Abundance and distribution of capelin from an acoustic survey in conjunction with the 1999 Pelagic Juvenile Survey

by

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Abstract

Acoustic data on capelin distribution and abundance in 2J3K were collected during the fall pelagic juvenile trawl survey from 1997-1999. In 1997-1998 only processed acoustic data were recorded. The 1999 survey was the first attempt to collect high-resolution acoustic data that allows post-processing and signal discrimination. Capelin distribution shifted northward from 1997 to 1999. In 1999 capelin were most abundant off southern Labrador. Capelin abundance offshore in 2J3K was estimated as 69,000 tons (33,000-116,000 tons) in 1999 using a capelin target strength of -34 dB kg^{-1}. This estimate is similar to biomass estimates from comparable Canadian fall acoustic surveys in 1990 and 1991 and lower than all estimates from the 1980s. A recent length-based model of capelin target strength was also applied to data from 1999. This model indicated that the target strength of -34 dB kg^{-1} used in previous Canadian acoustic surveys overestimates abundance of most (< 18cm) capelin. Using the new target strength model, absolute abundance of capelin in the surveyed region was 5.3 billion fish (3.4-7.3 billion) equivalent to 43,000 tons (27,000-61,000 tons). Other sources of uncertainty in the absolute acoustic estimate of biomass are also considered. The pelagic juvenile survey provides an excellent framework within which to conduct continuing acoustic research on capelin. The only major concession

required in a future combined trawl/acoustic surveys is allowance for more targeted fishing sets to identify near-bottom concentrations of capelin.

Introduction

Acoustic surveys for capelin off the east coast of Newfoundland and Labrador (NAFO Divisions 2J3KL) were conducted by Canada from 1981-1996 (Miller 1997), and by Russia from 1974-1993 (Bakanev & Sergeeva 1994). Biomass estimates of capelin from acoustic survey data declined dramatically in the early 1990s and the reason for this decline was never fully explained (Carscadden & Nakashima 1997). Canadian acoustic surveys in 2J3K were discontinued after 1994, although a spring survey in 3KL was conducted in 1996 (Miller 1997). Currently, capelin abundance is monitored offshore only through bottom-trawl by-catch (Lilly 1999), and pelagic juvenile fish surveys (Anderson *et al.* 1999). Both these methods target a relatively narrow depth range and there are potential biases in abundance estimates due to the vertical migration behaviour of capelin (e.g. O'Driscoll & Rose 1999) and trawl catchability (O'Driscoll *et al.* 2000.).

The pelagic juvenile trawl survey has been conducted annually every fall (August-September) since 1994. The survey design consists of a systematic grid of trawl stations at 30 nautical mile (nmi) intervals from southern Labrador to the southern Grand Banks. Since 1997, acoustic data (Simrad EK500) have been collected during the 30 nmi legs between trawl stations. In 1997 and 1998 only processed acoustic data (see Methods) was recorded and potential for analysis and interpretation of these data was limited. In 1999 we investigated the possibility of collecting high-resolution acoustic data on capelin distribution and abundance during the pelagic juvenile survey.

In this paper we present the results from our 1999 survey and compare these to observations on capelin distribution and abundance from 1997-1998 and to results from Canadian fall acoustic surveys for capelin in 1981-1994. We include acoustic estimates of offshore capelin biomass in 2J3K in 1998 and 1999. We also evaluate the potential for a future combined trawl/acoustic survey.

Methods

Acoustic data collection

The survey design is described in detail by Anderson & Dalley (1997). Surveys were conducted using two vessels (CCGS Teleost and CCGS Wilfred Templeman) from 11 August to 29 September 1997, from August 24 to September 10 1998, and from August 23 to September 17 1999. Acoustic data were collected on CCGS Teleost in 1997 and on both ships in 1998 and 1999. Only acoustic data collected on CCGS Teleost in 1997-1999 are considered in this paper. In all years CCGS Teleost covered the northern part of the survey area (2J3K) where capelin abundance was highest. Acoustic data from CCGS W. Templeman in 1998 are not presented because of concerns about calibration of the echo-sounder. Due to a vessel breakdown in 1999, CCGS W. Templeman only covered the very southern part of the survey area where no capelin were detected.

In 1997-1998 innermost trawl stations were visited on short east-west lines from south to north, and stations further offshore were visited in the same manner from south to north (Figs. 1-2). To enable easier analysis of acoustic data, in 1999 stations were visited sequentially in an east-west transect design (Fig. 3). Only acoustic data from the 30 nmi legs between trawl stations are presented in this paper. Acoustic data were also collected during IYGPT fishing sets to examine trawl catchability. The results of these experiments are summarised by O'Driscoll *et al.* (2000).

Acoustic data were collected on CCGS Teleost using a calibrated Simrad EK500 echo-sounder with a hull-mounted split-beam 38-kHz transducer. In 1997-1998 acoustic data was integrated by the echo-sounder in real-time into eight vertical bins (14-20 m, -75 dB integration threshold; 20-40 m, -75 dB; 40-60 m, -75 dB; 60-100 m, -73 dB; 100-150 m, -66 dB; 150-200 m, -60 dB; 200-250 m, -53 dB; 250-300 m, -47 dB). Integrated data were saved to a file every 5 min (1850 m at vessel speed 12 knots). Data output was in the form of average nautical area scattering (s_A = m^2/nmi^2) for each vertical bin over the preceding 5-min interval. In 1999 raw high-resolution acoustic data (volume backscattering strengths or S_v) were recorded using the custom-designed CH1 acquisition software (Simard et al. 1998). A summary of data acquisition parameters is provided in Table 1. To decrease interference due to vessel noise maximum speed between trawl stations was reduced from 12-13 knots to 10 knots in 1999.

Acoustic data processing

We distinguished acoustic signals from capelin based on echogram appearance and information from IYGPT fishing sets conducted at trawl stations. IYGPT trawls at stations only sampled between 20 and 60 m depth. In 1999 one targeted IYGPT set was also made between stations to confirm identification of a deep concentration of capelin signal off southern Labrador.

In 1997 and 1998 integrated acoustic data from vertical bins identified as containing capelin were summed to give an estimate of average area scattering due to capelin in each 1850 m (5-min) horizontal bin. Area scattering (S_A) was calculated by converting Simrad output (s_A) to standard units (m^2/m^2) by dividing by $(1852 \text{ m/nmi})^2$. Note that all acoustic terminology follows recommendations made at the ICES-FAST Working Group (MacLennan & Fernandes 1999).

Unrealistically high integration thresholds (>-70 dB) were applied to data collected at depths greater than 100m in 1997-1998. As a result some portion of the acoustic scattering due to capelin would not be integrated, biasing estimated fish densities downwards. To estimate the extent of the bias introduced by the high integration thresholds in 1997-1998 we integrated examples of capelin signal from 1999 using integration thresholds of −80 −75, -73, -66, -60, -53 and −47 dB (Table 2). This experiment revealed that over all depths abundance of capelin would be underestimated by a factor of approximately 0.66. At depths greater than 200 m the integration thresholds were so high (> -53 dB) that almost no capelin signal would be integrated. Fortunately few capelin were observed at depths greater than 200 m in 1997 or 1998 (Table 2). Note that we were still able to recognise capelin signal at all depths, because the printing threshold for the paper record was lower (-70 dB) than most of the integration thresholds. We used the correction factors in Table 2 to scale vertically binned s_A values from 1997-1998 prior to summation so the average area scattering was equivalent to that obtained by integrating at −80 dB.

In 1999 raw acoustic data were processed using CH2 data analysis software (Simard *et al.* 1998). An integration threshold of −80 dB was applied. Calculations showed that even a single small (<100 mm) capelin in the sampled volume would exceed this threshold at the range of depths commonly encountered in this survey (<300 m), while most other (biological and non-biological) "noise" would be filtered out. Signal identified as capelin was integrated throughout the water column in 100-m horizontal bins. The output of CH2 integration is average area backscattering (S_a). This was converted to average area scattering (S_A) by multiplying by 4π.

Mean capelin density (*d*) in each horizontal bin is calculated as:

$$d = \frac{S_A}{\sigma} \qquad (1)$$

where σ is the average acoustic cross-section. σ is related to target strength (*TS*) by the equation:

$$TS = 10\log_{10}(\frac{\sigma}{4\pi}) \qquad (2)$$

We used two estimates of capelin target strength. For comparison with previous Canadian acoustic surveys (Miller & Lilly 1991, Miller 1997) we scaled S_A by a TS of −34 dB kg^{-1}. We also used the length-scaled *TS* relationship for capelin of $TS = 20\log L - 73.1$ where L = fish length in centimetres (Rose 1998). Capelin length-frequency data were obtained from fishing sets.

Biomass estimation

Two methods were used to estimate capelin biomass. *Method 1* was designed to provide biomass estimates for NAFO 2J3K which were directly comparable with those obtained in previous Canadian fall acoustic surveys. *Method 1* was applied to data from 1998 and 1999. We did not attempt to estimate biomass in 1997 because not all lines in 2J3K were surveyed acoustically. *Method 2* provides what we believe is the "best" estimate of capelin biomass from the 1999 survey.

Method 1

The northern part of the survey area (in NAFO 2J3K) was divided into nine blocks corresponding to nine east-west transects (Figs 2-3). Blocks were 56 km wide (30 nmi) and between 190 and 280 km long. A single transect passed through the centre of each block. Capelin biomass was estimated independently for each block from the equation:

$$B_i = A_i \overline{d}_i \qquad (3)$$

where B_i is the biomass of capelin in block i (kg)
A_i is the area of block i (m^2)
$\overline{d_i}$ is the mean capelin density in block i (kg m^{-2})

Using equations (1) and (2) $\overline{d_i}$ was estimated from binned S_A values using a TS of −34 dB kg^{-1} (σ = 0.005 m^2/kg) (Miller 1997). This estimate assumes constant TS over all lengths and weights of capelin.

In 1998 S_A values were integrated in 1850-m horizontal bins. There was seldom autocorrelation between consecutive non-zero bins within a block, so 1850-m bins were treated as independent sample estimators of capelin density (d_i). 95% confidence intervals were defined as $\overline{d_i}$ +/- 1.96 standard errors (Table 3). To illustrate the effect on biomass of the correction for high integration thresholds (Table 2), we also calculated capelin biomass for 1998 using the uncorrected data (Table 4).

In 1999 S_A values were integrated in 100-m bins. These data were highly autocorrelated so to estimate sampling uncertainty we used a bootstrapping method (Robotham & Castillo 1990). We repeatedly (100 times) took a random sample of 5% of the 100-m binned data from each block. There was usually no significant autocorrelation in the 5% sampled data. The 100 sample means were used to calculate the bootstrapped mean density ($\overline{d_i}$) and 95% confidence intervals for each block (Table 5).

Total capelin biomass in 2J3K was calculated as the sum of the biomass in the nine blocks (Tables 3-5).

Method 2

We post-stratified the survey area into six strata (Fig. 4) based on the observed capelin distribution and length-frequency data from fishing sets (Table 6).

Capelin biomass in each stratum was calculated from the equation:

$$B_i = w_i A_i \overline{D}_i \qquad (4)$$

where B_i is the biomass of capelin in stratum *i* (kg)
w_i is the average weight of capelin from fishing sets in stratum *i* (kg)
A_i is the area of stratum *i* (m^2)
$\overline{D}_i$ is the mean fish density of capelin in stratum *i* (fish m^{-2})

$\overline{D}_i$ was estimated from 100-m binned S_A values using the length-scaled *TS* relationship for capelin of $TS = 20\log L - 73.1$ where L = fish length in centimetres (Rose 1998). Capelin length-frequency data were obtained from fishing sets in each stratum (Table 6).

To estimate sampling uncertainty we again used a bootstrapping method (Robotham & Castillo 1990) for each stratum based on repeated 5% sampling of the 100-m binned data (100 times). The 100 sample means were used to calculate the bootstrapped mean density ($\overline{D}_i$) and 95% confidence intervals for each stratum (Table 7).

Results

Capelin were readily identified in the northern part of the pelagic juvenile survey area (north of ~48.5° N). In this region capelin were the dominant acoustic scatterer in water <300 m deep. Arctic cod (*Boreogadus saida*) and shrimp (*Pandalus* spp.) were also present, but were distinguished from capelin based on *TS* (higher than capelin for arctic cod, lower for shrimp) and aggregation structure. A deep scattering layer comprised mainly of euphausiids and myctophids (our unpublished data) was associated with the shelf break in water >350 m. In 1999 the Teleost survey extended further south (Fig. 3). On the Grand Banks south of 48.5° N relatively low numbers of small capelin were commonly associated with large concentrations of sandlance (*Ammodytes* spp.). During the day it was sometimes possible to distinguish capelin and sandlance based on differences in school structure. At night, however, both capelin and sandlance formed a homogeneous layer near the surface and could not be distinguished acoustically. When this occurred we partitioned acoustic scattering due to capelin and sandlance based on IYGPT trawl catches and specific length-based *TS* values. For example, one IYGPT set on the mixed layer caught 11,000 sandlance with mean length 11cm and 1000 capelin mean length 10 cm. The *TS* of an 11 cm sandlance was calculated from the equation $TS = 20\log L - 83$ (George Rose pers. comm.) as −62.2 dB ($\sigma = 7.62 * 10^{-6}$ m^2). Similarly, *TS* of an 10 cm capelin was calculated from the equation $TS = 20\log L - 73.1$ (Rose 1998) as −53.1 dB ($\sigma = 6.15 * 10^{-5}$ m^2). Based on the trawl catch composition the proportion of the total acoustic scattering due to capelin (S_{Acapelin}) $= 1000(6.15 * 10^{-5}) / (1000(6.15 * 10^{-5}) + 11{,}000(7.62 * 10^{-6})) = 0.42$.

There was a northward shift in the spatial distribution of capelin between 1997 and 1999 (Figs. 1-3). Very few capelin were observed in 1997, with the exception of a very large concentration off Bonavista Bay (Fig. 1). In 1998 highest densities of capelin were detected off St. Anthony, with smaller aggregations north of Fogo Island, on outer Funk Island Bank and in the Bonavista corridor (Fig. 2). Capelin were further north again in 1999, with peak densities off southern Labrador. Concentrations of capelin were also detected on outer Funk Island Bank, on the Northeast Grand Banks and in Conception Bay in 1999 (Fig. 3).

There was general agreement between regions of high acoustic density and IYGPT trawl catches (Fig. 5). However, the concentration of capelin detected acoustically off Belle Isle and southern Labrador in 1999 (Fig. 3) remained close to the bottom and IYGPT trawls at stations in this area caught few capelin (Fig. 5). A targeted IYGPT trawl at 190 m depth confirmed that the acoustic signal was capelin.

Using a capelin *TS* of −34 dB kg^{-1} (c.f. Miller 1997) we estimated capelin biomass in 2J3K as 86,000 tons (95% confidence interval 36,000-135,000 tons) in 1998 (Table 3) and 69,000 tons (33,000-116,000 tons) in 1999 (Table 5). Note that these estimates do not include the inshore bays or areas of 2J3K to the north and east beyond the survey boundaries (Figs 2-3). Estimates of capelin biomass in 2J3K in 1998 and 1999 were similar to estimates from Canadian fall acoustic surveys in the early 1990s and lower than all estimates from 1981-1990 (Fig. 6).

Without the correction for depth-variable integration thresholds (Table 2), capelin biomass in 1998 data was estimated as 55,000 tons (23,000-87,000 tons) (Table 4), or 64% of the corrected biomass (Table 3).

Figure 6 provides a relative index of capelin abundance based on scaled S_A values. However, a more recent model of capelin *TS* (Rose 1998) suggests that a *TS* of –34 dB kg^{-1} will overestimate absolute abundance. We derived a length-weight relationship for capelin from measurements on fish captured during our 1999 survey (W (g) = $4.7361*10^{-8}$ L $(mm)^{3.9248}$, n = 468, r^2 = 0.95) Using this relationship we calculated capelin *TS* in dB kg^{-1} using the length based model of Rose (1998), and also a model by the same author which incorporates both length and weight (Fig. 7). Figure 7 shows that a *TS* of –34 dB kg^{-1} is only appropriate for large capelin (~180 mm). Smaller capelin, like those observed in our surveys, have a much higher *TS* per kg (-26 or –28 dB kg^{-1} depending on choice of model). Estimates of abundance based on *TS* –34 dB kg^{-1} will therefore overestimate abundance of smaller capelin by as much as a factor of four.

There was considerable geographical variation in size composition of capelin catches during the 1999 survey (Table 6, Fig. 8). Capelin from the targeted trawl in southern Labrador were larger and older (Fig. 8) than fish from other areas. Capelin from Funk Island Bank stations were also larger than capelin from the Grand Banks, Conception Bay and the inshore. Almost all capelin captured at trawl stations were one-year olds (Fig. 8).

Total survey biomass estimated using *Method 2* was 43,000 tons (27,000-61,000 tons) of capelin (Table 5). The discrepancy between this estimate and the much higher estimates for 2J3K from *Method 1*is due solely to the choice of a length-scaled *TS* model in *Method 2*. If we apply a *TS* of –34 dB kg^{-1} to the stratified survey area, total biomass was 94,000 tons (60,000-131,000 tons).

Discussion

The pelagic juvenile survey provides a cost-effective platform to conduct acoustic research on capelin distribution and abundance in Newfoundland waters. High quality acoustic data were collected in 1999 with little cost to the existing survey in terms of personnel (one additional scientist on each ship) or time (slight reduction in cruising speed). Acquisition and processing of acoustic data from the hull-mounted EK500 using CH1 and CH2 was straightforward. The coverage of the survey is extensive and includes much of the range of capelin over the Newfoundland shelf (2J3KLNO).

The major limitation of a combined pelagic trawl/acoustic survey is identification and sampling of acoustically detected capelin. Although an experienced observer is able to recognise capelin acoustic signal based on signal characteristics, it is necessary to "ground truth" subjective classifications with targeted fishing sets. Targeted fishing sets are also required to provide accurate age-composition data on capelin concentrations. We did not attempt to provide an age-structured estimate of capelin biomass in this paper because almost all of our length and age data came from standard tows on station. These shallow (20-60 m) tows were dominated by one-year old capelin. A single targeted deep set in 1999 caught a wider age range of capelin suggesting that there may be vertical segregation of ages, with larger older fish occurring below the zone sampled during pelagic juvenile tows.

Capelin exhibit variable vertical migration behaviour. Characteristically capelin are in layers near the surface at night and form schools in midwater and close to the bottom during the day. However there are interannual (Shackell *et al.* 1994) and seasonal (O'Driscoll & Rose 1999) variations in this general pattern. There may also be spatial variation in vertical distribution. In August-September 1999 the distribution of capelin in most areas was consistent with the general diurnal vertical migration model (Fig. 9). However, the major concentration of capelin off southern Labrador and Belle Isle did not appear to vertically migrate. Capelin in these areas were close to the bottom during the day and night (Fig. 9). Such near-bottom concentrations of capelin will not be caught by the standard surface tows of the pelagic survey and can only be sampled by targeted trawling.

In future combined trawl/acoustic surveys time should be built into the survey design to allow between 5-10 targeted trawls on capelin concentrations detected acoustically which are between stations or deeper than the pelagic zone sampled on stations. Alternatively a two-stage design might be implemented, where concentrations of capelin detected during the pelagic juvenile survey are revisited and sampled more extensively by a short dedicated capelin acoustic survey following the pelagic juvenile cruise.

The northward shift in the distribution of capelin we observed from 1997 to 1999 is consistent with the trend in the distribution of capelin catches from fall (October to December) bottom-trawl surveys (Lilly 1999). In 1998 large catches of capelin were made further north than in 1997 (Lilly 1999) and this northward trend seems to have continued in 1999 (George Lilly pers. comm.). Independent acoustic surveys for cod in the Hawke Channel area of southern Labrador have been conducted from June 1994-1999. Capelin were detected in these surveys for the first time in 1998. In June 1999 the abundance of capelin around Hawke Channel was at least an order of magnitude higher than in 1998 (O’Driscoll & George Rose unpublished data).

During the early 1990s the spatial distribution of capelin in NAFO 2J3KL changed dramatically (review by Carscadden & Nakashima 1997). Acoustic surveys, bottom-trawl surveys and cod-stomach-content analysis all showed a shift in the distribution of capelin towards the south and east. Capelin virtually disappeared from the northern part of their range, and the centre of the concentration of maturing fish shifted from NAFO 2J to southern 3K and 3L (Carscadden & Nakashima 1997). At the same time capelin increased in areas such as the Flemish Cap and Scotian Shelf where they were not common previously (Frank *et al.* 1996). Observations of a more northerly offshore distribution of capelin in 1998-1999 suggest that capelin are returning to historical distribution patterns.

Capelin biomass offshore in 2J3K in 1998 and 1999 was low compared to levels observed during the Canadian fall acoustic surveys in the 1980s and similar to abundance observed following the dramatic decline in the early 1990s.

Carscadden & Nakashima (1997) suggest that acoustic surveys in the early 1990s underestimated capelin abundance because of changes in the distribution and behaviour of the fish. For example, there was independent evidence from spring acoustic surveys for cod that capelin density on parts of the outer northeast Newfoundland shelf remained high from 1990-1994 (O'Driscoll & Rose submitted).

In light of our low acoustic estimates of abundance in 1998-1999 we believe it is worthwhile to consider the influence of fish distribution and behaviour on acoustic estimates of biomass. We also discuss sources of error associated with survey methodology.

The biomass estimates presented in this paper are estimates of capelin abundance in the surveyed area only. We did not extrapolate beyond the survey boundaries. The major influence of capelin distribution on estimated biomass will therefore be related to the proportion of total capelin in the surveyed area. The coverage of the pelagic juvenile survey is extensive, but there was evidence from our 1998 and 1999 surveys that transects did not extend far enough east to fully map the offshore distribution of capelin, particularly on Funk Island Bank and the northeast Grand Banks. In 1998 and 1999 capelin densities were high round the outermost stations on Funk Island Bank in blocks d and e. In 1999 we also observed relatively high densities of capelin at the outermost stations on the northern Grand Banks. It would be desirable to extend all transects east at least as far as the 500 m contour to determine the extent of these capelin aggregations.

Few capelin were detected on the northernmost transects in 1997-1999 suggesting that the pelagic juvenile survey area extended beyond the northern boundary of the capelin distribution in these years. The fall groundfish surveys in 1997 and 1998 caught few capelin north of 53°N (Lilly 1999). In the 1980s high concentrations of capelin were commonly observed on Hamilton Bank (Miller & Lilly 1991). If the northward shift in the distribution of capelin continues it may be necessary to extend the pelagic juvenile survey further north to cover this region.

The inshore coverage of the pelagic juvenile survey is limited. Typically trawl stations and acoustic transects surveyed the central portion of the major bays only. We re-emphasize that the abundance estimates in this paper reflect the surveyed area only. We did not have adequate coverage to accurately assess capelin abundance inshore. Some capelin occur in the large bays of the northeastern Newfoundland coast year-round (Winters 1969), but is uncertain how much these "coastal capelin" (Winters 1969) contribute to the total capelin biomass. We observed relatively high densities of capelin inshore on other acoustic surveys in January, May and June of 1999 suggesting that there may be significant concentrations of capelin in the bays at these times. Further work is necessary to quantify the relative importance of the inshore and offshore areas to capelin. The existence of concentrations of capelin which remain inshore, especially in Trinity Bay where most estimates of inshore abundance are carried out, might help to explain the apparent discrepancy between views of the stock based on beach spawning and offshore estimates of capelin abundance.

Carscadden & Nakashima (1997) hypothesised that capelin in the early 1990s may have been "undetectable by the acoustic gear because they were scattered rather than in schools" (p 466). Calculations based on the sampled acoustic volume showed that even individual small capelin would be detected and included in the integration at a threshold of –80dB. The issue is not one of detection but rather of recognition. Because capelin signal was classified subjectively, there is potential for an observer to fail to recognise low densities of capelin amongst the other sources of biological scattering. This *recognition threshold* accounts for the small catches of capelin sometimes made when no recognisable capelin signal is identified acoustically (O'Driscoll *et al.* 2000.).

We attempted to quantify the magnitude of bias in the biomass estimate introduced by the recognition threshold by comparing IYGPT trawl catches with acoustic estimates of capelin in the 20-60 m trawl zone (see O'Driscoll *et al.* 2000. for details). There were a total of 64 IYGPT sets in 1999 where no capelin were recognised acoustically in the 20-60 m trawl zone. In these 64 sets an average of 11.75 capelin were captured (range 0-175 capelin per set). This is equivalent to an average density of capelin of $8.16 * 10^{-5}$ fish m^{-3} if we assume trawl catchability equals 1 at low capelin densities. The average depth of the surveyed area was 224 m, so the estimated recognition threshold is equivalent to an areal density of capelin of 0.0183 fish m^{-2}

if the same low densities of capelin occurred throughout the water column. For the survey area of 196 billion m^2 this threshold equates to 3.6 billion capelin. Average individual weight of capelin was 3.18 g, so the estimated biomass of capelin not detected acoustically due to the recognition threshold was ~11,400 tons or 26% of the total biomass in 1999 (Table 7). This was well within the range of the sampling uncertainty.

Other potential sources of error related to capelin behaviour include boat avoidance, surface and bottom acoustic dead-zones, and acoustic shadowing. Capelin close to the surface (< 15 m depth) or to the bottom (< 0.5 m above bottom depending on depth) could not be detected acoustically by our equipment. Additionally capelin close to the surface may avoid the vessel. At very high fish densities S_A is not proportional to fish density because fish nearest the transducer attenuate the echo energy so that it cannot penetrate to the more distant fish (MacLennan & Simmonds 1992). We were not able to quantify the magnitude of these sources of bias, but it is generally accepted that capelin are ideal acoustic targets because they seldom distributed too close to the surface or to the bottom and they do not form very dense schools (Toresen *et al.* 1998).

A major source of uncertainty in the acoustic estimate of capelin biomass is acoustic target strength (*TS*). We have shown that total survey biomass in 1999 is more than doubled if we use a *TS* of -34 dB kg^{-1} instead of the length-scaled model of Rose (1998). Surveys for capelin in the Barents Sea use a third model of *TS* (Toresen *et al.* 1998). The Norwegian model is length-scaled by the relationship $TS = 19.1\log L - 74.0$. Capelin biomass obtained using the Norwegian *TS* model for our 1999 survey and *Method 2* was 67,000 tons (42,000-94,000 tons). This is higher than the estimate using the Rose (1998) model (43,000 tons), but lower than estimate obtained using -34 dB kg^{-1}. Further *in situ* measurements of *TS* are required to compare to existing models. Length-based *TS* models also require better information about the size composition of the capelin contributing to the scattering from targeted fishing sets.

Capelin are a key component of the northwest Atlantic ecosystem and a key prey species of many economically important species such as Atlantic cod (*Gadus morhua*), Atlantic salmon (*Salmo salar*) and harp seals (*Phoca *groenlandica*). Given this importance, we feel it is imperative for continued research on capelin abundance and distribution in Newfoundland waters. Research is especially important in the next few years, as there is continued evidence of changing ecosystem dynamics. Despite the limitations described we believe acoustics is the best method to quantify capelin abundance. Capelin can be detected throughout much of the water column, avoiding problems associated with vertical distribution and catchability that affect estimates based on trawl surveys (e.g. Anderson *et al.* 1999). We hope that the data presented in this paper form the basis for a time series of offshore capelin abundance from continued pelagic trawl/acoustic surveys.

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Table 1. Specifications for EK500 on Teleost surveys in August-September 1998 and 1999.

	1998	1999
Frequency	38kHz	38kHz
Ping Interval	1s	1s (250m range) 1.5s (400m) 2s (500m)
Pulse length	1.0ms	1.0ms
Bandwidth	3.8kHz	3.8kHz
Transmit Power	2000W	2000W
Absorption Coefficient	10dB km^{-1}	10dB km^{-1}
2-Way Beam Angle	-20.6 dB	-20.6 dB
Sv Transducer Gain	25.60 dB	25.77 dB
TS Transducer Gain	25.60 dB	26.00 dB
TVG	20logR	20logR
Angle Sensitivity Along.	21.9	21.9
Angle Sensitivity Athw.	21.9	21.9
3 dB Beamwidth Along.	7.1 dg	7.0 dg
3 dB Beamwidth Athw.	7.1 dg	6.8 dg
Along. Ship Offset	0.00 dg	-0.16 dg
Athw. Ship Offset	0.00 dg	-0.16 dg
Range of Raw Sv data collection	none	250m, 400m or 500m
Vertical Sampling Resolution	6-50m (see text)	0.1m
Bottom Removal	internal Simrad algorithm	none on raw data
Vessel Speed	~12 knots	10 knots

Table 2. Effect of depth-variable integration thresholds used in 1997 and 1998 on estimates of capelin density. Correction factors were obtained empirically using data from 1999 and are expressed as the proportion of (area scattering due to capelin calculated with integration threshold *x*) / (area scattering calculated with an integration threshold of –80 dB). Table also shows the percentage of total capelin observed in each vertical bin in 1997 and 1998.

Vertical Bin	Integration Threshold	Correction Factor	Percentage Capelin 1997	Percentage Capelin1998
14-20m	-75	0.92	14	5
20-40m	-75	0.92	17	14
40-60m	-75	0.92	11	14
60-100m	-73	0.87	14	23
100-150m	-66	0.56	20	25
150-200m	-60	0.21	18	11
200-250m	-53	0.02	5	5
250-300m	-47	0.00	1	3

Table 3. Capelin biomass estimate for NAFO 2J3K from Teleost 69 survey August 24 to September 10 1998 using *Method 1* (*TS* = -34 dB kg^{-1}). Data were scaled by values in Table 2 to correct for bias due to high integration thresholds. See Fig. 2 for block boundaries. 95% confidence intervals are sample mean +/-1.96 standard errors.

Survey Block	No. of 1850-m bins	Mean capelin density g m^{-2} ($\overline{d_i}$) (95% CI)	Transect area ($*10^9$ m^2)	Transect biomass (tons) (95% CI)
a	91	0.803 (0.464-1.141)	12.4	9917 (5739-14095)
b	100	1.494 (0.558-2.430)	12.4	18462 (6897-30027)
c	87	0.145 (0.058-0.232)	12.4	1788 (715-2861)
d	90	0.552 (0.280-0.824)	15.4	8522 (4320-12723)
e	118	2.281 (0.987-3.575)	15.4	35208 (15232-55184)
f	87	0.966 (0.283-1.650)	12.4	11942 (3498-20386)
g	89	0	13.9	0
h	73	0.004 (0.000-0.011)	10.7	39 (0-117)
i	104	0	10.7	0
Total	839		115	85878 (36402-135393)

Table 4. Uncorrected capelin biomass estimate for NAFO 2J3K from Teleost 69 survey August 24 to September 10 1998 using *Method 1* (TS = -34 dB kg^{-1}). No corrections for integration threshold were applied. See Fig. 2 for block boundaries. 95% confidence intervals are sample mean +/-1.96 standard errors.

Survey Block	No. of 1850-m bins	Mean capelin density g m^{-2} ($\overline{d_i}$) (95% CI)	Transect area (*10^9 m^2)	Transect biomass (tons) (95% CI)
a	91	0.582 (0.349-0.816)	12.4	7195 (4307-10083)
b	100	0.707 (0.252-1.163)	12.4	8741 (3115-14368)
c	87	0.057 (0.020-0.095)	12.4	709 (243-1176)
d	90	0.505 (0.256-0.755)	15.4	7799 (3944-11654)
e	118	1.816 (0.688-2.945)	15.4	28035 (10614-45457)
f	87	0.173 (0.025-0.321)	12.4	2136 (304-3967)
g	89	0	13.9	0
h	73	0.002 (0-0.002)	10.7	22 (0-65)
i	104	0	10.7	0
Total	839		115	54637 (22526-86770)

Table 5. Capelin biomass estimate for NAFO 2J3K from Teleost 81 survey August 23 to September 17 1999 using *Method 1* (TS = -34 dB kg^{-1}). See Fig. 3 for block boundaries. 95% confidence intervals are from 5% bootstrapping.

Survey Block	No. of 100-m bins	Mean capelin density g m^{-2} ($\overline{d_i}$) (95% CI)	Transect area (*10^9 m^2)	Transect biomass (tons) (95% CI)
a	2044	0.206 (0.058-0.549)	12.4	2540 (713-6778)
b	2179	0.377 (0.065-0.967)	12.4	4659 (805-11954)
c	1965	0.145 (0.047-0.340)	12.4	1794 (580-4207)
d	2482	0.766 (0.374-1.176)	15.4	11823 (5776-18152)
e	2498	0.186 (0.096-0.303)	15.4	2875 (1474-4674)
f	2162	2.031 (1.090-3.012)	12.4	25093 (13463-37217)
g	2276	1.460 (0.756-2.380)	13.9	20254 (10494-33025)
h	1634	0	10.7	0
i	1722	0	10.7	0
Total	18962		115	69038 (33305-116007)

Table 6. Capelin target strength calculated from length-frequency data for individual strata in fall 1999. See Fig. 4 for strata boundaries.

Stratum	Sample size	Mean σ (m^2)	Mean TS (dB)	Mean length (mm)	Mean weight (g)
LAB	206	1.28E-04	-49.9	144	14.6
FIB	640	9.62E-05	-51.2	125	8.7
NEGB	220	5.71E-05	-53.4	96	3.0
SGB	749	5.36E-05	-53.7	92	2.1
INS	981	5.01E-05	-54.0	89	3.4
CB	220	5.45E-05	-53.6	94	3.0

Table 7. Capelin abundance and biomass estimates from full Teleost 81 survey August 23 to September 17 1999 using *Method 2*. See Fig. 4 for strata boundaries. 95% confidence intervals are from 5% bootstrapping.

Stratum	No. of 100-m bins	Mean capelin density m^{-2} ($\overline{D}_i$) (95% CI)	Stratum area ($*10^9$ m^2)	Stratum abundance (billions) (95% CI)	Stratum biomass (tons) (95% CI)
LAB	7703	0.041 (0.026-0.059)	42.9	1.78 (1.13-2.53)	25924 (16471-36900)
FIB	5805	0.040 (0.024-0.058)	31.1	1.25 (0.74-1.79)	10888 (6460-15594)
NEGB	4265	0.045 (0.030-0.059)	25.0	1.13 (0.76-1.46)	3393 (2266-4391)
SGB	11700	0.013 (0.009-0.016)	52.4	0.67 (0.47-0.85)	1398 (988-1792)
INS	11995	0.006 (0.004-0.009)	43.9	0.29 (0.17-0.42)	968 (580-1410)
CB	722	0.156 (0.122-0.205)	1.0	0.16 (0.13-0.21)	485 (378-637)
Total	42190		196	5.27 (3.39-7.26)	43055 (27143-60724)

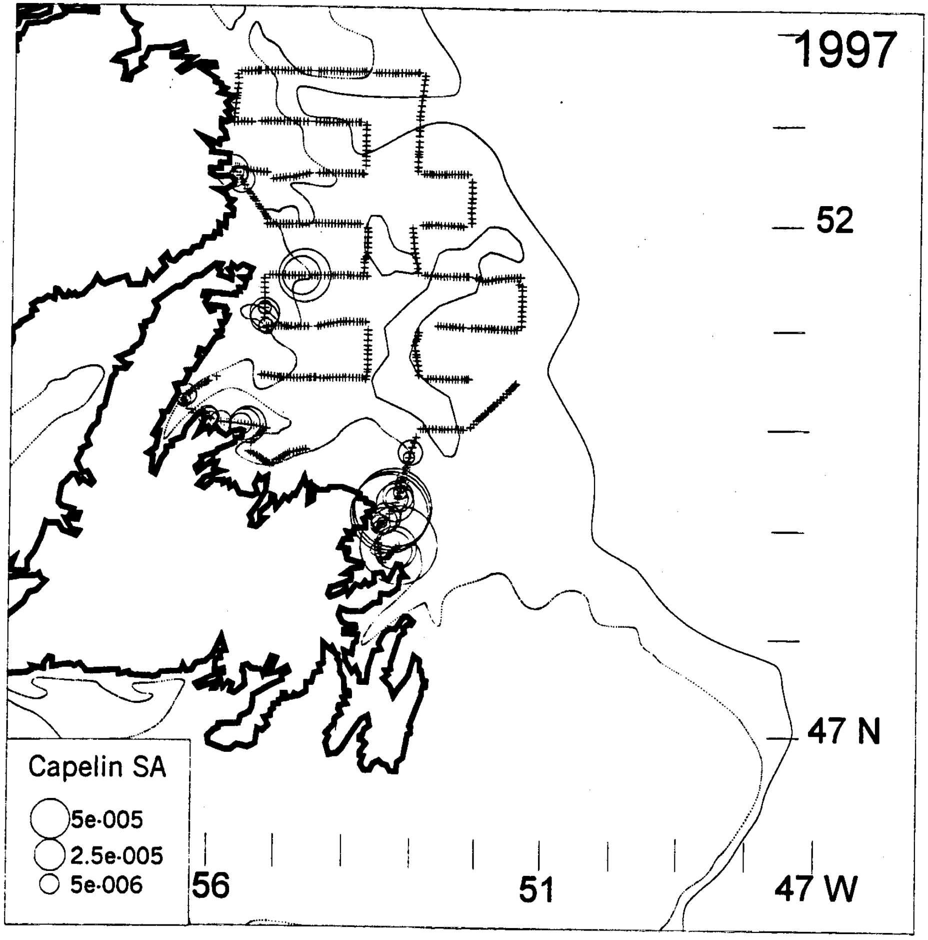

Fig. 1. Expanding symbol plot showing capelin distribution from fall 1997 pelagic juvenile survey. Acoustic data were corrected for depth-variable integration thresholds (Table 2) and averaged into 5-km bins for display. '+' symbol indicates no capelin were detected in that bin. Bathymetry shows 200 m (dotted) and 500 m (solid) depth contours.

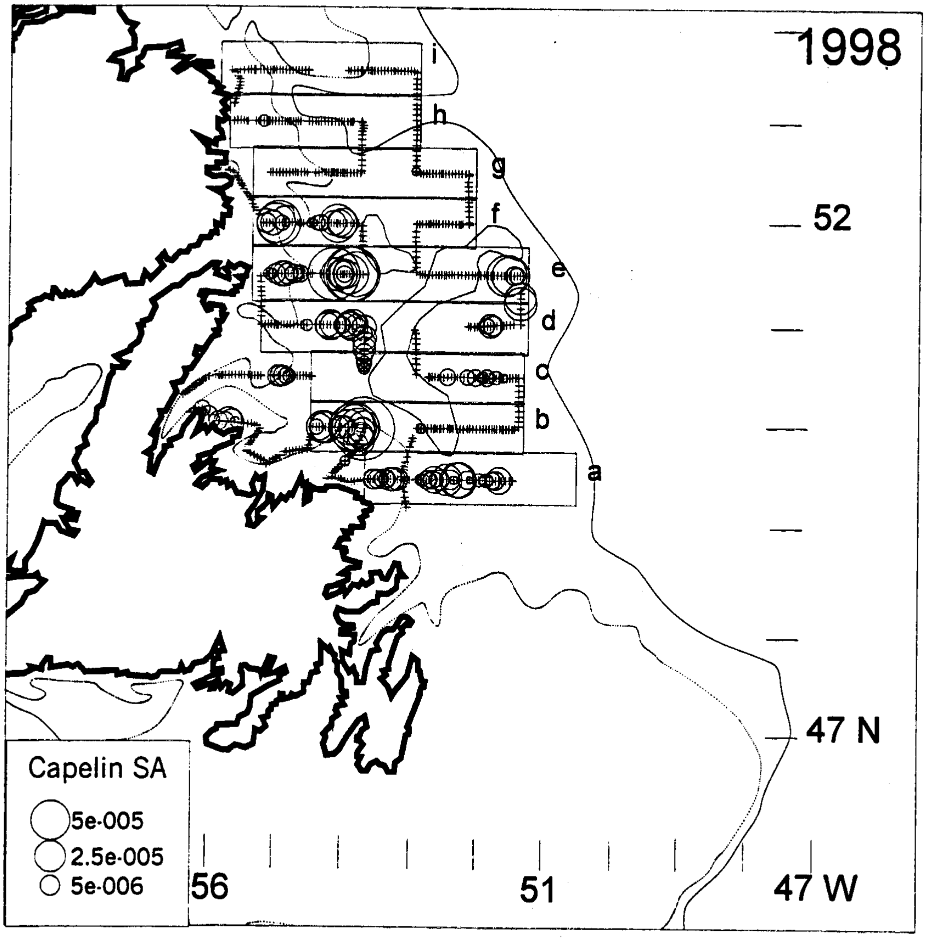

Fig. 2. Expanding symbol plot showing capelin distribution from fall 1998 pelagic juvenile survey. Acoustic data were corrected for depth-variable integration thresholds (Table 2) and averaged into 5-km bins for display. '+' symbol indicates no capelin were detected in that bin. Bathymetry shows 200 m (dotted) and 500 m (solid) depth contours. Blocks used for estimating biomass in 2J3K (*Method 1*) are indicated and lettered.

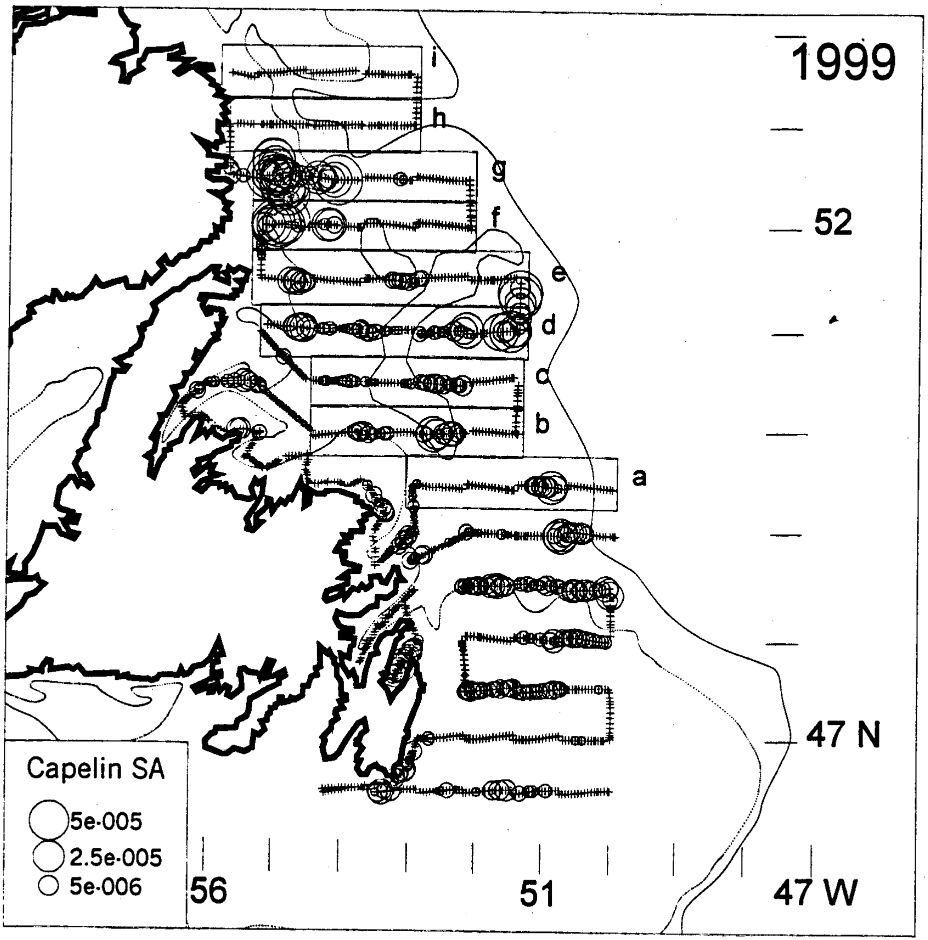

Fig. 3. Expanding symbol plot showing capelin distribution from fall 1999 pelagic juvenile survey. Acoustic data averaged into 5-km bins for display. '+' symbol indicates no capelin were detected in that bin. Bathymetry shows 200 m (dotted) and 500 m (solid) depth contours. Blocks used for estimating biomass in 2J3K (*Method 1*) are indicated and lettered.

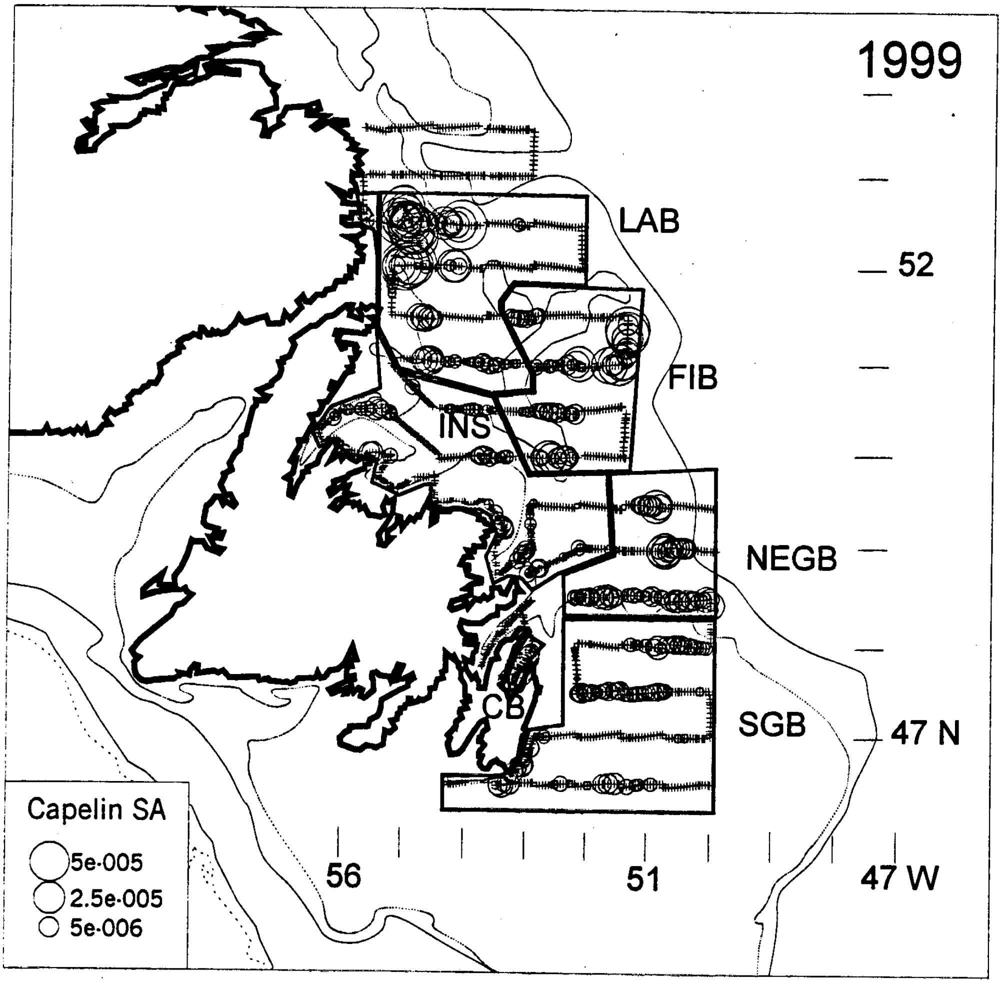

Fig. 4. Expanding symbol plot showing capelin distribution from fall 1999 pelagic juvenile survey and strata used to estimate total survey biomass (*Method 2*). See Fig. 3 for further details.

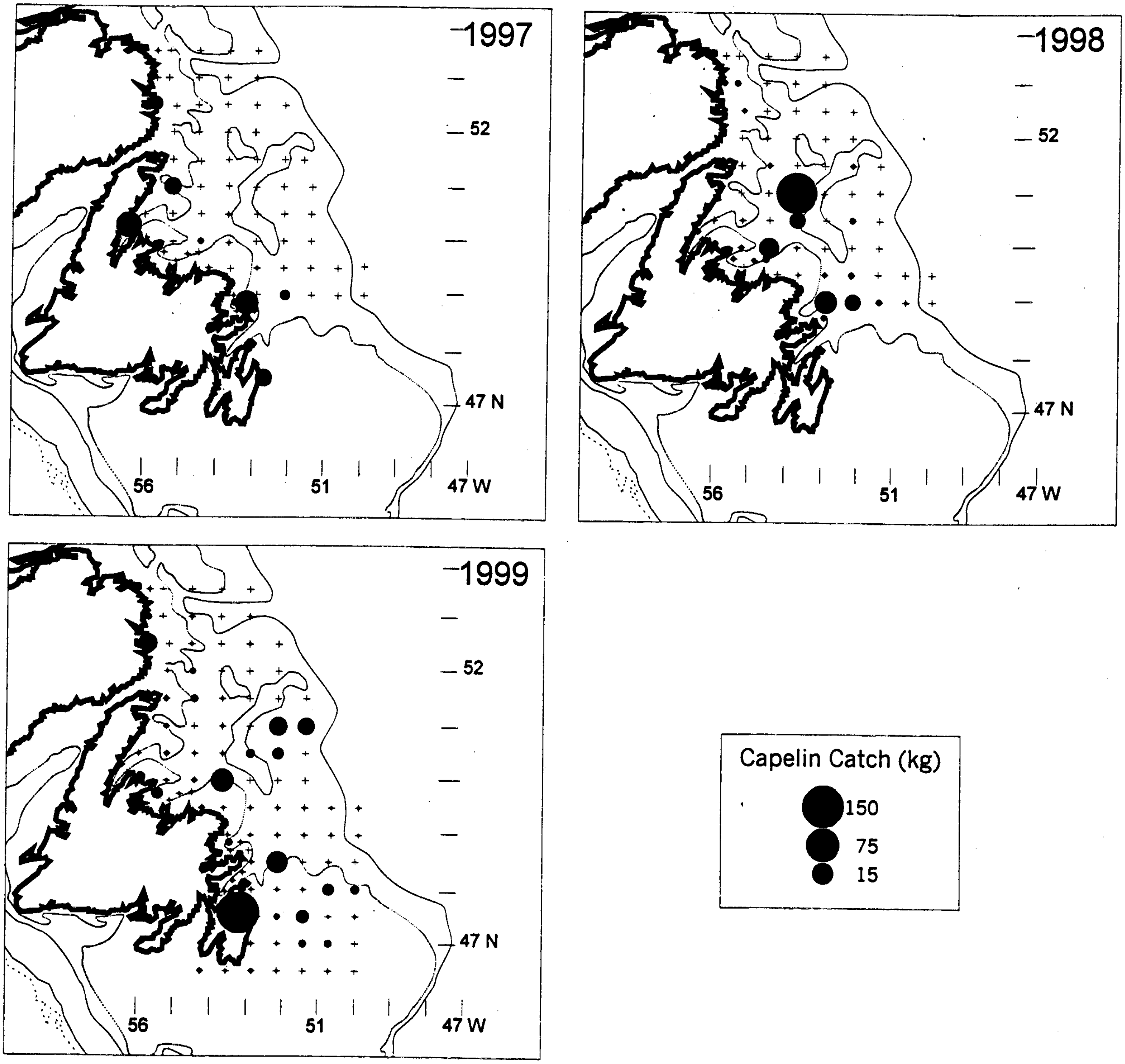

Fig. 5. Capelin catches in IYGPT trawls at 20-60 m depth during fall pelagic juvenile surveys 1997-1999. Circle size is proportional to catch. '+' symbol indicates no capelin were caught. Catches are not corrected for day-night differences in catchability.

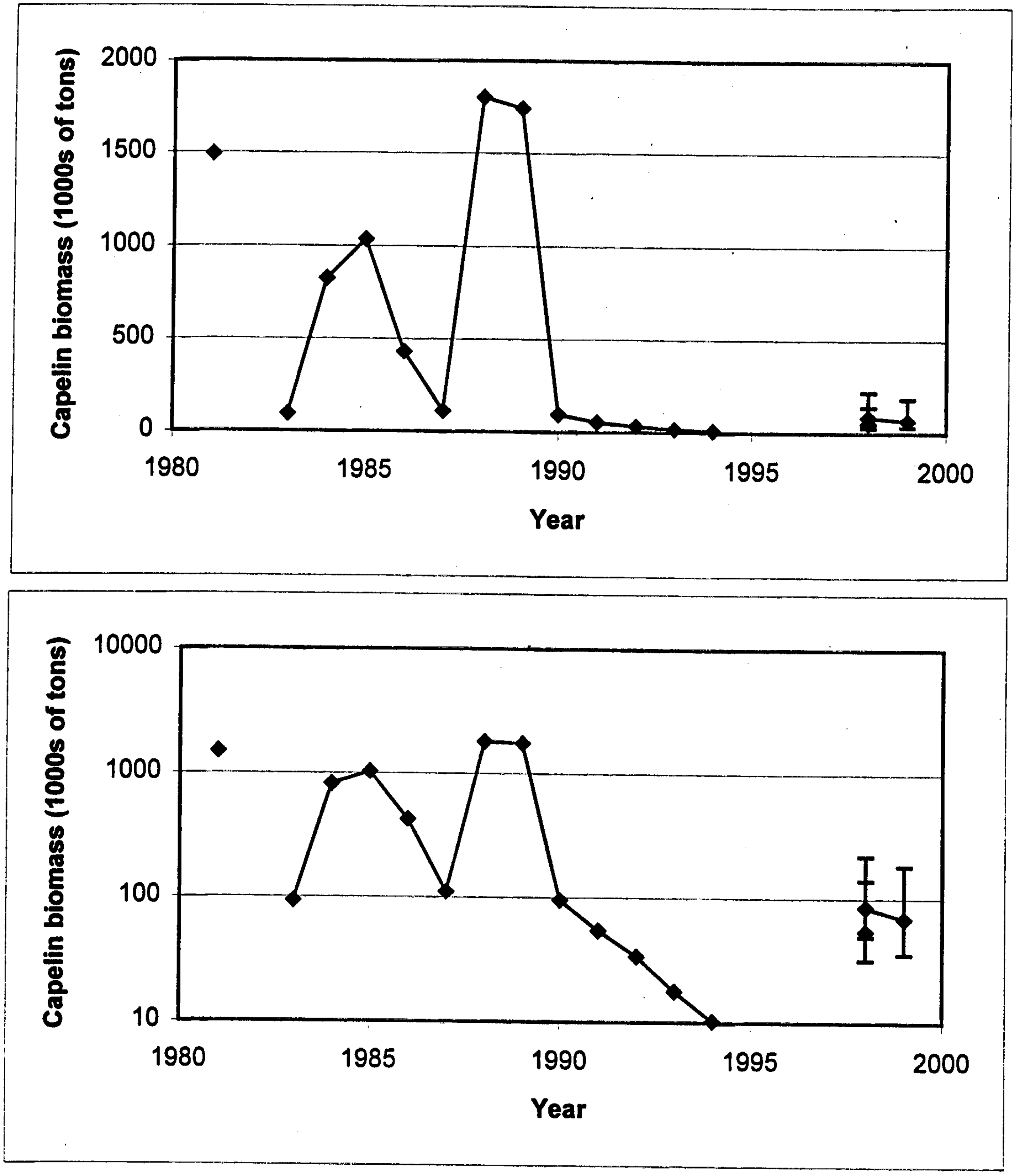

Fig. 6. Comparison of capelin biomass estimates in 2J3K from pelagic juvenile surveys in 1998-1999 (*Method 1*) with estimates from Canadian fall (September-October) acoustic surveys in 1981,1983-1994 (Miller 1995). A capelin target strength of –34 dB kg^{-1} was used in all calculations. In lower figure biomass is plotted on a logarithmic scale. Error bars show 95% confidence intervals. Two estimates are given for 1998. Higher estimate includes correction for depth-variable integration threshold (Table 3). Lower estimate is calculated from uncorrected data (Table 4).

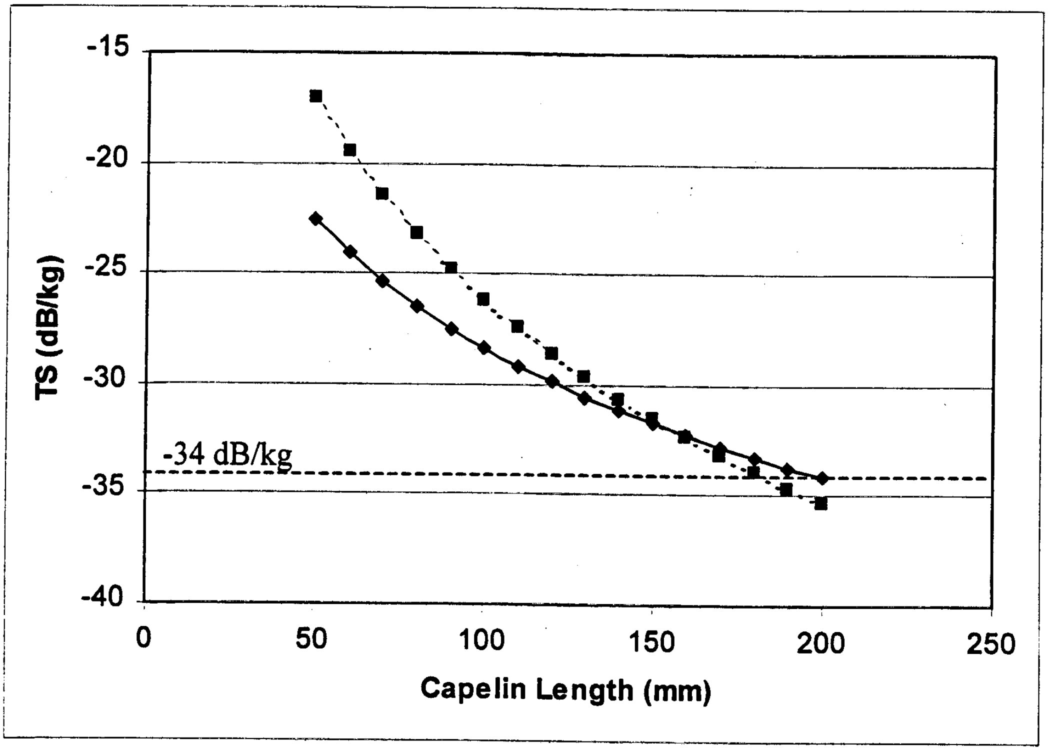

Fig. 7. Relationship between capelin *TS* per unit mass and capelin length based on capelin length-weight relationship from 1999 survey and *TS* models of Rose (1998). Solid line is the length-scaled *TS* model used in *Method 2*. Dotted line is a *TS* model based on both capelin length and weight. See text for details. The capelin *TS* used in *Method 1* is indicated.

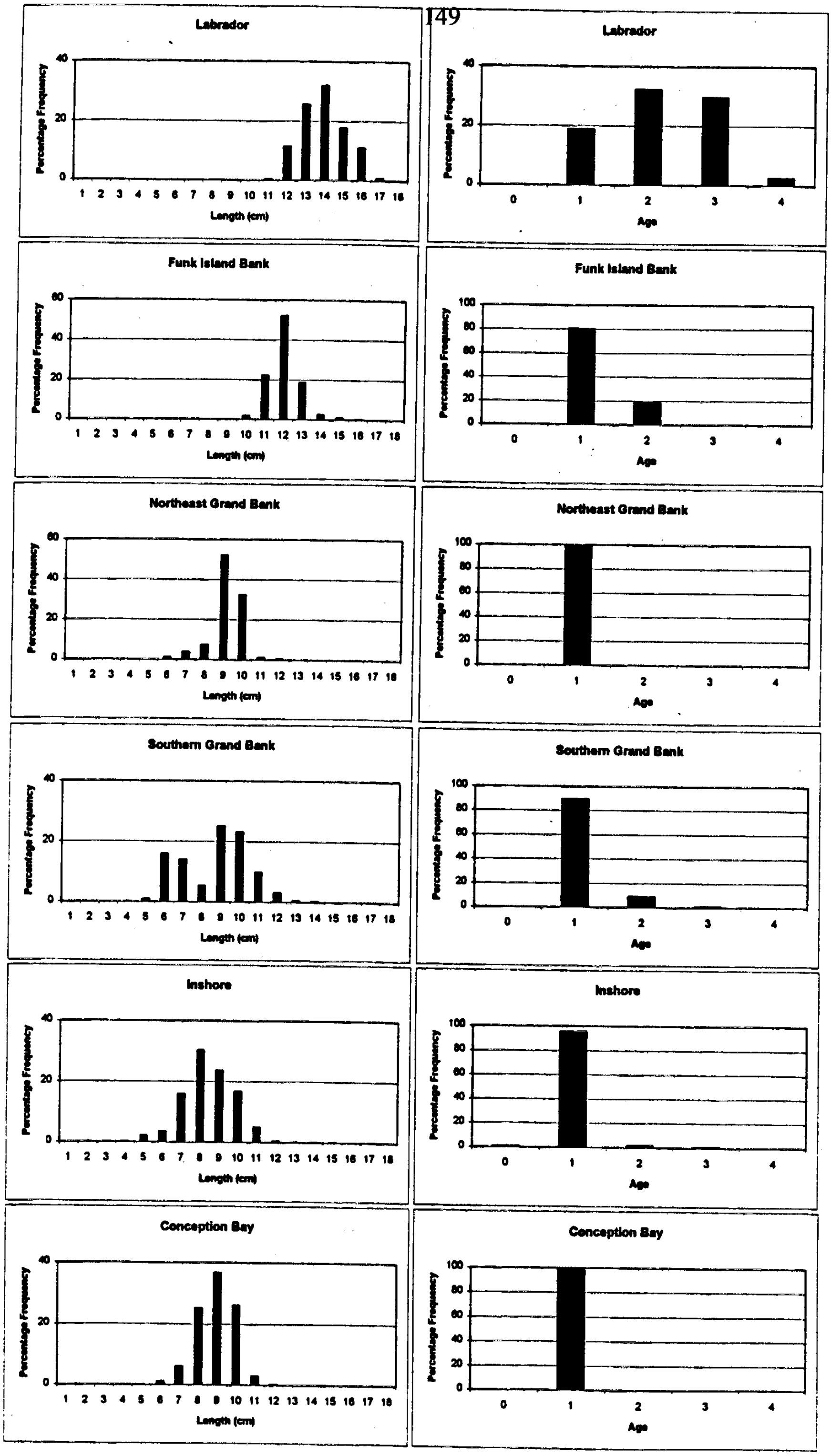

Fig. 8. Length and age composition of capelin caught in representative IYGPT sets in six geographical strata in 1999. See Fig. 4 for strata boundaries. Capelin from Labrador were caught in a targeted trawl at 190 m depth. All other capelin were caught in standard pelagic tows at 20-60 m.

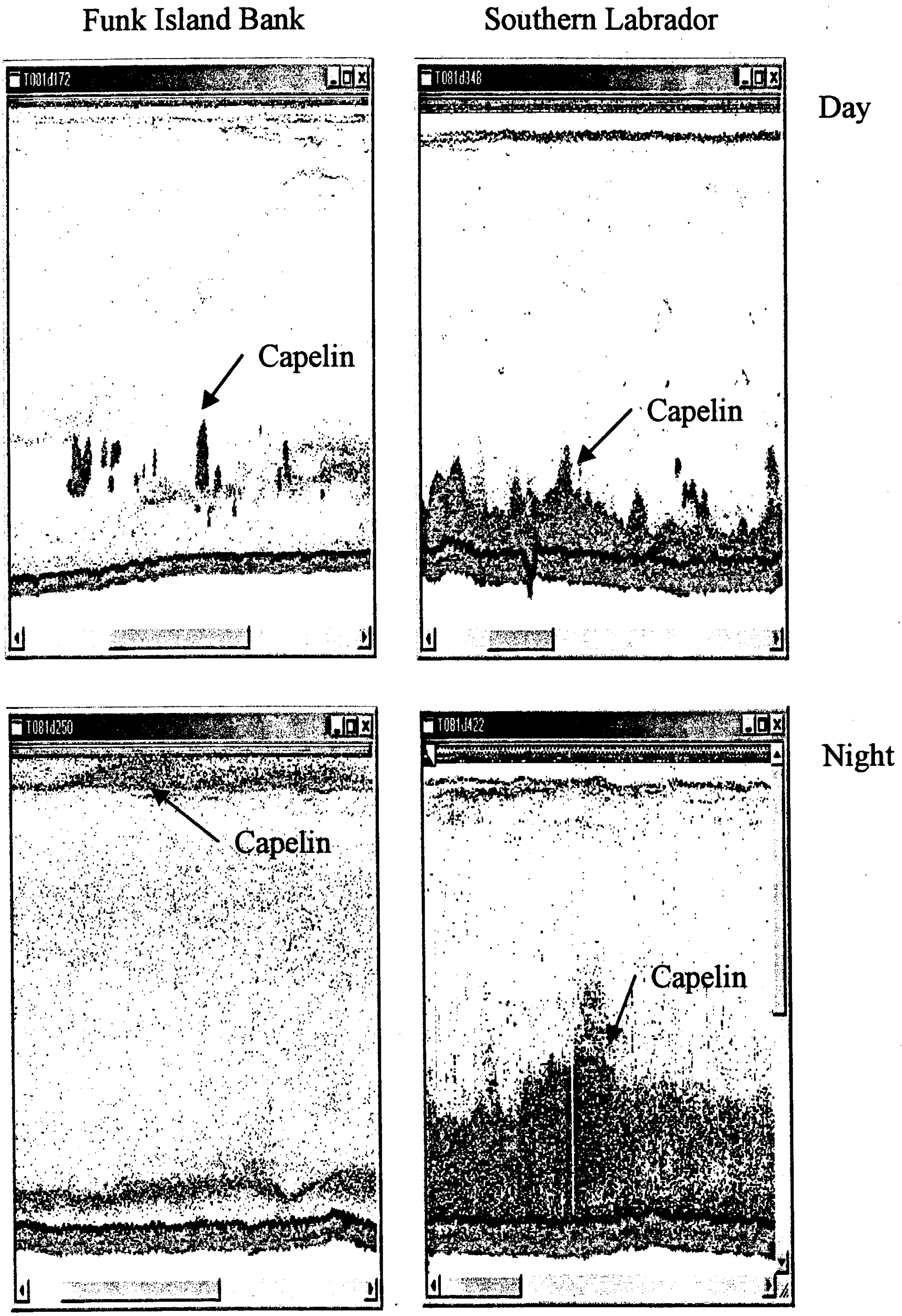

Fig. 9. Echograms showing diurnal variation in vertical distribution of capelin on Funk Island Bank and off southern Labrador. Water depth is ~200 m in each panel. Horizontal scale is ~4 km.

Relationship between acoustic estimates of capelin and trawl catches in Campelen and IYGPT trawls

by

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Abstract

Acoustic estimates of capelin density were compared to catches in Campelen and IYGPT trawls to assess the ability of trawl surveys to index capelin abundance. Trawl surveys were an unreliable indicator of capelin abundance. There were statistically significant, but very weak positive relationships between acoustic estimates of capelin density and trawl catches in the Campelen bottom trawl ($n = 148$, $r^2 = 0.23$, $p < 0.001$) and in the IYGPT mid-water trawl towed between 20-60 m depth ($n = 82$, $r^2 = 0.08$, $p = 0.009$). Much of the variability in trawl catches was related to vertical distribution of capelin. Trawl surveys did provide useful information on capelin spatial distribution (presence/absence). There were relatively few sets where capelin were observed acoustically but no capelin were caught. Catchability coefficients calculated for the Campelen and IYGPT trawls were often greater than one, indicating that the trawls caught more capelin than were expected from acoustic measurements of fish density in the trawl zone. Possible explanations for this discrepancy are discussed and the need for further experimental research is emphasised.

Introduction

Capelin are frequently caught in multispecies bottom-trawl surveys (e.g. Lilly 1999) and in mid-water trawl surveys for pelagic juvenile fish (e.g. Anderson *et al.* 1999a) in Newfoundland waters. Interest in the results from trawl surveys has increased since the dramatic decline in abundance of capelin estimated from acoustic surveys in the early 1990s. Annual capelin acoustic surveys were discontinued in 1996 and in recent years survey trawl catches have provided the only fisheries-independent measure of capelin abundance offshore. Capelin catches from fall bottom-trawl surveys in 1985-1994 are currently used in the multiplicative model used to estimate capelin year-class strength (Anon 1999). In 1999 Anderson *et al.* (1999b) used mid-water-trawl catches to estimate absolute abundance of capelin in the Newfoundland region from 1994-1998.

There are two major uncertainties associated with the use of trawl surveys to index capelin abundance. First, both mid-water and bottom trawls target a relatively narrow depth range so there are potential biases in abundance estimates due to the vertical migration behaviour of capelin (e.g. O'Driscoll & Rose 1999). Second, there is uncertainty associated with how effectively the trawl samples capelin in the trawl zone (catchability).

In this paper we present the results of experiments which compared acoustic estimates of capelin abundance with trawl catches in Campelen bottom trawls and IYGPT mid-water trawls. The Campelen trawl is the gear used in multispecies bottom-trawl surveys since 1995 (Lilly 1999). The IYGPT mid-water trawl is towed in an undulating path from 20-60 m depth during the pelagic juvenile survey (Anderson & Dalley 1997). We compared IYGPT catches using this tow pattern with acoustic estimates, and also examined IYGPT catches from targeted (non-undulating) tows on capelin aggregations.

Our work follows on from a previous series of experiments by Miller (1996). This previous study (Miller 1996) was limited because acoustic observations and trawl catches were separated in time and the range of experimental fish densities was narrow. Our study has much larger sample sizes over a broader range of capelin densities and acoustic measurements were made directly during the fishing sets.

Methods

Experiments using the Campelen bottom trawl were conducted during regular acoustic surveys for cod and capelin during January, March and June 1998, January and June 1999, and January 2000. A total of 149 Campelen sets were examined (Table 1). Sets covered an extensive geographical area, but were concentrated in Placentia Bay (NAFO 3Ps), Trinity Bay (3L), and southern Labrador (2J) (Fig. 1). Ten targeted fishing sets were also made using the IYGPT mid-water trawl during these surveys (Table 1). Most experiments with the IYGPT trawl were conducted during the pelagic juvenile survey in August-September 1999 (Table 1). In these 83 sets the mid-water trawl was towed in an undulating path from 20-60 m following standard pelagic juvenile survey protocol (Anderson & Dalley 1997).

All experiments were conducted from "CCGS Teleost" using trawls fitted to standard specifications. Acoustic data were collected using a calibrated Simrad EK500 split-beam 38-kHz echo-sounder with a hull-mounted transducer, and analysed using custom FASIT and CH2 software. We distinguished signals from capelin based on signal characteristics and information from fishing sets.

Trawls were typically of 15 min (Campelen bottom trawl) or 30 min duration (IYGPT mid-water trawl). Acoustic measurements were made during the fishing sets. To ensure complete spatial and temporal correspondence between acoustic and trawl estimates of capelin density the acoustic file was marked at the start and end of each fishing set. Trawl catches were compared with the acoustic measurements corresponding to the position and duration of the tow with corrections for the distance of the trawl behind the vessel (and hence the hull-mounted acoustic transducer).

We made two comparisons between trawl and acoustic estimates. First, we compared trawl catches with total acoustic estimates of capelin throughout the water column to determine whether trawl catches reflect total capelin abundance. We integrated acoustic data corresponding to the fishing set from 11 m below the surface to the bottom using an integration threshold of –80 dB and scaled by acoustic target strength to give an acoustic estimate of areal density of capelin (fish m^{-2}) during the set. Capelin target strengths were calculated independently for each set from the length-frequency of capelin in the catch using the relationship $TS = 20\log L - 73.1$ where L = fish length in centimetres (Rose 1998). A corresponding trawl estimate of capelin density (fish m^{-2}) was obtained by dividing the trawl catch (number of fish) by the swept area. Swept area was estimated as the tow length (m) multiplied by the wing spread (17.0 m for Campelen trawl and 9.4 m for IYGPT trawl). We used the comparison of acoustic and trawlable estimates of density to assess detectability of capelin by the trawl.

Second, we compared trawl catches with acoustic estimates of capelin abundance in the trawl zone to examine trawl catchability. For sets with the Campelen bottom trawl the trawl zone was considered to be the area within 5 m of the bottom. The trawl height is only 4.1 m, but allowance was made for the height of the rockhopper rollers and some bouncing of the gear. For targeted IYGPT sets the trawl zone was taken as a zone of 20 m depth around the mean depth of the tow. For undulating pelagic juvenile IYGPT sets the trawl zone was 20-60 m depth. We calculated mean volume scattering (in $m^2\ m^{-3}$, equivalent to mean volume backscattering * 4π) from acoustic data in the trawl zone and scaled by set specific acoustic target strength (see above) to give an acoustic estimate of volumetric density of capelin (fish m^{-3}) in the trawl zone during the set. From estimates of volumetric density and volume sampled by the trawl we were able to calculate the "predicted catch" (number of fish) in the trawl based on the acoustic estimate. For the Campelen trawl the volume sampled was calculated based on standard trawl opening (tow length (m) * trawl opening = 69.7 m^2). For IYGPT tows the volume sampled was calculated from actual trawl geometry during the set measured using Scanmar. Note that tow length and sampled volume were based on fishing time only and did not include the period of net deployment and retrieval. Predicted catches were compared to actual catches. We defined the catchability coefficient as the ratio of the actual catch to the acoustically predicted catch.

In summary five measures were calculated for each set:

- Acoustic density (d_A):

$$d_A = \frac{S_A}{\sigma} \tag{1}$$

where S_A is acoustic area scattering integrated over the whole water column from 11 m to the bottom and σ is the average acoustic cross-section. σ is related to target strength (TS) by the equation:

$$TS = 10\log_{10}(\frac{\sigma}{4\pi}) \tag{2}$$

- Trawlable density (d_T):

$$d_T = \frac{c_T}{A_T} \tag{3}$$

where c_T is the catch in the trawl and A_T is the swept area of the trawl calculated from the tow length (l) and the wingspread (w).

$$A_T = lw \tag{4}$$

- Predicted catch from acoustics (c_A):

$$c_A = \frac{S_V}{\sigma} V_T \tag{5}$$

where S_V is the mean acoustic volume scattering in the trawl zone. V_T is the volume sampled by the trawl, equivalent to the tow length multiplied by the area of the trawl mouth opening (m).

$$V_T = lm \tag{6}$$

- Actual catch is the observed catch from the trawl (c_T).

- Catchability coefficient (q):

$$q = \frac{c_A}{c_T} \qquad (7)$$

Results

Campelen trawl detectability

Most estimates of trawlable density of capelin were lower than acoustic density estimates (Fig. 2). This was expected because the Campelen trawl only samples the near-bottom zone (~5 m above the bottom), while acoustic estimates of density are based on samples from almost the whole water column (11 m to the bottom). There were 32 tows when capelin were caught in the trawl but no capelin were measured acoustically. Catches of capelin in these 32 tows were very small (median catch = 6, maximum catch = 111). There were 10 tows when capelin were observed acoustically in the water column, but no capelin were caught in the trawl. There was one anomalously large catch (845 kg) made in Trinity Bay in June 1999 (Fig. 2) which was removed prior to the regression analysis.

Campelen trawl catches were not a good measure of capelin abundance. There was a statistically significant positive regression between acoustic and trawlable estimates of capelin density (Fig. 2), but variability was high ($n = 148$, $r^2 = 0.23$, $p < 0.001$). At the same acoustic density, Campelen trawl catches varied by as much as three orders of magnitude (Fig. 2).

Some of the variation in trawlable density was related to the vertical distribution of capelin. We compared acoustic density in the bottom 5 m “trawl zone” with acoustic density in the whole water column. Vertical distribution of capelin showed a diurnal pattern (Fig. 3a), with the majority of sets with capelin concentrated close to the bottom occurring during daylight hours. Most high catches of capelin were also made during the day. Consequently the relationship between trawlable density and acoustic density was stronger during the day ($n = 83$, $r^2 = 0.28$, $p = 0.003$) than at night ($n = 66$, $r^2 = 0.04$, $p = 0.09$) (Fig. 4).

Campelen trawl catchability

Catches in the Campelen trawl were generally similar to predicted catches based on acoustic measurements of capelin density in the trawl zone (Fig. 5). There were 50 tows where low numbers (median catch = 7, maximum catch = 201) of capelin were caught but no capelin were measured acoustically in the trawl zone. There were no instances where capelin were observed acoustically in the trawl zone and not caught. Campelen trawl catchability varied with capelin density (Fig. 6). At low capelin densities (expected catch < 1000), catchability was usually greater than one ($n = 26$, median $q = 5.37$), that is the trawl caught more capelin than predicted by acoustic measurements. At high capelin densities (expected catch > 1000) the trawl caught fewer capelin than were observed acoustically and catchability was less than one ($n = 16$, median $q = 0.28$).

Undulating (pelagic juvenile survey) IYGPT trawl detectability

Estimates of trawlable density from the IYGPT trawl towed between 20-60 m below the surface are compared with acoustic estimates of density (11 m to the bottom) in Figure 7. No high densities of capelin were detected at trawl stations during the pelagic juvenile survey in 1999, so the range of acoustic densities is less than for the Campelen trawl (Fig. 2). As for the Campelen trawl, there were a number of tows when a few capelin were caught in the trawl but not recorded acoustically ($n = 33$, median catch = 8, maximum catch = 175). There were 7 sets when capelin were observed acoustically, but no capelin were caught in the IYGPT trawl.

Pelagic juvenile survey IYGPT trawl catches were also a poor indicator of capelin abundance. The relationship between acoustic and trawlable estimates of capelin density was weak and variable (Fig. 7). There was one very large catch of capelin (150 kg) in Conception Bay (Fig. 7). When this outlier was removed, the r^2 for the linear regression was only 0.08 ($n = 82$, $p = 0.009$).

Again, some of the variability in trawlable density was related to vertical distribution of capelin. The proportion of capelin in the trawl zone was higher at night (Fig. 3b) and this was when most high catches of capelin were made. There was a stronger relationship between trawlable density and acoustic density at night ($n = 37$, $r^2 = 0.19$, $p = 0.006$) than during the day ($n = 45$, $r^2 = 0.10$, $p = 0.03$) (Fig. 8).

Undulating IYGPT trawl catchability

Catches in the undulating IYGPT trawl were usually higher than catches predicted by acoustic measurements of capelin in the trawl zone (Fig. 9). There were 40 tows where capelin were caught in the trawl but none were recognised acoustically in the 20-60 m trawl zone (median catch = 6 capelin, maximum catch = 175). There was only one tow where capelin were observed acoustically from 20-60 m but none were caught. Catchability coefficients from the 18 sets where capelin were recorded acoustically and captured were high (median $q = 4.43$). More capelin were caught in the trawl than predicted by acoustics in 14 of the 18 sets. There was no evidence of a decrease in catchability with increasing capelin density as was observed for the Campelen trawl (Fig. 10), although it should be noted that there was only one set with an expected catch of > 1000 capelin.

Targeted IYGPT trawl detectability

Because these ten sets were targeted on acoustically detected concentrations of capelin we didn’t examine the relationship between acoustic density in the whole water column and trawlable density.

Targeted IYGPT trawl catchability

Catches in targeted IYGPT sets were usually lower than predicted catches based on acoustic estimates of capelin in the trawl zone (Fig. 11). In 7 of 10 tows the trawl caught fewer capelin than expected from acoustics. Catchability coefficients ranged from 0.03-11.26 (median $q = 0.41$).

Discussion

There was little agreement between trawl and acoustic estimates of capelin density for either the Campelen bottom trawl or the IYGPT mid-water trawl. As expected, acoustic density estimates were usually higher than trawlable density estimates because trawls sampled a very limited portion of the water column covered acoustically. Relationships between acoustic and trawl estimates were highly variable. Part of this variability was related to diurnal movement of fish into and out of the trawl zone.

Campelen bottom-trawl catches were generally higher during the day and pelagic juvenile IYGPT catches were almost always greater at night. However, much of the variability in the proportion of capelin in the trawl zone could not be explained by simple day-night differences. The vertical migratory behaviour of capelin appears to be complex, with seasonal (O'Driscoll & Rose 1999) and spatial (O'Driscoll *et al.* 2000) differences in behaviour. Because of these uncertainties associated with vertical distribution and unresolved questions about catchability (discussed below) we believe trawl surveys provide an unreliable estimate of capelin abundance.

Trawl surveys may provide more useful information about capelin distribution (presence/absence). There were relatively few sets where capelin were observed acoustically in the water column but no capelin were caught for either the Campelen (only 10 of 149 sets) or the IYGPT mid-water trawl (7 of 82 sets). The ability of the trawls to sample capelin even when the major concentration was outside the trawl zone was probably related to non-cohesive shoaling behaviour of the fish. There are likely to be a few scattered individuals around a shoal that will be exposed to and sampled by the trawl. Trawls, particularly the Campelen bottom trawl may also have sampled capelin while being deployed or retrieved through the water column.

Trawl sampling may, in fact, be more sensitive to detecting the presence of capelin than acoustic measurements. There were 32 Campelen sets and 33 IYGPT sets where a few (<200) capelin were captured but no capelin were recorded acoustically in the water column. Our inability to measure capelin acoustically at these very low densities is not due to instrumentation. Calculations based on the sampled acoustic volume showed that even individual small capelin would be detected and included in the integration at a threshold of −80 dB. The issue is thus not one of detection, but rather of recognition. Because capelin signal was classified based mainly on signal characteristics, there was potential for an operator to fail to recognise low densities of capelin amongst the other sources of biological scattering.

This "recognition threshold" also accounts for the relatively high number of Campelen (50 of 149) and pelagic juvenile survey IYGPT (40 of 82) sets where capelin were caught but not detected in the trawl zone. In all cases the number of capelin captured was low. We confirmed that this an issue of recognition and not of detection by integrating total (unclassified) acoustic scattering from the trawl zone. In all cases the amount of total acoustic scattering exceeded the amount which would be caused by these very low densities of capelin. It should be noted that it is not sensible to classify this background level of acoustic scattering as being due mainly to capelin. There are many other biological organisms that contribute to acoustic scattering. Often total scattering from the sample zones of trawls that didn't catch capelin was very much higher than total scattering from trawls with capelin.

Failure to recognise low densities of capelin will tend to bias acoustic estimates downward. However, because the densities involved are very low this bias is probably small. O'Driscoll *et al.* (2000) estimated that ~11,400 tons of capelin was not measured acoustically during the 1999 pelagic juvenile survey due to the recognition threshold. This was 26% of the total survey biomass and well within the range of the sampling uncertainty.

Of greater concern was our observation that at moderate acoustic densities of capelin, both the Campelen bottom trawl and the undulating IYGPT trawl usually caught more capelin than were measured acoustically in the trawl zone ($q > 1$). This was not related to signal classification (recognition of capelin). Even if the total (unclassified) acoustic scattering was all capelin, many of the catches were still greater than expected.

The high levels of catchability we measured for the pelagic juvenile survey IYGPT trawls accounts for the large discrepancy between acoustic and trawl estimates of capelin abundance from the same surveys. Anderson *et al.* (1999b) applied a published (Koslow *et al.* 1997) estimate of catchability of $q = 0.14$ to IYGPT trawl data. Our direct estimate of median catchability for the undulating IYGPT trawl from comparison of trawl catches with acoustic estimates of capelin in the trawl zone was 4.43. The difference between these catchability values would result in a ~30-fold difference in biomass estimates.

Several possible explanations exist for the high catchability we observed. These explanations may be broadly grouped into two categories: 1) trawl catches too high; or 2) acoustic estimates too low.

Trawl catches too high

Estimates of predicted catch were based on the volume filtered during the fishing time of the trawl only and did not include the volume sampled during period of net deployment and retrieval. Scanmar measurements show both trawls appear to have some (reduced) mouth opening during deployment and retrieval so it is likely that capelin are captured during these times. However, the volumes sampled are small relative to the volume sampled during the fishing time. Increasing the sampled volume to include the periods of net deployment and retrieval would not account for the very high catchabilities (median q = 4-5) observed in the undulating IYGPT trawl or the Campelen trawl (at moderate capelin densities) unless capelin densities in the water sampled outside the trawl zone were very much higher than acoustic densities in the zone. We have little acoustic information on capelin densities above the zone of the undulating IYGPT trawl (< 20 m) because of the surface dead-zone (see below). There were sets with the Campelen trawl where very high densities of capelin were observed acoustically above the trawl zone and unexpectedly high catches in these sets may be explained by the net fishing on the way up and down.

Trawl catches could also be increased relative to acoustic estimates due to herding. That is fish becoming concentrated in front of the trawl. One possible biological mechanism for herding would be a tendency to school when danger (in this case a trawl) approaches. We have no evidence that herding occurs for capelin, but this would explain the high catchabilities observed. Density-dependent differences in capelin behaviour in response to the trawl might also account for the decrease in catchability in the Campelen trawl with increasing capelin density.

Small “catches” of capelin when none or few were detected acoustically may arise because of backwash from previous tows. Capelin commonly get meshed in the trawl and are washed into the cod-end on subsequent tows, even when the net is cleaned on deck between deployments (our personal observations). If tows occur close together in time it is difficult to separate fresh capelin from backwash and this introduces a further (albeit small) level of uncertainty in trawl catches.

Acoustic estimates of capelin density in the trawl zone were based on *mean* volume scattering. There was usually considerable variability in capelin density over the tow length (patchiness). Unexpectedly high catches might result from hitting a high density patch with the trawl. On several occasions there was only one small school observed acoustically during the set (and consequently low mean capelin density), but the trawl catch was high suggesting that the entire school was captured. Patchiness helps explain the variability in trawl catches, but does not explain why catches were consistently higher than predicted by acoustic measurements. We assume the trawl is equally likely to miss a patch as to capture it.

Acoustic estimates too low

We have already discussed how acoustics fails to detect low densities of capelin because of the subjective recognition threshold and pointed out that this does not account for the high catchabilities observed at moderate fish densities. Acoustics might also underestimate capelin density (expected catch) because of boat avoidance, surface and bottom acoustic dead-zones, and acoustic shadowing.

Capelin close to the surface may avoid the vessel. This should not affect comparisons with Campelen bottom trawl catches, but acoustics may underestimate capelin densities in the 20-60 m pelagic juvenile IYGPT trawl zone if capelin avoid the vessel (and the hull-mounted transducer) but not the trawl.

Capelin close to the surface (< 15 m depth) or to the bottom (< 0.5 m above bottom depending on depth) could not be detected acoustically. If high capelin densities occur very near the bottom, acoustics will underestimate the amount of capelin susceptible to the Campelen bottom trawl. The surface dead-zone should not affect our estimates of catchability because both gears were fished below the dead-zone (> 20 m). However, as noted previously, high densities of capelin close to the surface might be captured by the trawl during deployment and retrieval.

At very high fish densities S_A is not proportional to fish density because fish nearest the transducer attenuate the echo energy so that it cannot penetrate to the more distant fish (MacLennan & Simmonds 1992). We do not believe this was a major source of bias in our experiments because capelin densities were not very high.

A further source of uncertainty in acoustic estimates is target strength. Expected catch was determined from acoustic estimates using the length-target strength relationship of Rose (1998) and the lengths of capelin caught in each set. If we apply an alternative target strength model to our data ($TS = 19.1\log L - 74.0$; Toresen *et al.* 1998) expected catch is increased by about 1.5 times, but estimates of trawl catchability (q) still usually exceed one for the undulating IYGPT trawl and the Campelen trawl at moderate capelin densities.

Our observations of high catchability support the earlier findings of Miller (1996). Miller (1996) found that trawl catches of capelin in the IYGPT (5 of 12 sets) and Campelen trawls (19 of 19 sets) were often higher than acoustic estimates. These two studies suggest that further experimental work is required to examine capelin behaviour in response to trawling. Understanding of catchability and also capelin vertical distribution patterns are required before trawl surveys can be used to provide estimates of capelin abundance.

Acknowledgements

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Table 1. Summary of experimental sets used to compare acoustic estimates and trawl catch.

Cruise	Survey Date	Survey Areas	Number of Experimental Sets		
			Campelen	Undulating IYGPT	Targeted IYGPT
Teleost 59	1-17 Jan 98	2J,3Ps	7		
Teleost 60	28 Mar-2 Apr 98	3Ps	13		
Teleost 65	7-26 Jun 1998	2J,3L,3Ps	53		4
Teleost 77	4-16 Jan 1999	2J,3K,3L,3Ps	26		3
Teleost 79	30 May-18 Jun 99	2J,3L,3Ps	34		2
Teleost 81	23 Aug-17 Sep 99	2J,3K,3L		83	1
Teleost 89	4-16 Jan 2000	2J,3K,3L	16		

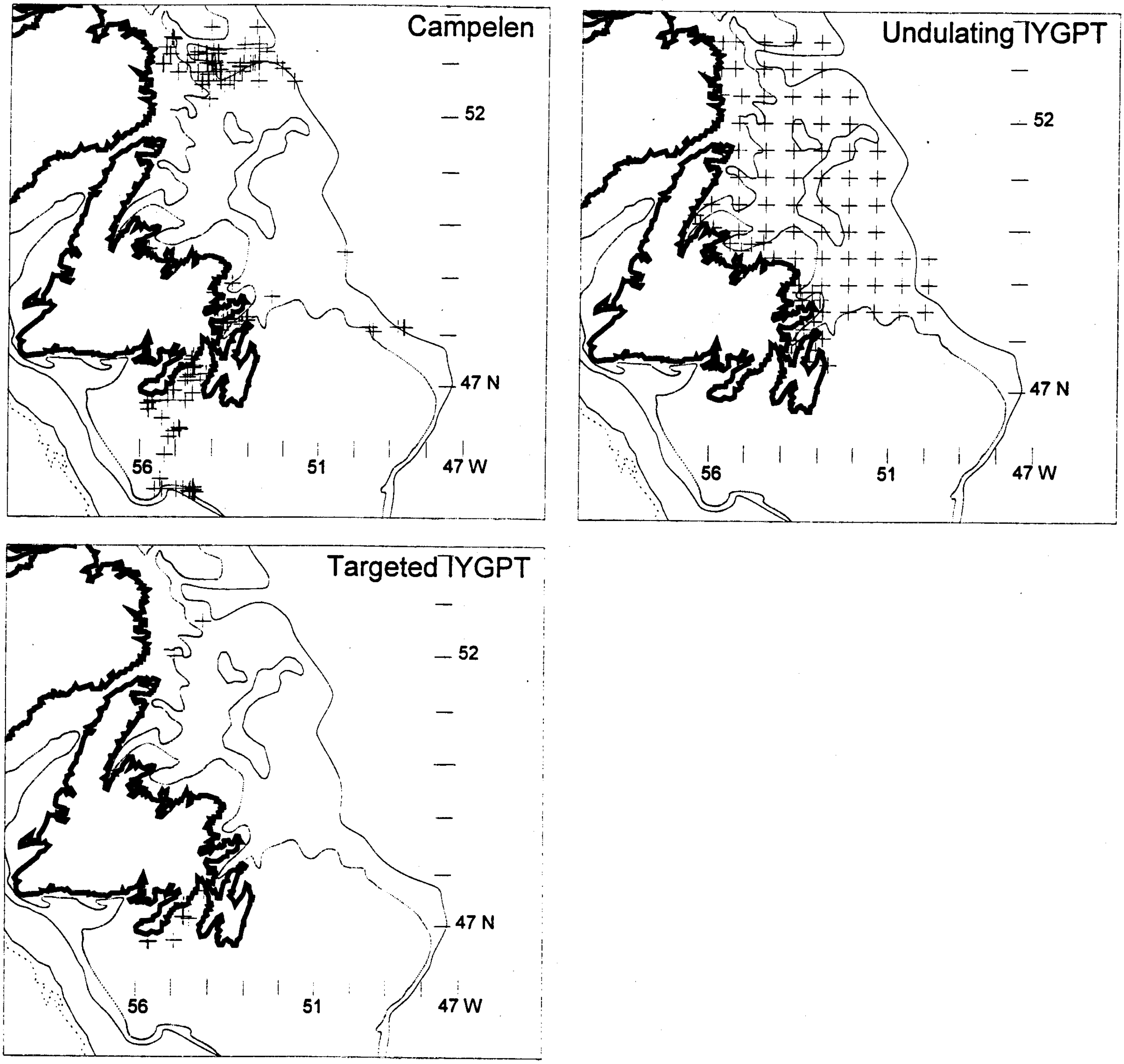
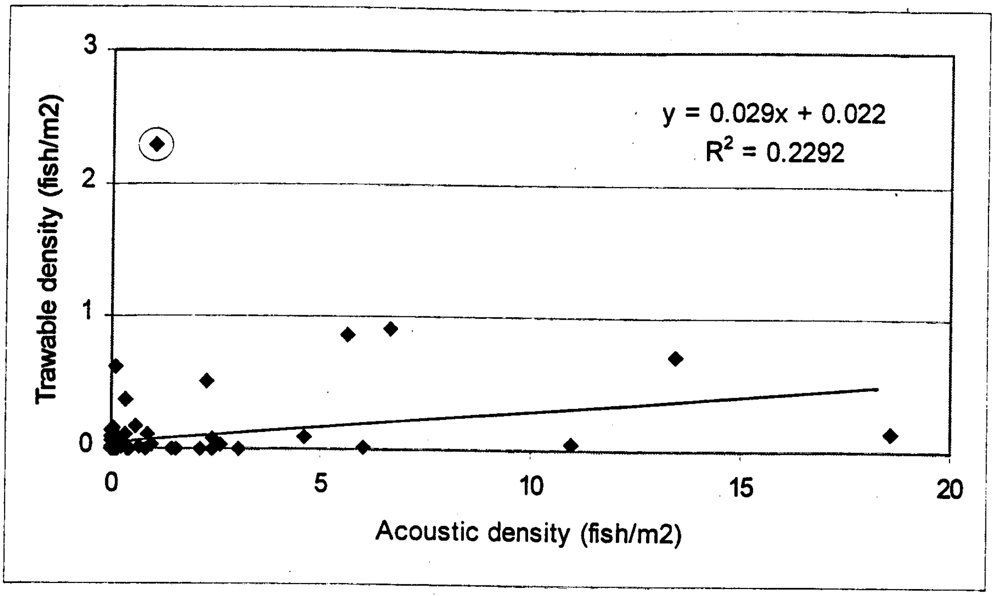


Fig. 1. Location of experimental sets used to compare acoustic estimates and trawl catch.



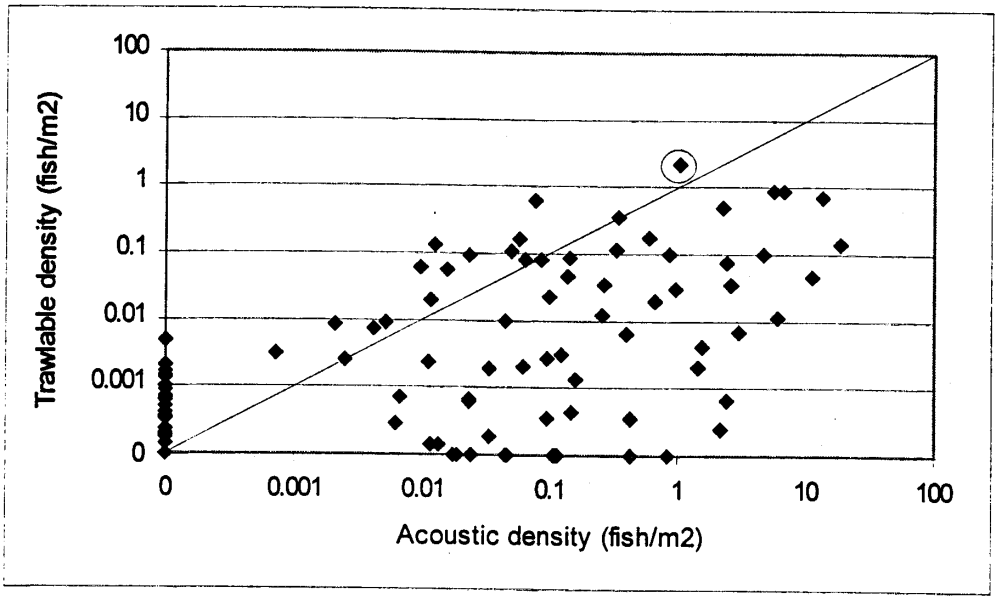


Fig. 2. Comparison of trawlable capelin density calculated from Campelen trawl catches with acoustic density of capelin throughout the water column (11 m to the bottom). Circled point was removed prior to regression analysis. Lower plot is the same data on a log scale with a line indicating x = y.

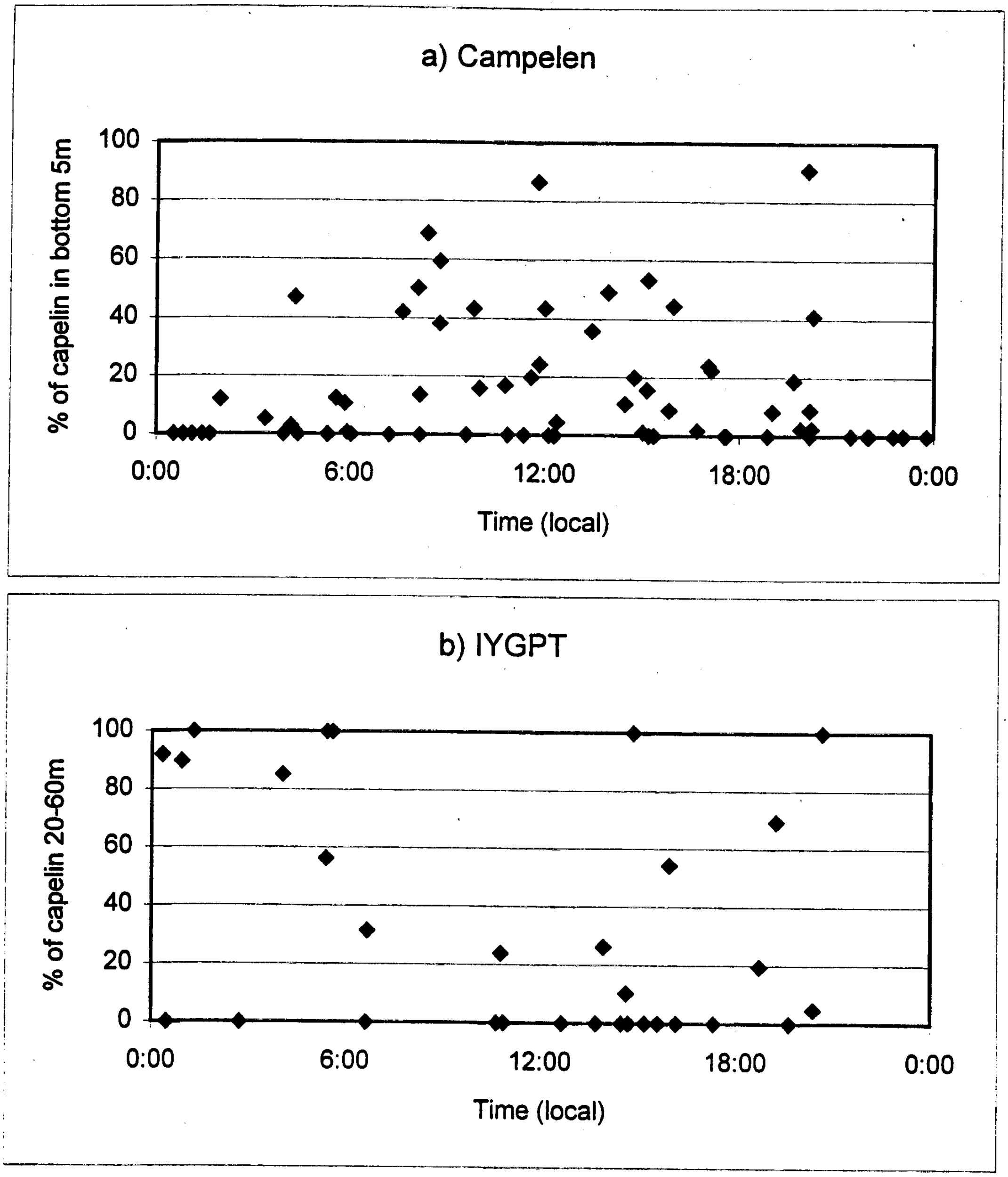


Fig. 3. Diurnal differences in the proportion of capelin detected acoustically in the trawl zone for experimental sets with a) Campelen (trawl zone 5 m from bottom) and b) undulating IYGPT mid-water trawls (trawl zone 20-60 m depth).

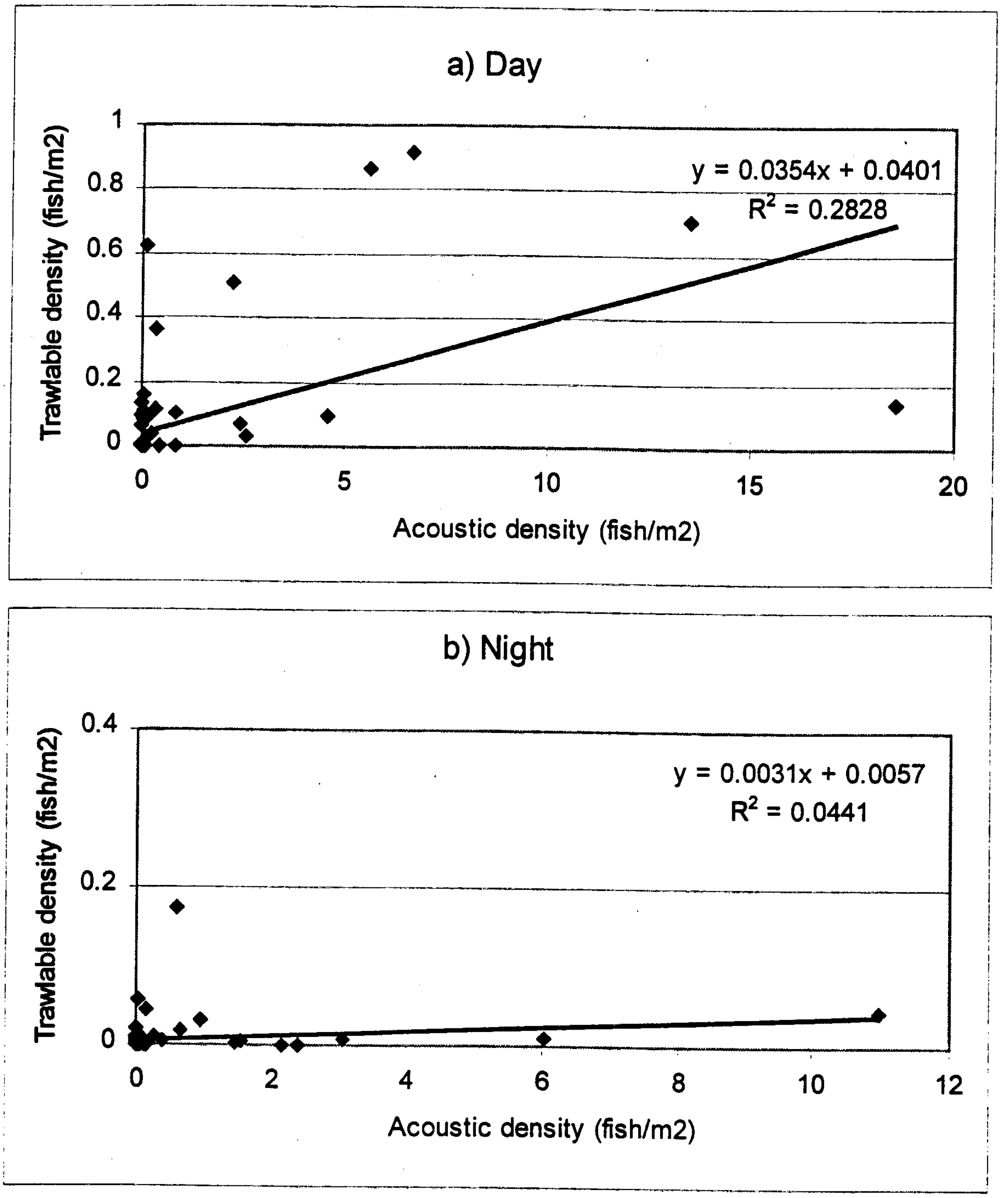


Fig. 4. Comparison of trawlable capelin density from Campelen trawl catches with acoustic density of capelin throughout the water column (11 m to the bottom) for experimental sets during a) daylight and b) at night.

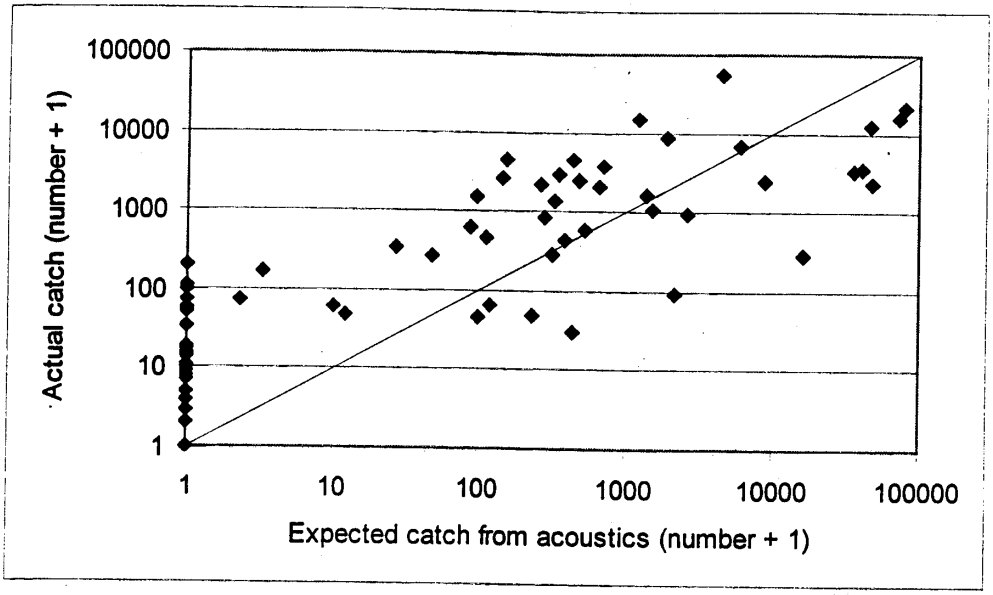


Fig. 5. Comparison of observed and expected catches of capelin in the Campelen trawl. Expected catches were calculated from acoustic estimates of capelin density in the trawl zone (5m from bottom). Data are plotted on a log scale. Line indicates a catchability of one.

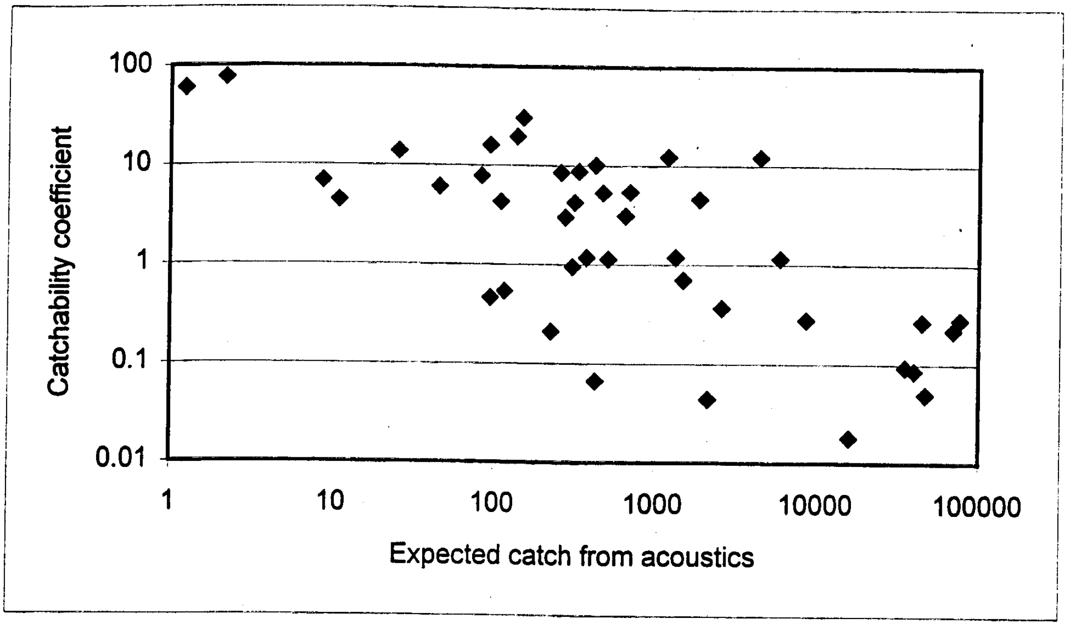
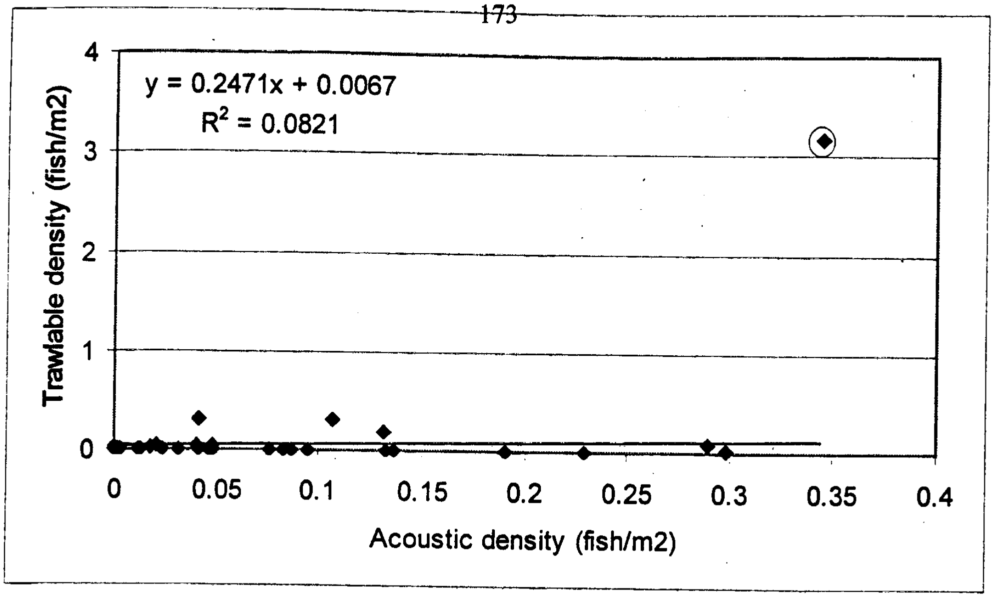


Fig. 6. Catchability in the Campelen trawl as a function of acoustic density of capelin in the trawl zone. Catchability is the ratio of observed to expected catch of capelin. Data are only plotted for sets where capelin were detected acoustically and caught.



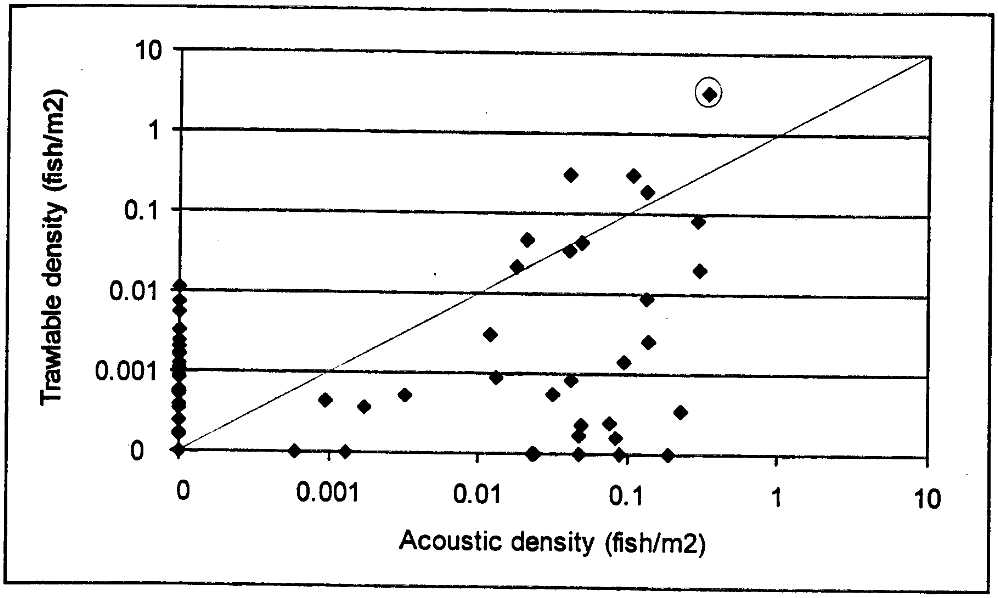


Fig. 7. Comparison of trawlable capelin density calculated from undulating (20-60 m depth) IYGPT trawl catches with acoustic density of capelin throughout the water column (11 m to the bottom). Circled point was removed prior to regression analysis. Lower plot is the same data on a log scale with a line indicating x = y.

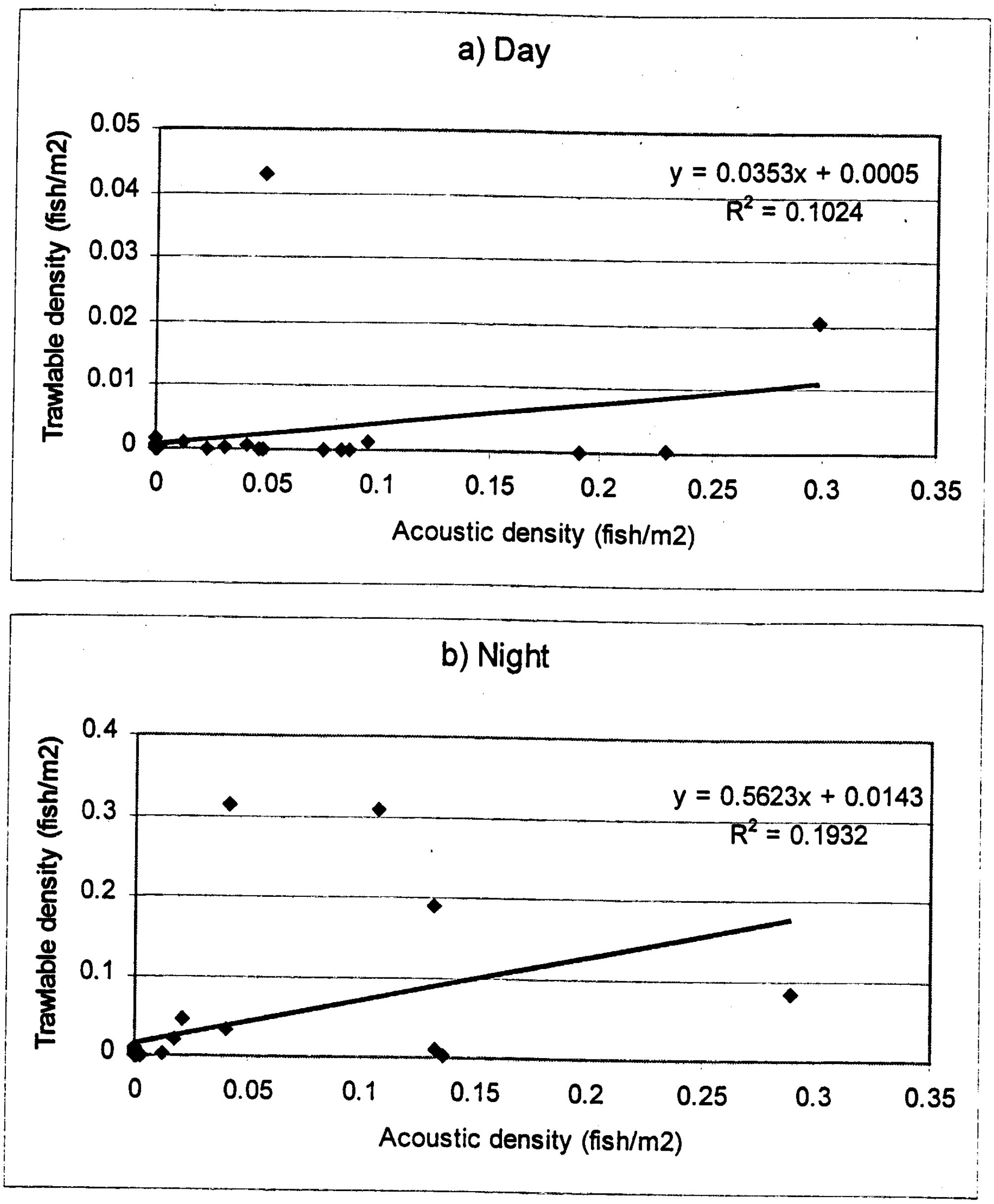


Fig. 8. Comparison of trawlable capelin density from undulating IYGPT trawl catches with acoustic density of capelin throughout the water column (11 m to the bottom) for experimental sets during a) daylight and b) at night.

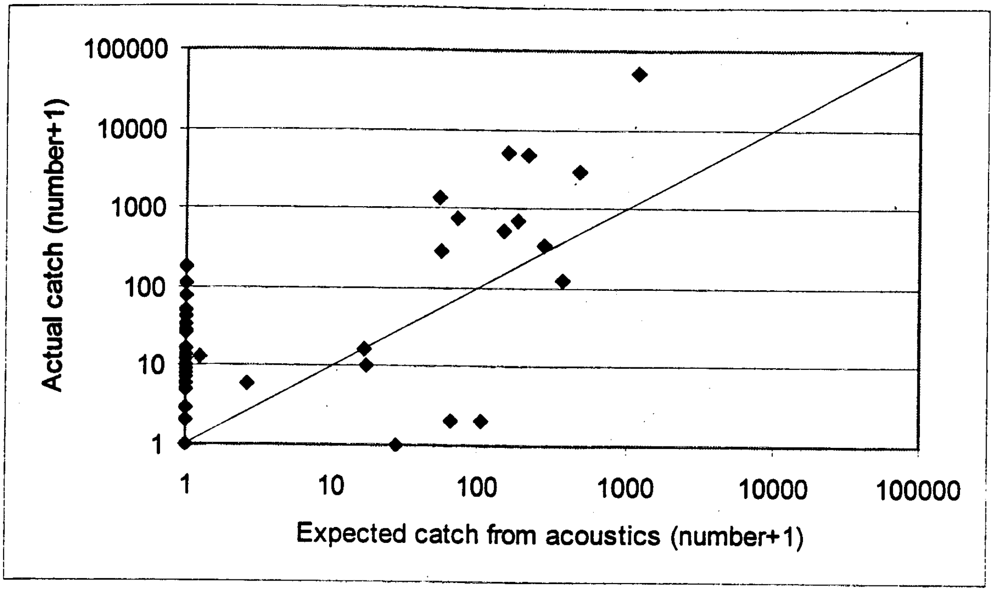


Fig. 9. Comparison of observed and expected catches of capelin in the undulating IYGPT trawl. Expected catches were calculated from acoustic estimates of capelin density in the trawl zone (20-60 m depth). Data are plotted on a log scale. Line indicates a catchability of one.

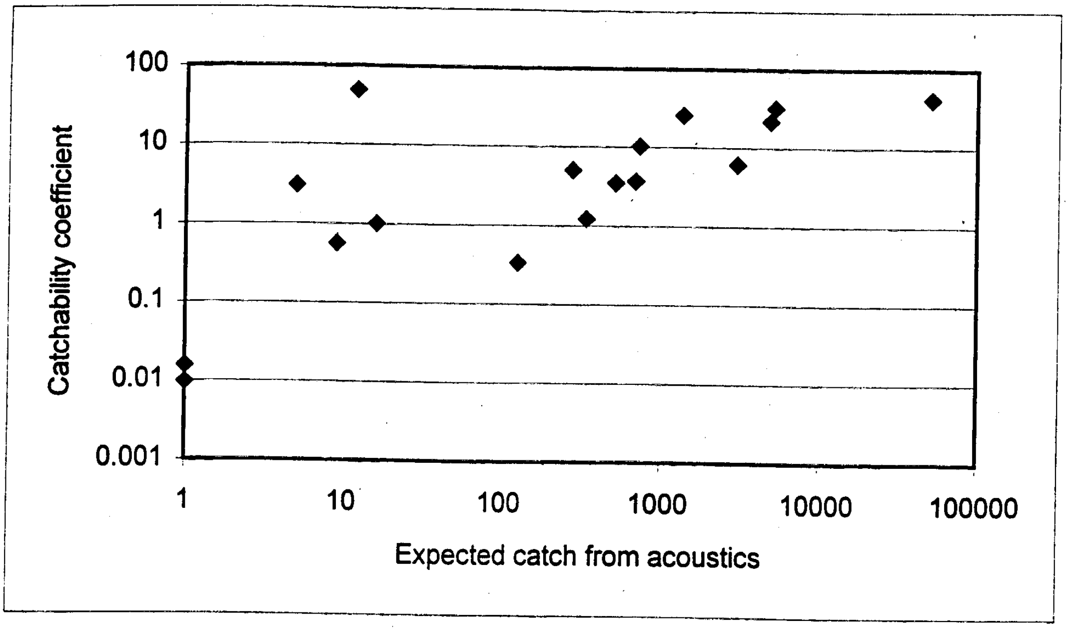


Fig. 10. Catchability in the undulating IYGPT trawl as a function of acoustic density of capelin in the trawl zone. Catchability is the ratio of observed to expected catch of capelin. Data are only plotted for sets where capelin were detected acoustically and caught.

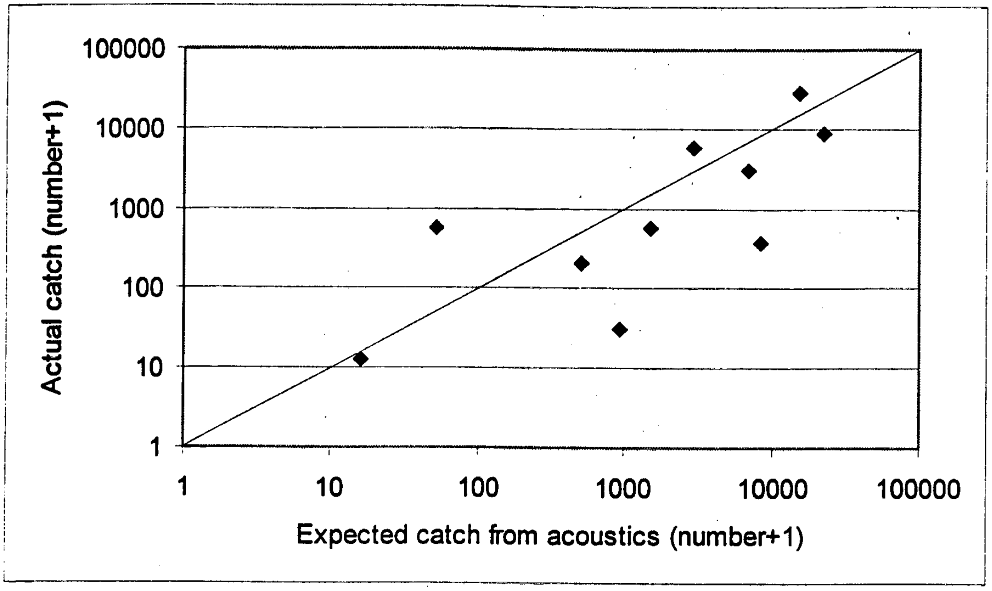


Fig. 11. Comparison of observed and expected catches of capelin in targeted IYGPT trawls. Expected catches were calculated from acoustic estimates of capelin density in the trawl zone (20 m around targeted depth). Data are plotted on a log scale. Line indicates a catchability of one.

Predicting Mean Lengths of Female Capelin in SA2+Div. 3KL

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Introduction

In past assessments, it has been noted that there is a positive relationship between mean lengths of maturing capelin from fall offshore surveys and the mean lengths of spawning capelin the following year. In fact, two relationships might exist, one for the fall/summer mean length combination 1981/1982 to 1989/1990 and from 1990/1991 onward (Carscadden and Evans 1998). These authors also reported that growth between the fall of one year and spring of the following year could not be predicted. As a result, since that assessment, two probability distributions, using data from the 1980s and 1990s, have been produced to provide insight into the likely mean lengths of the females in the mature population the following spawning season (Carscadden et al. 1999).

In this paper, we present the mean lengths of females sampled during 1999, thereby providing an evaluation of the probability distributions presented the previous year (Carscaden et al 1999). In addition, we present another probability distribution analysis using historical mean length data and the observed mean lengths of female capelin during the fall of 1999.

The 1999 Analysis and Prediction

From capelin by-catch in the Campelen gear in the autumn 1998 groundfish survey in Div. 2J3KL, the mean length of maturing females was 139 mm, one of the smallest estimates in the series. Using data from the 1980s and 1990s, probability distributions were presented. If growth increments between the sampling period during the fall of 1998 and spring 1999 resembled growth increments observed in the 1990s, there was no chance that the average counts would be less than 50 (ie. mean length greater than 151 mm). If growth increments were similar to those observed during the 1980s, there was about a 75% chance that the average counts in 1999 would be less than 50.

The mean length of mature female capelin in the 1999 commercial fishery was 150 mm. This mean length falls in the group of mean lengths from the 1990s (Fig 1), suggesting that growth between the fall of 1998 and spring of 19999 was again low and typical of the 1990s.

Predicted Mean Length of Females in 2000

The only source of samples from the autumn in 1999 was by-catch in the Div. 2J3KL groundfish survey using Campelen gear. The overall mean length of maturing female capelin in the fall of 1999 was 144 mm which is 5 mm larger than the mean lengths of maturing females in 1998 and in the mid-range of mean lengths from the 1990s (Table 1).

Using the non-parametric method of Evans and Rice (1988), we present a probability distribution for the mean length of 144 mm measured in the fall of 1999. Two distributions are presented: one if the increments of the 1990s prevail, another (higher) if the system reverts to the increments of the 1980s. For reference, we also illustrate the positions of lengths corresponding to the approximate 50 and 40 counts (Fig. 2). The positions of the 50 and 40 counts are approximate. They are derived from length-weight regressions for females during the spawning season and the weights of these females (from which counts are derived) are variable at this time because of rapid maturation.

If growth between late 1999 and the 2000 fishery is similar to that observed during the 1990s, there is about a 50% probability that counts will average less than 50 (Fig. 2). On the other hand, if growth is similar to that observed during the 1980s, there is a 100% probability that counts will average less than 50 and about a 65% probability that counts will average less than 40.

These graphs (Fig. 2) describe only the variation in increments observed since 1981 and cannot rule out accidents as yet unobserved. The analysis is based on pooled data from the stock area and consequently, it is not possible to account for differences that may occur between geographical areas and between spawning runs.

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Table 1. Mean lengths of mature females inshore during the spawning season and maturing females during the fall. All inshore mean lengths are derived from fishery data except 1994 and 1995 which are derived from collections from spawning beaches. The lengths are provided for the actual year of collection, however, the relationships illustrated in Figure 1 compare mean lengths in the fall to mean lengths inshore the following year.

Year	Mean lengths inshore (mm)	Mean lengths fall (mm)
1981		137
1982	166	147
1983	163	151
1984	170	146
1985	161	146
1986	165	163
1987	172	160
1988	170	148
1989	167	150
1990	167	159
1991	159	145
1992	151	146
1993	152	143
1994	152	131
1995	142	141
1996	151	149
1997	149	144
1998	147	139
1999	150	144

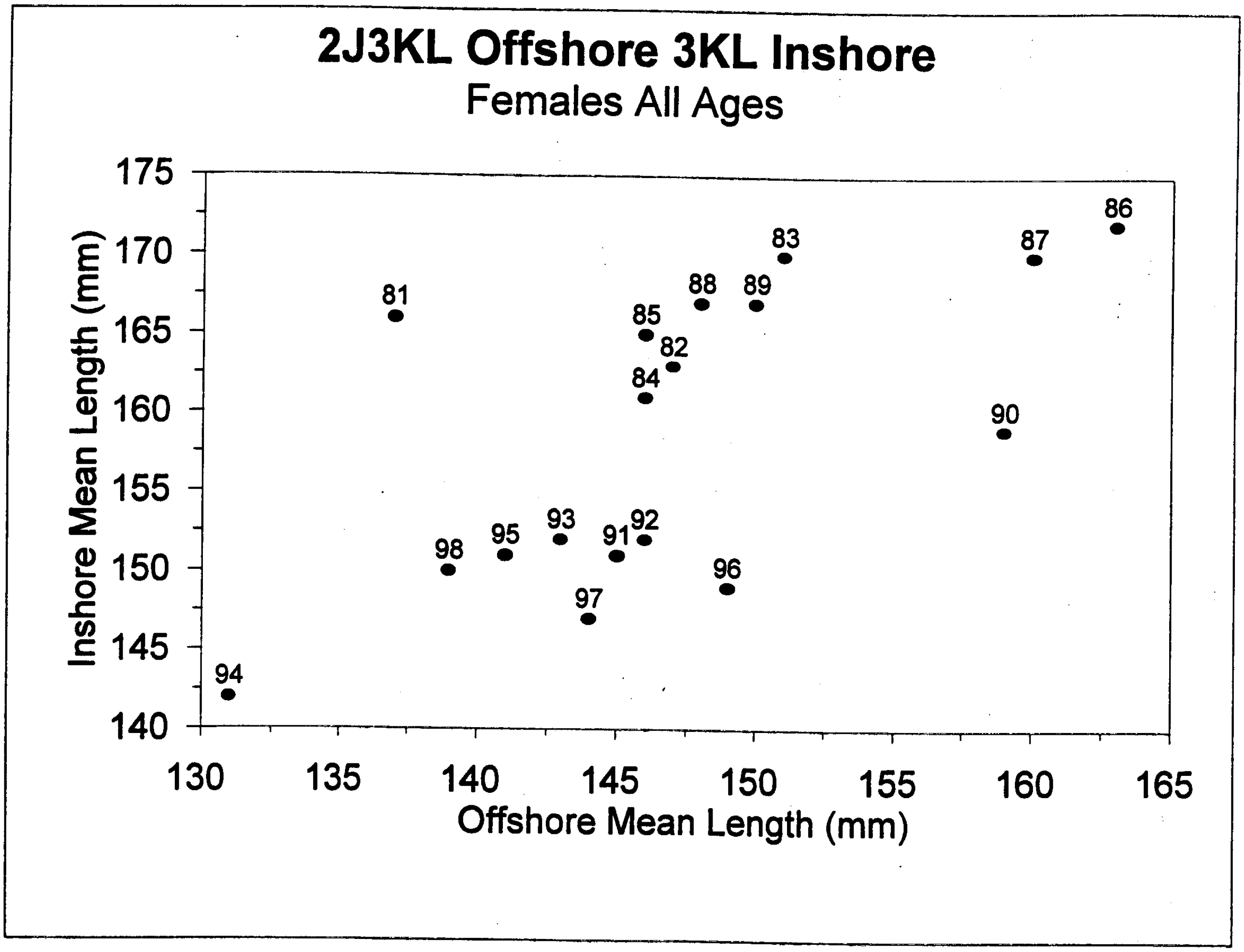

Fig. 1. Relationship between mean lengths of mature female capelin from fall offshore surveys and from inshore the following year, fall 1981 to inshroe 1999. The labels (year) are the year the fall samples were collected (eg. 81 point is for fall 1981/inshore 1982).

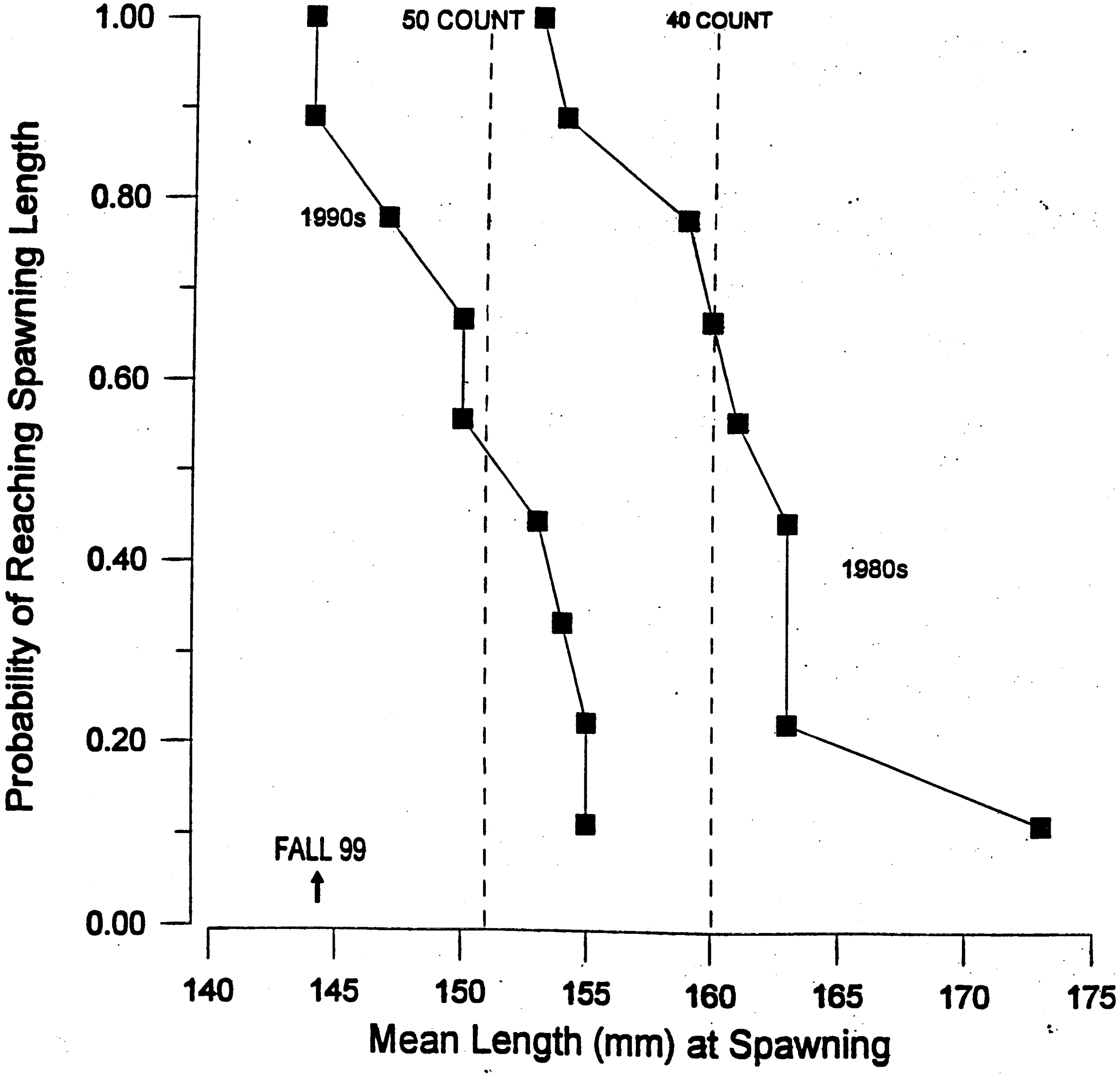

Fig. 2. Probabilities of reaching particular spawning lengths using growth increments observed during the 1980's and 1990's, and a fall mean length of 144 mm. The dotted lines identify the approximate mean lengths corresponding to 50 and 40 count (numbers of females per kg.) capelin.