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Estimating abundance and management

Counting capelin: a comparison of acoustic density and trawl catchability

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Acoustic estimates of capelin, *Mallotus villosus* (Müller), density were compared with catches in 97 Campelen 1800 bottom and 113 IYGPT midwater fishing sets to assess catching efficiency (q_e) relative to acoustic estimates, and the ability of trawl and acoustic surveys to index capelin abundance. Catches in experimental IYGPT sets targeted at capelin and towed at constant depth or undulated over 40 m did not differ from acoustic predictions over a range of densities from 0.00001 to 0.2 fish per m^2 (q_e=1; $p<0.05$). Catch and q_e did not differ between fishing methods ($p>0.05$, paired t-test). Campelen catches were typically bigger than acoustic estimates in the trawl zone at low or medium densities, likely a consequence of dead-zone non-detectability. Campelen q_es were strongly density-dependent (>1 at densities >0.05 fish per m^3; <1 at higher densities), and ranged over several orders of magnitude, making catches representative only of presence/absence. For the IYGPT trawl undulated at fixed survey stations, not targeted at capelin, mean q_e averaged 11.6, and high variability, in part related to vertical distribution (s.e.=3.76), limited usefulness as an abundance index. A recognition threshold caused acoustic integrations based on *a priori* allocation of backscatter to underestimate capelin distributed at low densities (<0.05 fish per m^3), as did dead-zone bias. *A posteriori* allocation reduced bias. It is concluded that acoustic integration supported by directed trawling is the most reliable method of counting capelin.

Keywords: acoustics, capelin, q, trawl catchability.

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Introduction

Capelin, *Mallotus villosus* (Müller), have been surveyed acoustically in the Norwegian-Russian and Icelandic waters of the North Atlantic for decades (Dommasnes and Rottingen, 1984; Vilhjálmsson, 1994). In Newfoundland waters, annual capelin acoustic surveys (e.g. Miller and Carscadden, 1990) were discontinued in the mid-1990s and, in recent years, survey trawl catches have provided the only broad-scale and fisheries-independent measure of capelin abundance. Capelin catches from autumn bottom-trawl surveys (Lilly, 1999) have been used in a multiplicative model to estimate capelin year-class strength (Anon., 1999). Anderson *et al.* (1999) used midwater trawl catches to estimate absolute abundance of capelin off Newfoundland from 1994 to 1998.

There are two major uncertainties associated with the use of trawl surveys to index capelin abundance. First, there is uncertainty associated with how representative trawl catches are of capelin density within the volume sampled (trawl-zone catchability). Second, the volume sampled by both midwater and bottom trawls represents a narrow depth range with respect to the known vertical distribution and migration behaviour of the species (e.g. O'Driscoll and Rose, 1999), which could result in variable proportions of capelin being available within the trawl zone. These two biases correspond to the catching

Table 1. Summary of fishing sets used to compare acoustic estimates and trawl catch. All cruises were on CCGS "Teleost" (a 65 m research acoustic-trawler).

Survey date	Survey area	Number of sets		
		Campelen	Undulating IYGPT	Targeted IYGPT
1–17 Jan. 1998	2J, 3Ps	4	—	—
28 Mar.–2 Apr. 1998	3Ps	8	—	—
7–26 Jun. 1998	2J, 3L, 3Ps	32	—	4
4–16 Jan. 1999	2J, 3K, 3L, 3Ps	16	—	3
30 May–18 Jun. 1999	2J, 3L, 3Ps	26	—	2
23 Aug.–17 Sep. 1999	2J, 3K, 3L	—	83	1
4–16 Jan. 2000	2J, 3K, 3L	6	—	—
6–21 Jun. 2001	3L, 3Ps	5	10	10

efficiency (q_e) and availability (q_a) components of survey catchability (Jennings *et al.*, 2001). A useful survey whose goal is to provide a quantitative index or absolute measure of abundance should result in q having minimal variability and no density-dependence.

In this paper we report the results of experiments conducted in Newfoundland waters in which catches of a Campelen 1800 shrimp trawl and an IYGPT midwater trawl were compared with acoustic estimates of capelin abundance. In all cases, the null hypothesis of no difference between methods was tested. Fishing was conducted in several ways, in the standard practice (predetermined sites) and configurations of Canada Department of Fisheries and Oceans (DFO) surveys, and directed experimentally at fish recognized acoustically. The IYGPT trawl was fished both at constant depth and undulated over a 40 m vertical height (juvenile fish survey mode). The objectives of the study were to compare and quantify q in the different fishing methods relative to acoustic measurements, and to investigate optimal methods of capelin biomass estimation. Experiments were conducted over several years and seasons, and under a wide variety of capelin densities and environmental conditions.

Methods

Fishing sets were made using the Campelen bottom trawl during acoustic surveys for cod and capelin in January, March, and June 1998, January and June 1999, and January 2000. A total of 97 Campelen sets (15 min duration) in which capelin were either caught or recognized acoustically was analysed (Table 1). Sets covered an extensive geographical area, but were concentrated in Placentia Bay (NAFO 3Ps), Trinity Bay (3L), the Bonavista Corridor (3K) and southern Labrador (2J) – see Figure 1. A total of 10 midwater sets (30 min) was targeted at acoustically identified capelin during these surveys (Table 1). In all, 83 sets were made with the IYGPT trawl during a pelagic juvenile survey in August–September 1999 (Table 1), in which the midwater trawl was towed in an undulating path from 20 to 60 m deep (Anderson *et al.*, 1999). In June 2001, the undulating IYGPT method was repeated in 10 experiments in which non-undulating tows (identical to "target"-type tows) were made immediately afterwards (five at different depths and five at the middle depth of the undulation). During three of these 10 experiments a Campelen set was also made. All qs are referenced to acoustic estimates of biomass.

All work was conducted from CCGS "Teleost" using trawls fitted to standard specifications of the Northwest Atlantic Fisheries Centre (B. MacCallum, DFO, St

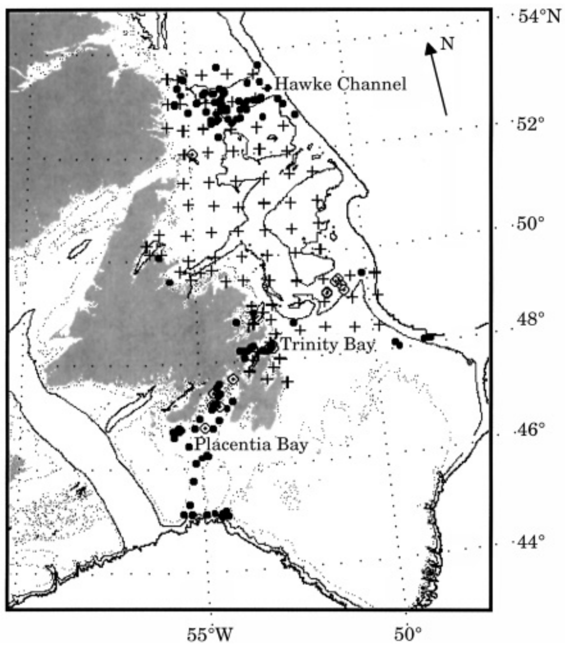

Figure 1. Map of the study region and the location of IYGPT survey (crosses), Campelen survey (filled circles), and experimental sets (dotted open circles) used to compare acoustic estimates and trawl catch.

John's, pers. comm.). Acoustic data were collected using a SIMRAD EK500 split-beam 38-kHz echosounder with hull-mounted transducer calibrated with copper and tungsten-carbide spheres (Foote *et al.*, 1987), and analysed using FASIT (LeFeuvre *et al.*, 2000) and CH2 software (Savard *et al.*, 1999). The method of allocation of backscatter to species differed between survey and experimental sets. For experimental sets, a full species decomposition was based on the proportion of the catch attributable to species of known target strength, TS (MacLennan and Simmonds, 1992). For survey sets, species allocation used visual examination of echograms, signal characteristics, and qualitative information from fishing sets, to mimic survey situations wherein a sample of all regions of allocated backscatter cannot be net-captured, and net species composition provides only a guide to allocation. Gear selectivity was unknown.

Two comparisons were made between trawl and acoustic estimates. First, trawl catches were compared with acoustic estimates of capelin abundance in the trawl zone to examine catching efficiency (q_e). The Campelen bottom-trawl zone was considered to be the volume 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 20 m centred on the mean depth of the tow. For undulating IYGPT sets, the trawl zone was 20–60 m from the surface for survey sets, and the same 40 m but at differing depths in the water column for experiments. Mean volume scattering (in $m^2\ m^{-3}$, equivalent to mean volume backscattering $\times 4\pi$) was calculated from acoustic data in the trawl zone and scaled by TS to give an estimate of volumetric density of capelin (fish per m^3) in the trawl zone. Capelin TS was calculated for each set from the total length frequency of capelin in the catch from: TS (dB)=20log (length in cm) − 73.1 (Rose, 1998). The "predicted catch" (number of fish) was calculated from estimates of volumetric acoustic density within the trawl zone and volume sampled by the trawl. For the Campelen trawl, volume sampled was based on a standard trawl opening [tow length (m) × trawl opening=69.7 m^2], swept area on wing spread (17 m), and acoustic densities were compensated for dead-zone loss by extrapolation of densities observed in the 2 m above the recognized seabed to the estimated true seabed (in most cases a range of 0.5–2.0 m). For IYGPT tows, the volume sampled was calculated from trawl geometry measured by SCANMAR. Tow length and sampled volume were based on fishing time and did not include the period of net deployment and retrieval. The q was defined as the ratio of the observed catch to the acoustically predicted catch (or net to acoustic density).

Second, trawl catches were compared with total acoustic estimates of capelin throughout the water column to determine the overall water column catchability (q). Acoustic data were integrated over the fishing set from 11 m (6 m vessel draft plus 5 m transducer near field) below the surface to the bottom using an integration threshold of − 80 dB, then scaled by TS to estimate areal density of capelin (fish per m^2) during the set. A corresponding trawl estimate of capelin density (fish per m^2) was obtained by dividing the trawl catch (number of fish) by the swept area.

Results

Acoustic densities and directed fishing

Acoustic area densities ranged from 0 to 40 capelin per m^2 during fishing experiments directed at capelin (Figure 2 echograms). Capelin showed a wide variety of pelagic and demersal shoaling formations (schools, loose shoals, nondescript aggregations, and layers). In most, but not all, cases capelin were clearly separable from the bottom, but signal recognition was at times in doubt, almost always at low density. For all experiments, backscatter was edited visually to remove any larger single fish (e.g. Atlantic cod *Gadus morhua*), then the remainder was allocated to pelagic species *a posteriori* in proportion to catch. In all cases the majority (typically >80%) of the small pelagic catch by weight was capelin (the remainder being shrimp or invertebrates with relatively low TS). A few sets contained large numbers of sand lance (*Ammodytes* sp.), which were assigned a TS 10 dB less than capelin of equivalent length for backscatter allocation.

Catches in the 30 IYGPT sets targeted at capelin and towed at constant depth (n=20) or undulated (n=10) did not differ by method or from catches predicted by acoustic estimates of capelin in the trawl zone [slope=0.77 (s.e.=0.14); d.f.=29; r^2=0.51; $p<0.05$; Figure 3a]. The slope did not differ from 1 ($p>0.05$). In keeping with that result, q_e ranged from 0.04 to 11.07, mean q_e was 1.42 (s.e.=0.49), and the hypothesis that q_e=1 could not be rejected ($p>0.05$; Figure 4a).

In the 10 experiments in which the IYGPT trawl was fished both in the undulating method and at a constant depth over the same grounds and at similar capelin densities (five at overlapping depths), there was no significant difference in the catches or q_es of these fishing methods ($p>0.05$; paired t-tests) and the null hypothesis of no difference between the performance of the fishing types could not be rejected (Table 2). Targeted IYGPT catches were significantly related to overall acoustic estimates of capelin in the water column, but the relationship explained little of the observed variance (r^2=0.17), and was highly dependent on a few points (Figure 5a).

Campelen sets directed at capelin identified *a priori* from the acoustic record indicated a ratio between acoustic density and catch that differed significantly

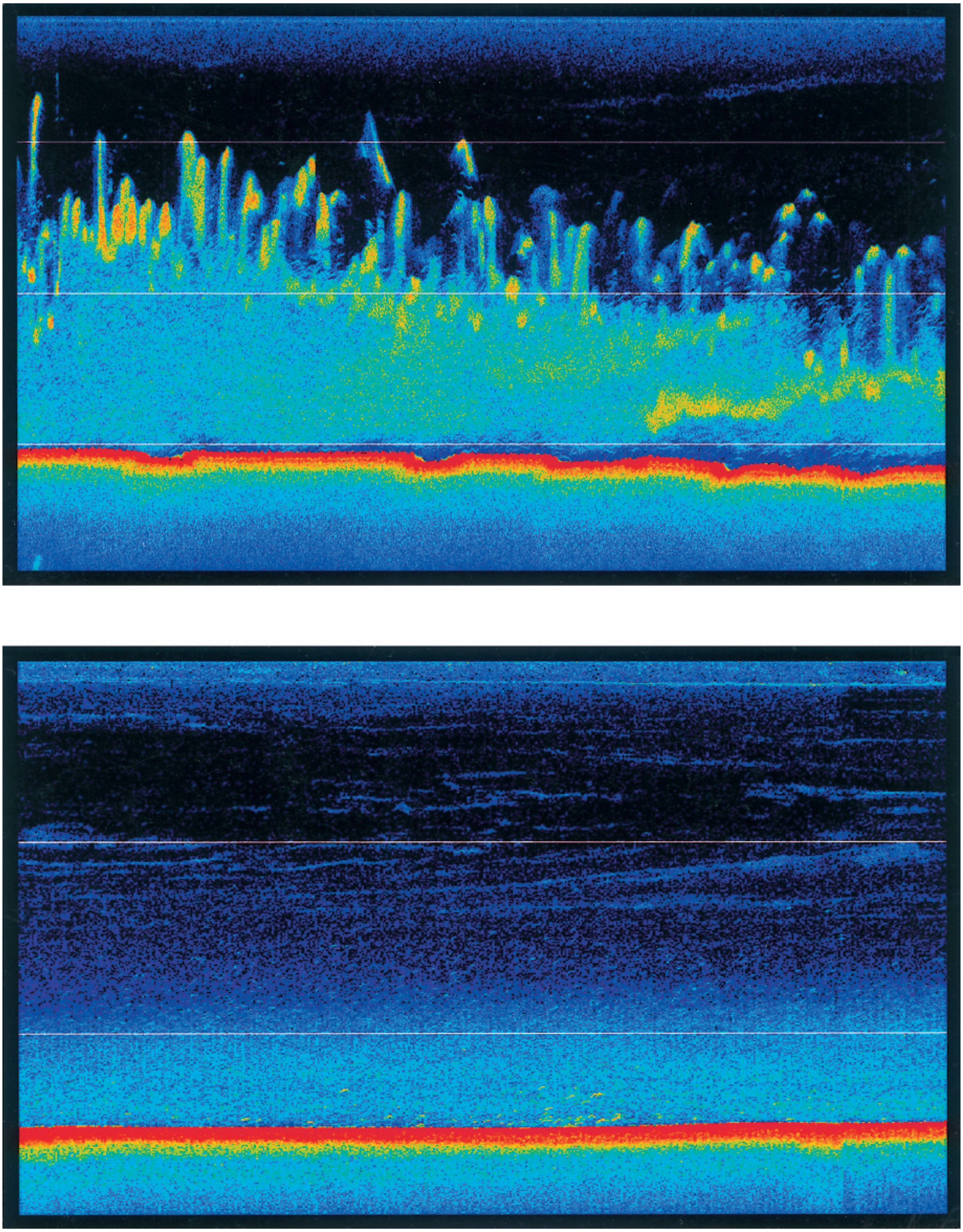

Figure 2. Echograms of capelin from experiments. Each panel represents approximately 5 nautical miles (9 km) – horizontal lines indicate 50 m depth. Top panel shows high-density shoals from Placentia Bay in June 1998; bottom panel shows lower-density layers from the Bonavista Corridor in June 2001.

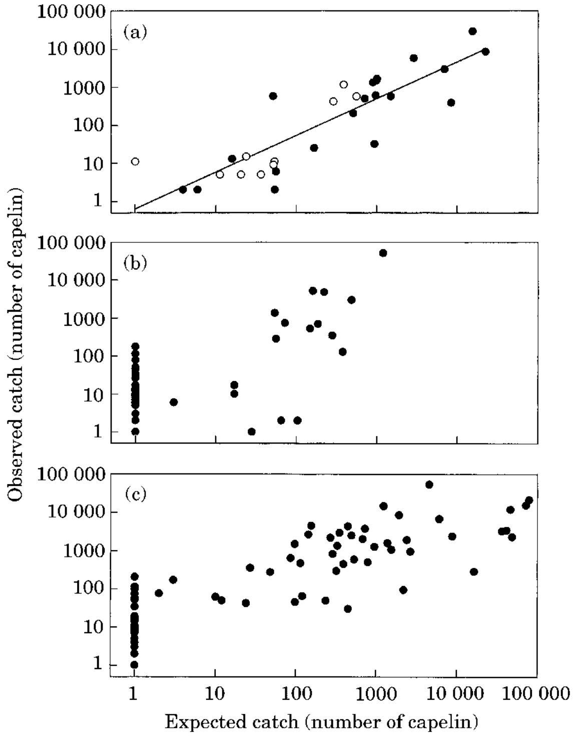

Figure 3. Comparison of observed and expected catches of capelin in (a) the IYGPT targeted sets (open circles are undulated, filled are constant depth), (b) the IYGPT undulated survey sets (not targeted), and (c) the Campelen survey sets. Expected catches were calculated from acoustic estimates of capelin density in the trawl zone. All correlations were significant (p<0.05), but only (a) had a regression slope not different from 1 (see text for details).

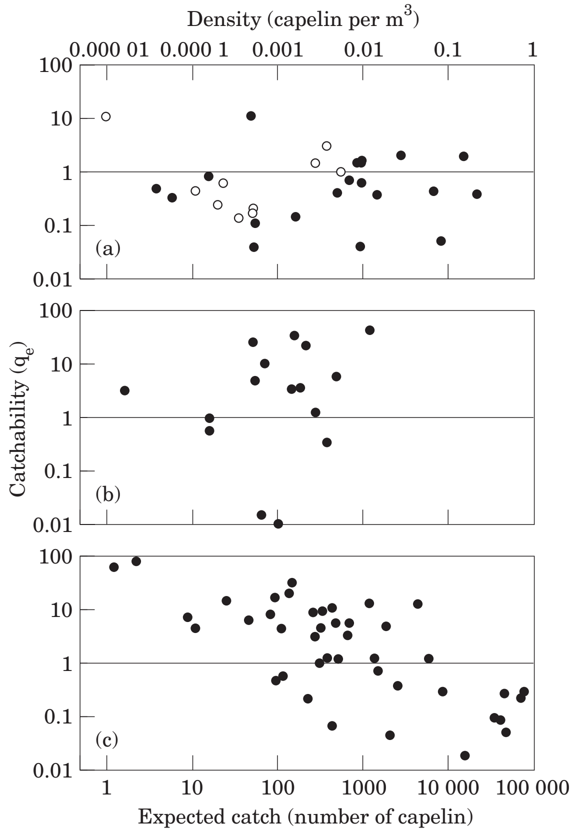

Figure 4. Catching efficiency (q_e) plotted against catch predicted by acoustic density within the trawl zone for (a) the IYGPT targeted sets (open circles are undulated, filled are constant depth), (b) the IYGPT undulated survey sets (not targeted), and (c) the Campelen survey sets. Expected catches are calculated from acoustic estimates of capelin density in the trawl zone.

from 1:1 [slope=0.42 (s.e.=0.11), d.f.=26, r^2=0.35, $p<0.05$]. For those sets, q_e ranged from 0.04 to 63, mean q_e was 5.25 (s.e.=2.33) and density-dependent (not shown but similar to the survey Campelen results). The hypothesis that $q_e=1$ was rejected.

IYGPT survey trawl

Catches of capelin in the IYGPT trawl undulated between 20 and 60 m deep ranged from 0 to 51 522 capelin and were in some cases greater than predicted by *a priori* recognition of capelin acoustic densities within the trawl zone (Figure 3b). Most capelin densities were very low. In 40 tows only a few capelin were caught and none were recognized *a priori* from the acoustic record from the trawl zone (median catch=6 fish, maximum=175). In only one tow were capelin observed acoustically in the trawl zone with zero catch. For 18 sets in which capelin were identified acoustically and caught, catches were strongly related to those predicted by acoustic densities within the trawl zone (r^2=0.81). However, the slope of the regression was $\gg 1$ [slope=37.5 (s.e.=4.59); d.f.=17; $p<0.05$]. Mean q_e for these 18 sets was high (11.6), with substantial variability (s.e.=3.8; Table 3). There was no evidence of a relationship between q_e and density (slope n.s.; Figure 4b), although the small range of expected densities (only one expected catch >1000 capelin) limited the power of this test. The hypothesis that $q_e=1$ was rejected.

To test if the high q_es could be attributed to an inability to recognize low densities of capelin from the acoustic record, a comparison was made between total acoustic backscatter within the trawl zone converted to capelin density and catch density. For the 83 survey sets, 76% had equivalent total acoustic backscatter and catch (a difference of ± 0.1 fish per m^2 was used to assign equivalence – allowing for some random error), 10% caught more than could be accounted for by the backscatter, and 14% caught less.

Availability (q_a) of capelin to the IYGPT trawl was related to the vertical distributions of capelin, and

Table 2. Summary of paired t-test comparisons of targeted IYGPT sets fished at constant depth (IT) and undulated (IU). Centred tows were fished at the centre depth of the IU (alternate order). Non-centred tows were not necessarily fished at the centre depth of IU. The null hypothesis of no difference cannot be rejected for any comparison.

	Centred tows Mean (n=5)	Paired t	p	Non-centred tows Mean (n=10)	Paired t	p
IT-IU catch	330, 349	− 0.11	0.92	559, 221	1.86	0.10
IT-IU q_e	0.52, 0.95	− 1.73	0.16	0.71, 1.83	− 1.19	0.27
IT-IU density	0.06, 0.04	0.62	0.57	0.04, 0.12	− 1.69	0.13

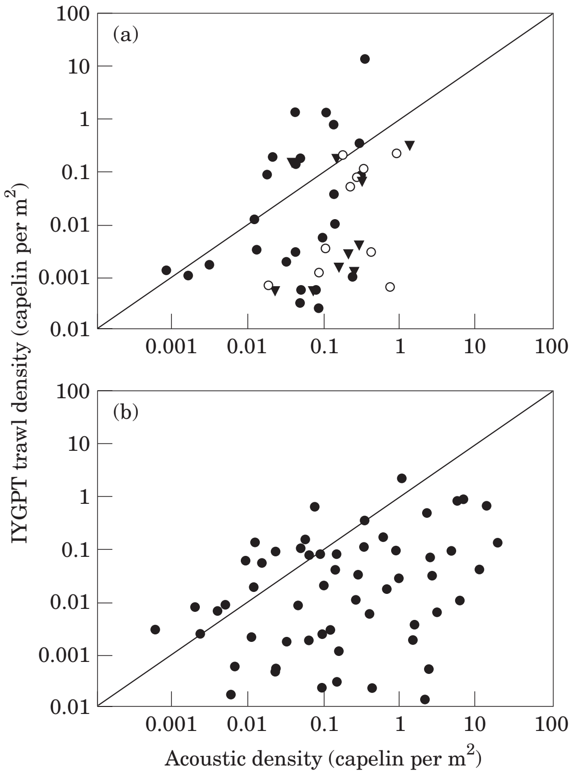

Figure 5. Capelin density calculated from (a) IYGPT trawls (open circles are undulated targeted, triangles are constant-depth targeted, and filled circles are undulated survey), and (b) Campelen trawls, compared with acoustic density in the full measured water column. Diagonal lines represent equality of trawl and acoustic estimates (q=1).

ranged from 0 to 100%. For survey sets, the proportion of capelin in the trawl zone was higher at night (Figure 6a), when most big catches were made. This result was supported by limited day–night comparisons during the experimental sets.

IYGPT catches were highly variable (over 4–5 orders of magnitude) with respect to acoustic densities determined over the entire water column (Figure 5a). Catchability (q) calculated from experimental sets was in most cases $\ll 1$. However, for survey sets, q was often >1. There was no significant relationship between experimental IYGPT trawl density and acoustic density. For the survey data there was a weak relationship ($r^2=0.17$) with a slope >1 (this result was almost certainly caused by the high q_es estimated from *a priori* classification).

Campelen survey trawl

Campelen trawl catches were correlated with those predicted by acoustic measurements of capelin density in the trawl zone ($r^2=0.77$, $p<0.05$; Figure 3c). Mean Campelen trawl q_e was 6.4 (s.e.=1.9) and strongly density-dependent (Figure 4c). At low densities of capelin (expected catch <1000), the trawl typically caught more than expected from the acoustic densities and $q_e>1$, but at high densities of capelin (expected catch >1000), the trawl caught fewer capelin than expected and $q_e<1$. There were 50 tows in which few capelin (mean=20 fish, maximum=201) were caught but none was recognized *a priori* from the acoustic record from the trawl zone. There were no instances of large numbers of capelin caught but not recognized acoustically, and no instances of capelin being recognized acoustically in the trawl zone and not being caught. The null hypothesis that trawl catch would equal acoustic density predictions ($q_e=1$) was rejected.

Availability of capelin (q_a) to the Campelen trawl was related to the vertical distribution of capelin, and varied from 0 to 90%. Acoustic densities in the bottom 5 m "trawl zone" and spanning the whole water column indicated a diurnal pattern in which capelin concentrated close to the bottom during daylight (Figure 6b). Most large Campelen catches were made during the day.

Campelen trawl catches were weakly correlated with acoustically determined capelin densities throughout the water column ($r^2=0.13$; $p<0.05$; Figure 5b). Overall acoustic estimates tended to be much greater than trawl estimates at high density ($q<1$), but lower at low densities ($q>1$). Variability was high, and at typical mid-range acoustic densities, Campelen catches varied by as much as three orders of magnitude. Overall average qs did not differ from unity for either survey or directed sets.

Table 3. Catchabilities of different fishing gear and methods compared with acoustic densities in the trawl zone (q_e) and over the full water column (q). Asterisks indicate that the null hypothesis of q=1 is rejected (p>0.05).

	q_e		q	
Method	Mean (s.e.)	Median (n)	Mean (s.e.)	Median (n)
IYGPT constant depth targeted	1.22 (0.54)	0.47 (20)	0.38 (0.09)*	0.37 (10)
IYGPT undulated targeted	1.83 (1.06)	0.54 (10)	0.11 (0.04)*	0.05 (10)
Campelen targeted	5.25 (2.33)*	0.96 (27)	0.95 (0.34)	0.22 (27)
IYGPT undulated survey	11.6 (3.76)*	3.66 (18)	3.69 (1.59)*	0.18 (32)
Campelen survey	6.40 (1.90)*	2.46 (42)	1.10 (0.3)	0.08 (60)

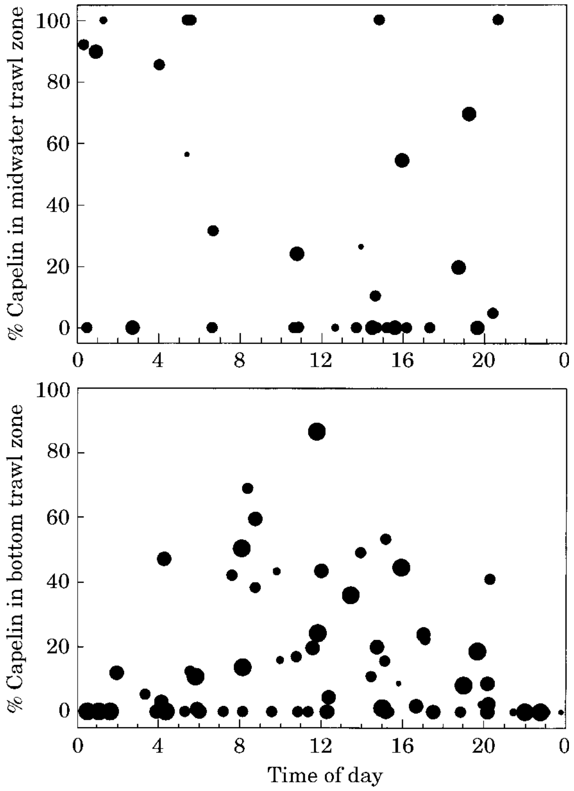

Figure 6. Diurnal differences in the proportion of capelin detected acoustically in the trawl zone for experimental sets with (top) undulating IYGPT midwater sets (trawl zone 20–60 m deep), and (bottom) Campelen sets (trawl zone 5 m from seabed). Symbol diameters scaled in five steps representing <0.001, >0.001–0.01, >0.01–0.1, >0.1–1, and >1 fish per m^2.

Acoustic measures were less variable than non-directed survey catches of either the Campelen or IYGPT trawls (Table 4). In 92 Campelen sets in which capelin were either caught or recognized acoustically, the CVs of acoustic and trawl densities were 2.84 and 3.23 respectively. For IYGPT sets, CVs were 1.12 and 4.22 for acoustic and trawl densities respectively.

Discussion

The data suggest that acoustic estimates of capelin within the trawl zone are consistent with estimates from IYGPT trawls fished at constant depth or undulated and targeted at capelin signal recognized *a priori* from the acoustic record. On average, targeted IYGPT sets caught numbers of capelin equivalent to acoustic density estimates (q_e=1). There were exceptions to this generalization, most notably with the undulating method, for which variability in catch was high relative to the acoustic density estimates. In contrast, undirected survey sets employing the undulating IYGPT method typically caught more capelin at low densities than registered acoustically. A plausible reason for this result is that targeted sets identified capelin *a priori* as the acoustic target, whereas net survey sets may have not, and *a priori* identification is almost certainly more difficult at low densities. Sufficient total backscatter was present in most cases to account for the capelin catches that exceeded those predicted by backscatter allocated *a priori* to capelin. Hence, the problem is one of recognition of low densities of capelin, and not of acoustic threshold or sensitivity.

Direct experimental comparisons between the IYGPT fished in an undulating pattern and at a constant depth over the same ground indicated that the differences in catch and q_e were not significant, and the hypothesis that q_e=1 could not be rejected, over a somewhat larger range of densities than measured during survey use of the undulating method. This result further supports the notion that acoustic signal recognition and allocation during surveys (where a full species decomposition of biomass conducted *a posteriori* was not feasible) might account for the difference, at least at low densities.

The Campelen trawl systematically caught more capelin than predicted by the acoustic backscatter in the trawl zone at low densities (q_e>1), but far fewer at high densities. These differences cannot be totally attributed to incorrect recognition of capelin, because in some cases the total (unclassified) acoustic scattering within the trawl zone would not predict the observed catches. Miller (1996) also found that Campelen catches in 19 of

Table 4. Comparisons of measures of capelin density per m^2 made with an EK500 echosounder (38 kHz) and Campelen 1800 (15 min) and IYGPT trawls (30 min undulated from 20 to 60 m). Campelen and IYGPT sets are not over the same grounds. Each n had either echosounder reading >0 or catch >0, and all were survey sets (not directed at capelin).

		Acoustic		Trawl	
Set	n	Mean (s.d.) [CV]	Range	Mean (s.d.) [CV]	Range
Campelen	92	1.000 (2.845) [2.841]	0–18.607	0.089 (0.289) [3.233]	0–2.295
IYGPT	32	0.083 (0.093) [1.121]	0–0.340	0.567 (2.392) [4.220]	0–13.535

19 sets exceeded acoustic estimates (mostly measured at low density). Much of this difference may be attributable to underestimation of capelin within the acoustic dead-zone (Ona and Mitson, 1996). In contrast, low q_e at high capelin density is suggestive of avoidance behaviour or catch saturation. Whatever the cause, where capelin were schooling densely, our data indicate that the Campelen trawl caught only 1–10% of the capelin present in the trawl zone. That the overall mean q for the Campelen sets did not differ from unity is thought to be curious, but spurious given the variability.

Both trawl and acoustic measures are not without considerable error (e.g. Rose *et al.*, 2000), and the influence of a few fish on catch predictions and trawl: acoustic ratios increases at low densities. Small "catches" of capelin could arise from meshed backwash from previous tows (despite care to prevent this), and cause very high q_es at low densities. Of note, there was scant evidence that Campelen trawls caught more capelin than indicated acoustically ($q>1$) at high density, such as would result if the majority of capelin occupied the acoustic dead-zone. Of 18 sets with densities >0.01 capelin per m^3, only three had $q_e s \gg 1$. However, the surface unensonified zone was approximately 11 m (vessel draft and beam-forming range), so there was potential for underestimation of overall densities and for unknown vessel avoidance.

There was only limited agreement between acoustic measures of capelin density over the full water column and Campelen bottom and the IYGPT midwater (undulated) trawl catches. Availability of capelin to both trawls (q_a) was typically highly variable, and acoustic density estimates were often substantially higher than trawl density estimates over the same ground. Acoustically determined densities were consistently less variable. This result was not surprising, because in many cases capelin were distributed well outside the trawl zone. Part of the large variability in q_a can be attributed to vertical movements 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. Over the full range of densities measured, catches of both the IYGPT and Campelen trawls were highly variable (>3 orders of magnitude) with respect to the densities of capelin measured acoustically.

Our work indicates that there is a "recognition threshold" to acoustic signal from capelin, below which the species cannot be differentiated *a priori* within the acoustic record from other biological scatterers of small size. There were many Campelen and IYGPT survey sets where a few (<200) capelin were caught but none were recognized *a priori* acoustically in the trawl zone, and in a few cases anywhere in the water column. We confirmed that this was an issue of recognition and not of detection by integrating total (unclassified) acoustic scattering from the trawl zone. In most, but not all, cases the amount of total acoustic scattering exceeded that attributable to the catch. Moreover, where species allocation was based on signal recognition, catch composition and total acoustic backscatter (the experiments), there was no evidence of any threshold (backscatter equivalent to a catch of one capelin was assigned in one instance to capelin). It is therefore concluded that, with current techniques, it is not feasible to recognize low densities of capelin among the other sources of biological scattering, and until a better method is developed, species decomposition by trawl catch must be employed in such instances.

Counting capelin

Uncertainties associated with vertical distribution of capelin and imprecision of q lead us to conclude that Campelen bottom-trawl surveys are unlikely to provide a reliable index of capelin abundance. Campelen trawl data are difficult to interpret quantitatively because of the variability and density-dependence of q, which ranged from 0.001 to 10 over a range of densities from 1 to 0.00001 capelin per m^3. Nevertheless, Campelen surveys provide useful information about capelin distribution (presence/absence). In only a few (10 of 159) sets were capelin observed acoustically in the water column but not caught.

The IYGPT undulated survey provides a reasonable index of presence/absence in the upper pelagic zone.

Capelin were absent in only seven sets for which they were recorded acoustically, and there were many sets in which capelin were caught in numbers so low that *a priori* acoustic recognition was not possible. As a quantitative index, the use of the undulating IYGPT is not as clear. On the one hand, q_e appears not to be density-dependent and did not differ from 1 under experimental conditions. On the other hand, there is substantial unexplained variability in q_e that limits the usefulness of a quantitative survey of capelin abundance based on trawling alone. We conclude that IYGPT density estimates are best treated as relative estimates or scaled by a q of 1. Anderson *et al.* (1999) applied a published (Koslow *et al.*, 1997) estimate of q=0.14 to IYGPT trawl data for capelin, much lower than we have estimated here.

Acoustic estimates of capelin density were consistent with (1:1) and complementary to directed midwater trawl catch; together these methods are thought to provide the most accurate method of counting capelin over the full water column. Acoustics provides the widest water-column coverage possible and trawling provides details of species identification and size, as well as confirmation of density ranges. Failure to recognize low densities of capelin in the pelagic zone and near the seabed may tend to bias acoustic estimates downwards. The concerns registered by Carscadden and Nakashima (1997) that acoustic estimates of capelin in the early 1990s in Newfoundland waters were underestimates because of environmentally induced changes in distribution at the low densities of that era, clearly have foundation. However, the magnitude of this bias is likely small, because it is proportional to the recognition density threshold that was relatively low (approximately 0.01–0.001 capelin per m^3). Based on our Campelen data, if capelin of mean weight 15 g were distributed universally in the trawl zone at the recognition threshold (0.01) over the full NAFO 2J 3KL stock area (267 000 km^2), the acoustic estimate would be deficient by approximately 200 000 t. At a recognition threshold of 0.001 capelin per m^3 for pelagic acoustic signal distributed universally over 40 m (the trawl zone), an estimate might be deficient by 100 000 t (for capelin of mean weight 10 g). These are thought to be maximum biases because it is highly unlikely that capelin would be distributed everywhere at low densities, and areas where there are no capelin or higher densities are adequately measured. Nevertheless, acoustic species decomposition and near-bottom detectability (e.g. Lawson and Rose, 1999) corrections based on frequent trawling are recommended to ameliorate these biases. In conclusion, acoustic measures combined with directed trawling are recommended to provide the most consistent and easily interpreted density data and are most likely to provide the basis for an unbiased estimate of capelin abundance.

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