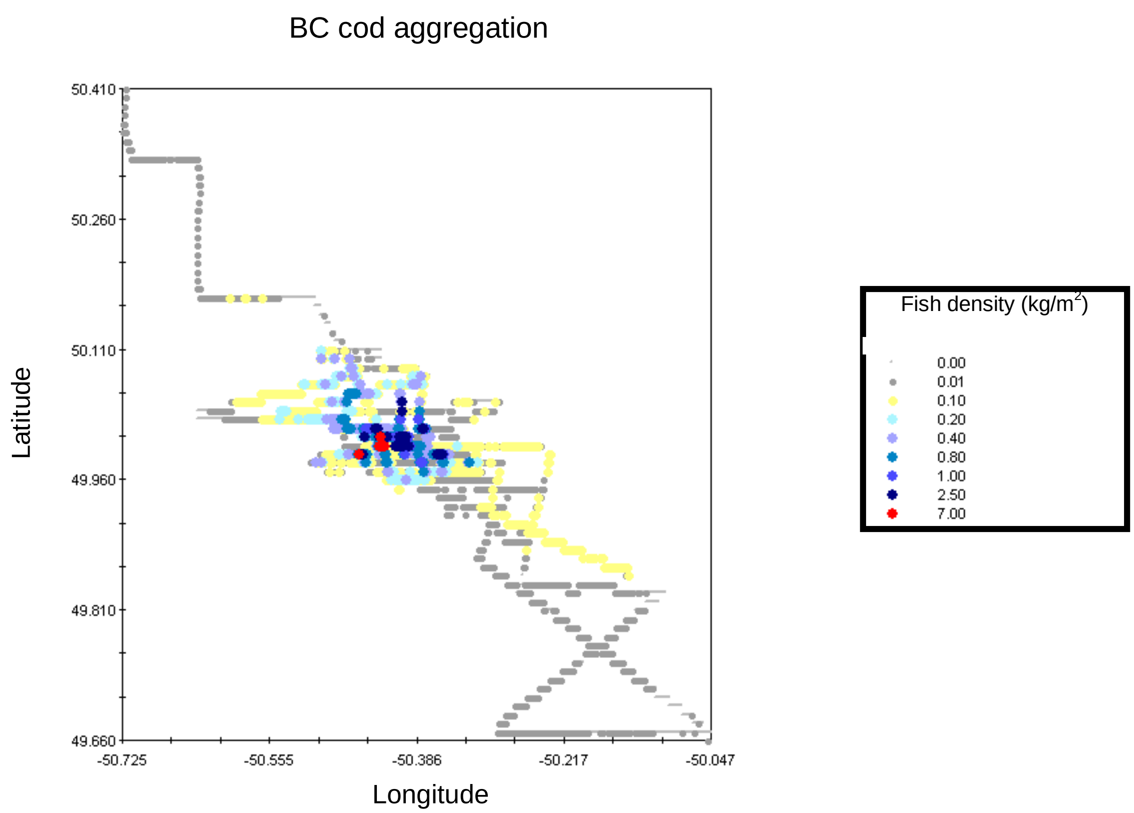


Figure 13. Map showing distribution of sampling and densities of cod in the Bonavista Corridor in March 2008.

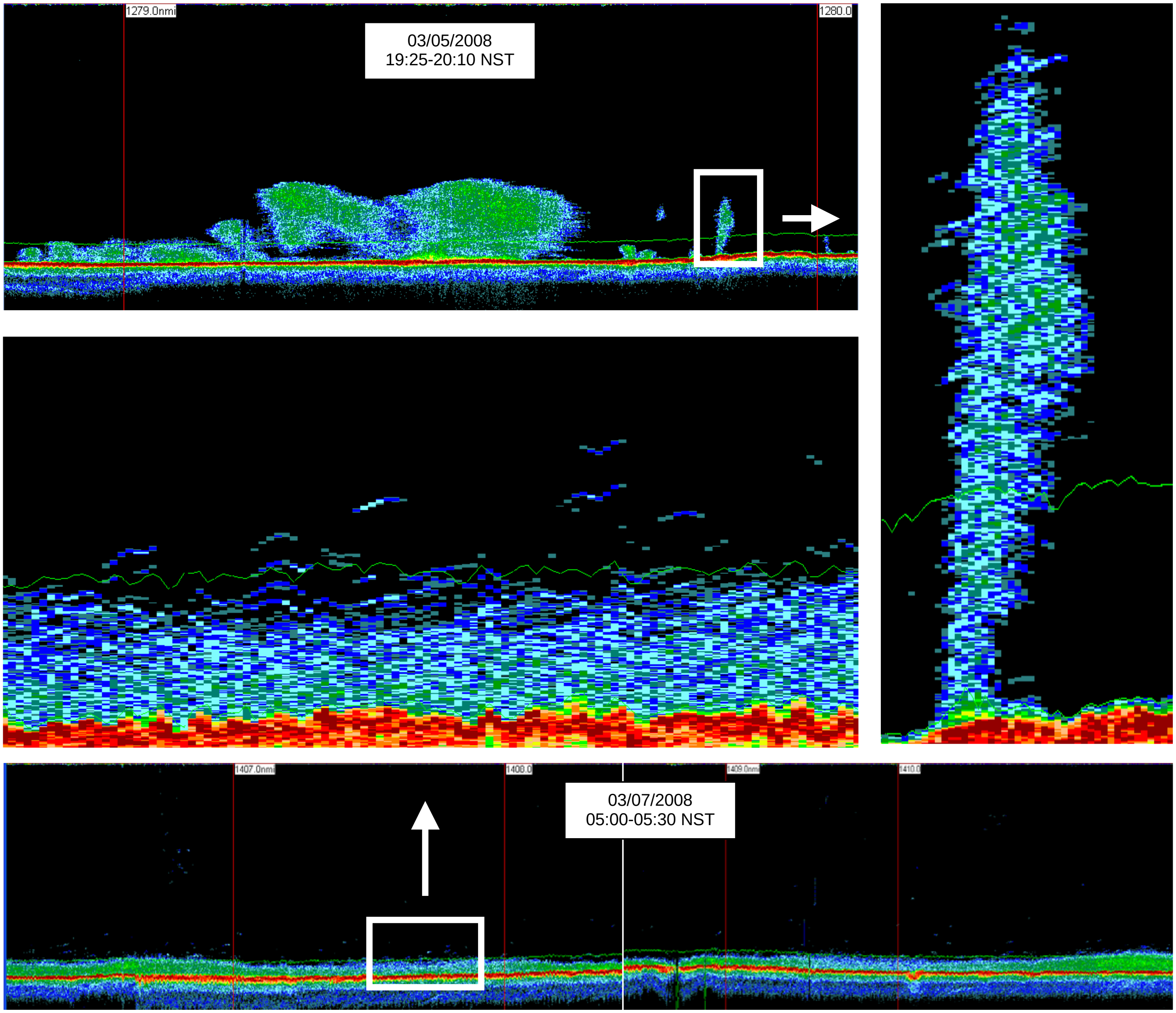
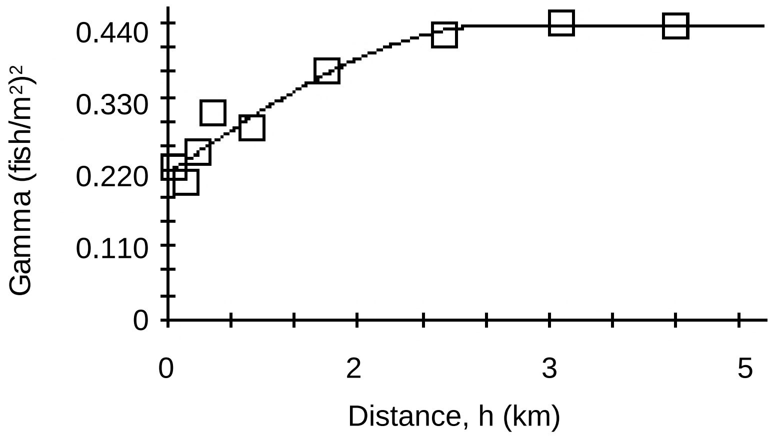


Figure 14. Echograms showing cod aggregations in the Bonavista Corridor (NAFO Division 3K) as recorded during the 2008 winter acoustic-trawl survey. Echogram *TS* colour scale varies from -13 dB (orange) to -71 dB (blue). Distance between vertical red lines = 1.852 m, and bottom (red) to dashed green line offset = 25 m.



Spherical model (Co = 0.2173; Co + C = 0.4356; Ao = 0.03; r2: RSS = 3.093^{-3})

Figure 15. Empirical (squares) and theoretical (line) semi-variogram model determined for cod aggregations in the Bonavista Corridor in winter 2008 and used during kriging.

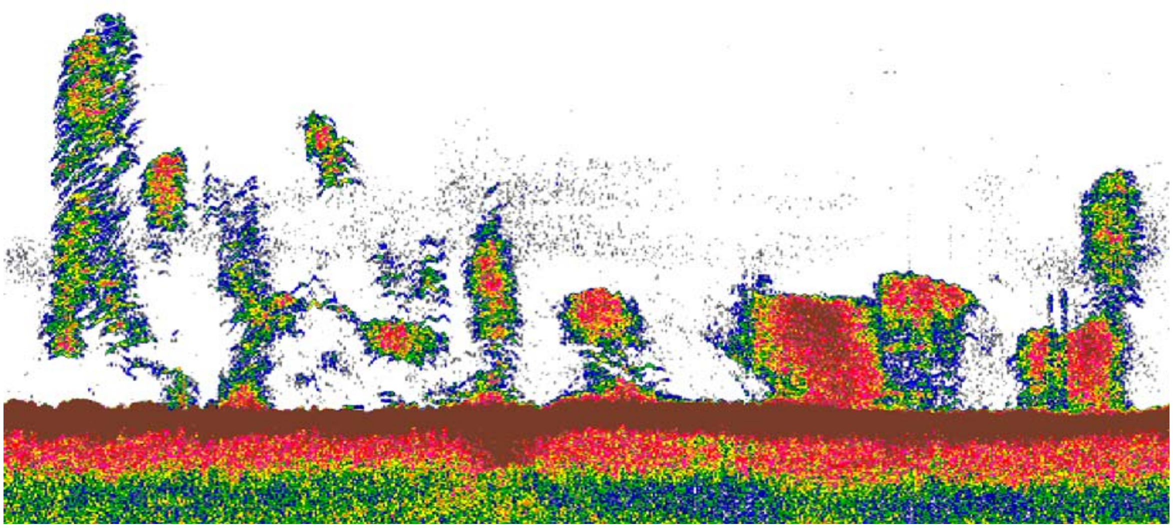


Figure 16. Echogram of formations of cod showing small-scale variability in density. Echogram spans about 1 km and fish columns extend up to 100 m off bottom.