

Year-Class Strength of Northwest Atlantic Capelin (2J3KLNO)
Estimated at the Larval Stage and Age One Based on the
Pelagic Juvenile Fish Surveys, 1994-1998

by

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Introduction

Research trawl surveys to estimate the year-class strength of capelin within NAFO Divisions 2J3KLNO have been carried out since 1991 (Anderson and Dalley 1995, 1996, 1997, 1998). Two gear types are used to sample capelin in the upper water column, for the larval stage (0-Group; 3-50 mm) and one year old (1-Group, 50-119 mm). The survey is carried out at the end of August and early September, timed to sample pelagic juvenile cod before they settle to the bottom, and larval capelin released from beach and bottom sediments.

The purpose of this paper is to report on the abundance and distribution of larval and juvenile capelin from the 1998 survey, and to compare these results to the previous surveys carried out 1994-1997. Materials and methods used in this project have been previously described by Anderson and Dalley (1995, 1996, 1997).

Results and Discussion

Survey

The survey was conducted from August 24 to September 10, 1998 (Table 1). In 1998, 132 stations were sampled with the bongo and IYGPT samplers. These stations covered the inshore areas along the northeast coast of Newfoundland and six offshore areas over the Northeast Newfoundland Shelf and on the Grand Banks (Fig. 1). Survey stations in the outer most areas along the shelfbreak were not occupied due to time constraints. Bonavista Bay was not sampled in 1998 due to the early recall of the research ship Teleost.

Abundance Indices Ages 0 and 1 Year

Previously, we have reported the abundance of larval capelin (0-group) based on the bongo samples using three different indices. The purpose of the different indices was to extend the time series of observations to the 1991-1993 period, before the two ship surveys began in 1994. It was rationalized that the majority of capelin observed during the 1990's were distributed within the area surveyed by the single ship during 1991-1993. We now have five years of data based on the two-ship survey which covers a much wider geographic distribution. Comparisons of year-class indices during the last five years, 1994-1998, demonstrated a linear and highly significant relationship between the Weighted Index Area index (WIA) and both the "common area" and "non-zero catches" indices (Table 2, Fig. 2). The best comparison of the WIA index was with the index for the common area, but both regressions have a high degree of predictive power.

Similarly, we compared the index of abundance at the larval stage to that estimated at age one based on the WIA index. There was a highly linear and statistically significant relationship estimating year-class strength between ages (Table 2, Fig. 3). Both indices estimate the year-class abundance ranked as: 1996 > 1995 > 1997 > 1994.

We note that Bonavista Bay was not sampled in 1998, due to the early recall of the research ship Teleost. Previously, Bonavista Bay has been an important index area for capelin at both the larval stage and at age one. We compared the ratio of abundance measured in Bonavista Bay to the total for the other inshore areas (Conception Bay, Trinity Bay, Notre Dame Bay, White Bay) for the previous four survey years, 1994-1997. For larvae, the mean ratio was 0.183 (Std Dev 0.0628, CV 34.4%). We felt this ratio was stable enough over the previous four years that it could be used to estimate the abundance of capelin larvae in the Bonavista Bay Index Area for 1998. Therefore, we have used this ratio in the estimate for the WIA (Table 3). Compared to the overall (i.e. total) estimate where Bonavista Bay was left not sampled, the predicted value increased the total WIA for 1998 by 7.0%. This increase had the effect of increasing the 1998 larval abundance index to a value similar to the 1997 year-class.

For age one capelin, the ratio of Bonavista Bay to the other inshore areas averaged 19.85 (Std Dev 38.50, CV 194%, range 0.23-77.6). The huge range among years precludes predicting the abundance of one-year-old capelin in the Bonavista Bay Index Area in 1998 based on the abundance observed in the other inshore areas. If such an estimate is used it would result in an increase to the total WIA estimate of 37.9%. We felt this increase based on such a highly variable ratio was not justified. Therefore, our estimate of year-class strength for the 1997 year-class at age one is biased low due to the absence of any data from Bonavista Bay in 1998. However, while the degree of this bias remains unknown, it is apparent from the comparison of the WIA indices at the larval stage compared to age one that the abundance of one year old capelin in Bonavista Bay in 1998 may have been relatively low (Fig. 3).

The year-class strength estimate based on larval capelin increased from 1994 to a peak in 1996 (Fig. 4). During 1997 and 1998 year-class strength has been less than 1995 but greater than 1994. At age one, year-class strength was highest in 1993, reached a minimum in 1994 and increased to relatively high values for the 1996 year class (Fig. 5). The estimate for the 1997 year-class at age one based on the 1998 survey is clearly biased low due to the absence of abundance data from Bonavista Bay.

Distribution of Larvae and Juveniles and Adults

Capelin larvae were distributed along the northeast coast of Newfoundland, as in previous years (Fig. 6). However, in 1998 capelin larvae were observed off the coast of Southern Labrador and on the Southeast Shoal of the Grand Bank for the first time. These distributions indicate that capelin spawning occurred further to the north and south in 1998 than in the previous four years of the survey. Spawning on the Southern Grand Bank previously occurred during August (Frank and Carscadden 1989) as did spawning in Southern Labrador (B. Nakashima, pers. comm.). Large capelin larvae were also observed dispersed onto the northern portion of the Grand Bank in 1998.

Juvenile capelin, age one, occurred extensively on the southern portion of the Northeast Newfoundland Shelf and on the Northern Grand Bank in 1998, as observed in previous years (Fig. 7). In 1998, juveniles were distributed off Southern Labrador more abundantly than in previous years.

Adult capelin in late spawning condition were observed on the Southern Grand Bank in 1998 for the first time.

Size of Capelin

Mean length of capelin in the bongos was 11.7 mm, range 3-27 mm, which was very similar to mean lengths of 8.9-10.7 mm, 1994-1997.

Mean length of age one capelin in 1998 (i.e. the 1997 year-class) was 96.2 mm, range 51-119 mm (Fig. 8). This mean length was approximately in the middle of the range of mean lengths measured at age one for the 1993-1996 year-classes (range 84.6-103.1 mm). The ranking of mean length of capelin measured at age one for the 1994-1997 year-classes is: 1994 > 1997 > 1995 = 1996 > 1993.

References

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Table 1. Summary of Pelagic Juvenile Fish Surveys conducted, 1994-1998. Bongo-bongo plankton sampler; IYGPT—International Young Gadoids Pelagic Trawl. DoY—refers to the calendar day of the year; Start, End and Mid refer to the starting, ending and middle day of the year for each survey. The numbers below each gear type list the number of stations sampled each year by each gear type.

Year	Ship-Trip	Dates	DoY Start	DoY End	DoY Mid	Bongo	IYGPT
1994	TEM157/GAD247	22 Aug–3 Sep	234	246	241	99	99
1995	TEM175/TEL018	5 Sep–22 Sep	248	264	257	139	139
1996	TEM193/TEL034	19 Aug–6 Sep	231	249	241	147	147
1997	TEM210/TEL050	11 Aug–29 Aug	223	241	233	148	148
1998	TEM226/TEL069	24 Aug–10 Sep	236	253	244	132	132

Table 2. Summary of linear regressions comparing different abundance indices. Non-Zero refers to the mean standardized catch rate (number m-3) for all positive catches each year. Common Area refers to the mean standardized catch rate (number m-3) for a commonly sampled area and includes null catches. WIA refers to the Weighted Index Area method where "0" is larval capelin and "1" is age one juvenile capelin.

Variables	Regression	df	F-Value	P-Value	r^2
Non-Zero (Y) vs WIA 0 (X)	$Y = -70.03 + 0.0028X$	4	13.3	0.01	0.930
Common Area (Y) vs WIA 0 (X)	$Y = 3.75 + 0.0017X$	4	170.0	0.001	0.994
Age 1 WIA (Y) vs Age 0 WIA (X)	$Y = -952.4 + 0.0285X$	4	340.1	0.001	0.997

Table 3. Abundance indices for Northwest Atlantic capelin (NAFO Divisions 2J3KLNC) based on the two-ship surveys, 1994-1997 using the Weighted Index Area method for non-transformed data (number 10^3 m^{-3}). * - indicates estimated value see text

	NOM3	10^5	Sampling Year 1994		Sampling Year 1995		Sampling Year 1996		Sampling Year 1997		Sampling Year 1998	
Area	0-Group	1-Group	0-Group	1-Group	0-Group	1-Group	0-Group	1-Group	0-Group	1-Group	0-Group	1-Group
Inshore												
CB	7865.39	2151.19	27825.12	8.62	59170.22	0.42	18101.30	15.18	18203.82	14.64		
TB	3797.05	258.49	13760.88	8.46	35682.76	24.29	13363.79	1676.25	1801.22	23.72		
BB	4615.81	1067.86	13439.82	7.74	37952.82	3216.28	17749.19	3079.55	11830.7*			
NDB	18803.24	45.93	19478.60	234.63	45499.36	12.04	17034.89	2.00	30448.79	30.14		
WB	17589.24	34.44	7671.55	1.58	57695.52	4.70	23459.91	1022.81	14383.76	14.12		
SUM	52670.73	3557.91	82175.97	261.03	236000.68	3257.73	89709.08	5795.79	76668.29	82.62		
Offshore												
HB			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4404.30	0.00
ISN			4311.18	0.00	0.00	0.16	286.38	52.80	6041.34	1.66		
ISS	28081.33	50.95	34173.79	14.64	196751.14	10.82	76000.98	1.34	65324.17	68.54		
BIBI			0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00		
BIBO												
FIBI			5805.14	8.31	3201.03	1798.45	0.00	3.32	5560.74	408.08		
FIBO												
NGB	9181.50	16834.73	143567.73	718.82	63705.86	1675.37	12943.71	7392.86	11740.84	3922.34		
SA	8064.32	219.38			14021.44	16.95	21928.66	1126.22				
SGB	53.28	812.65	973.80	341.09	0.00	0.00	340.81	0.62	16548.69	59.25		
NOSE					0.00	606.74	0.00	51.78	776.38	1638.66		
TAIL												
SGBO												
WD												
SUM	37316.11	17698.33	188831.64	1082.86	263658.03	3484.80	89571.88	7451.14	105215.78	4459.87		
TOTAL	89986.84	21256.24	271007.61	1343.89	499658.71	6742.53	179280.96	13246.93	181884.07	4542.49		

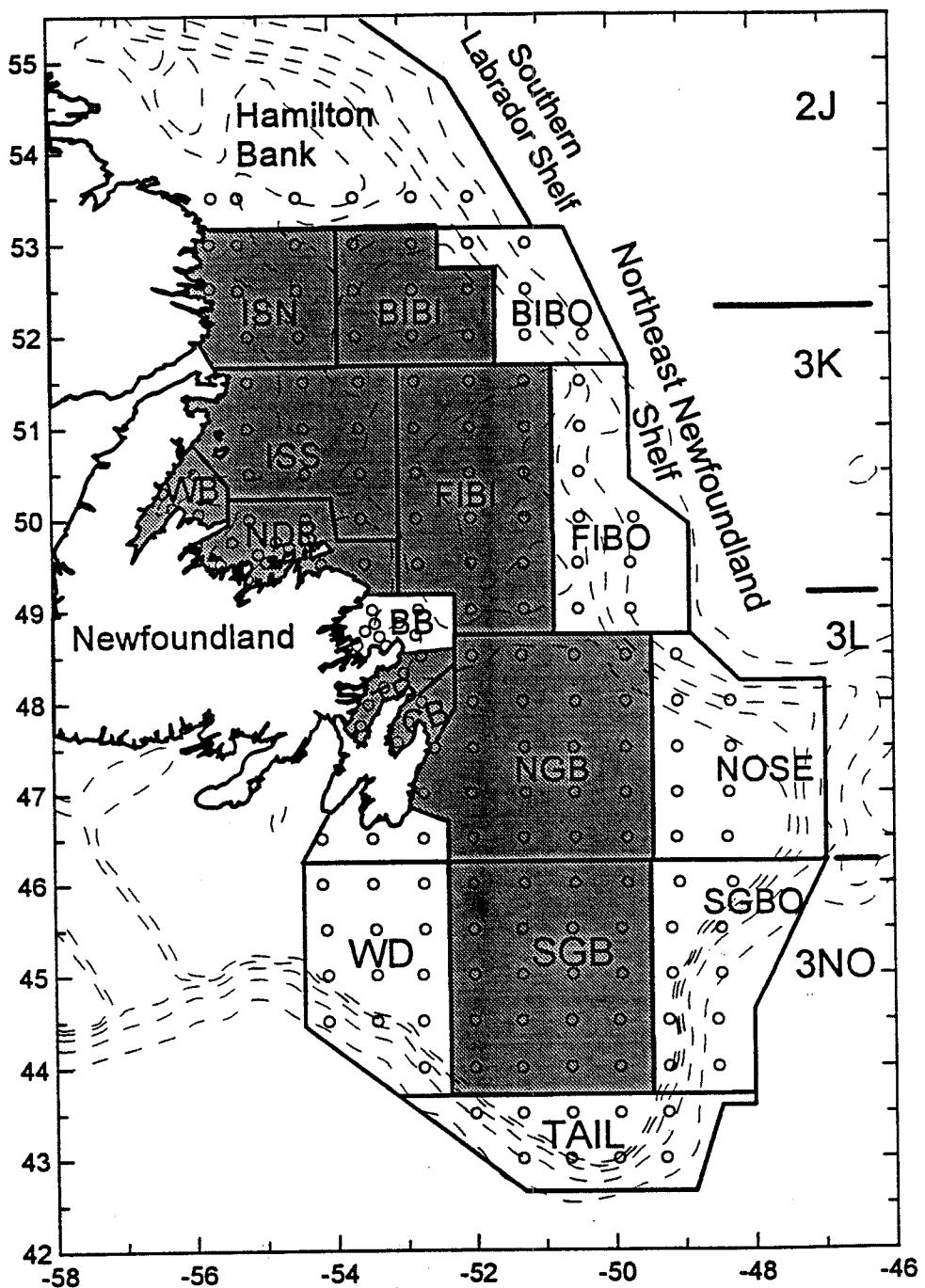


Figure 1. Pelagic Juvenile Fish Survey area, showing sampling locations (indicated by 'o') and Index Areas in 1998. The shaded areas represent the Index Areas used in the calculation of annual abundance indices. See text for explanation of areas.

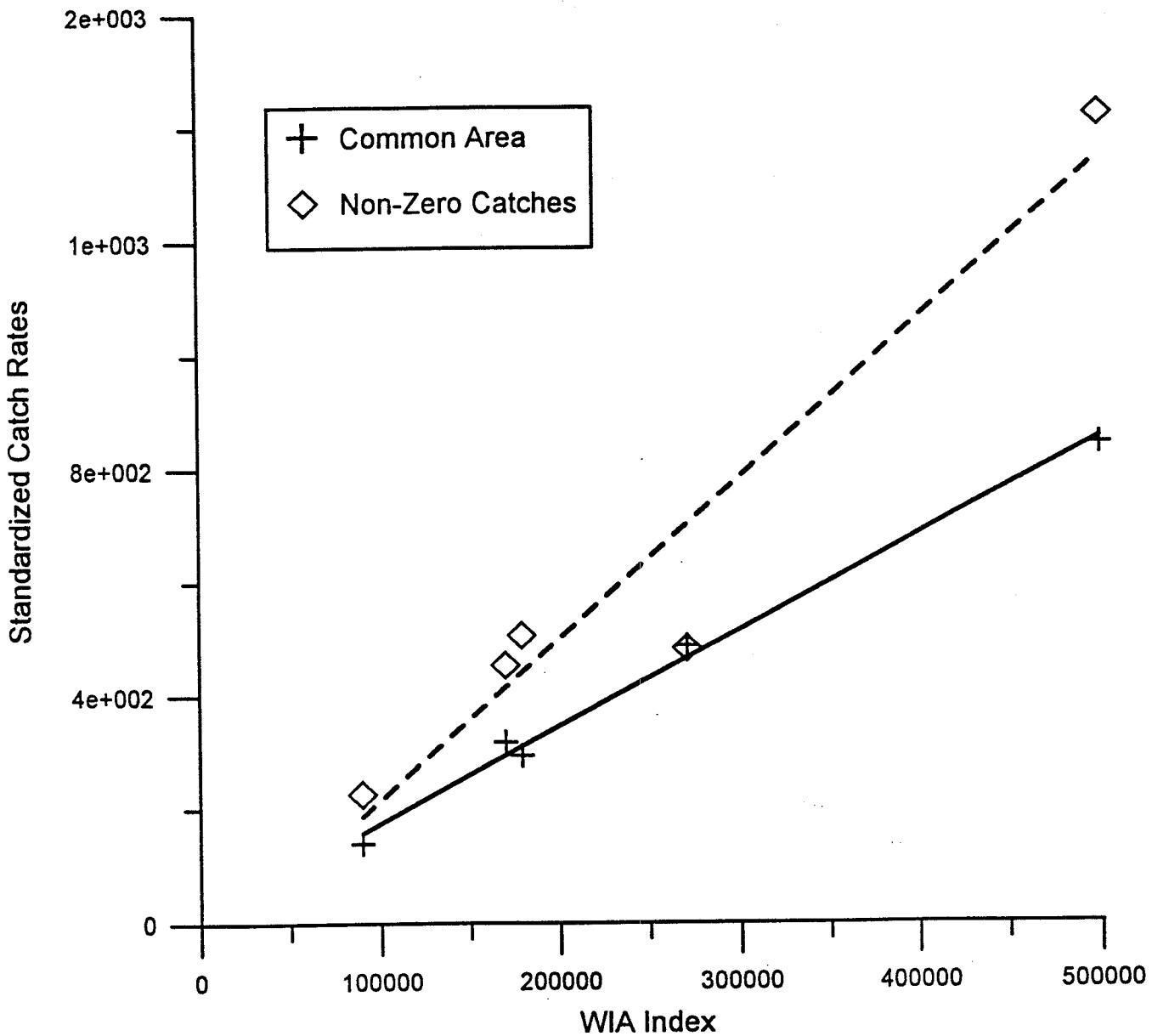


Figure 2. Comparison of different indices of larval capelin (0-group) abundance. The Weighted Index Areas index (WIA) is compared to two different standardized catch rate indices used in previous analyses.

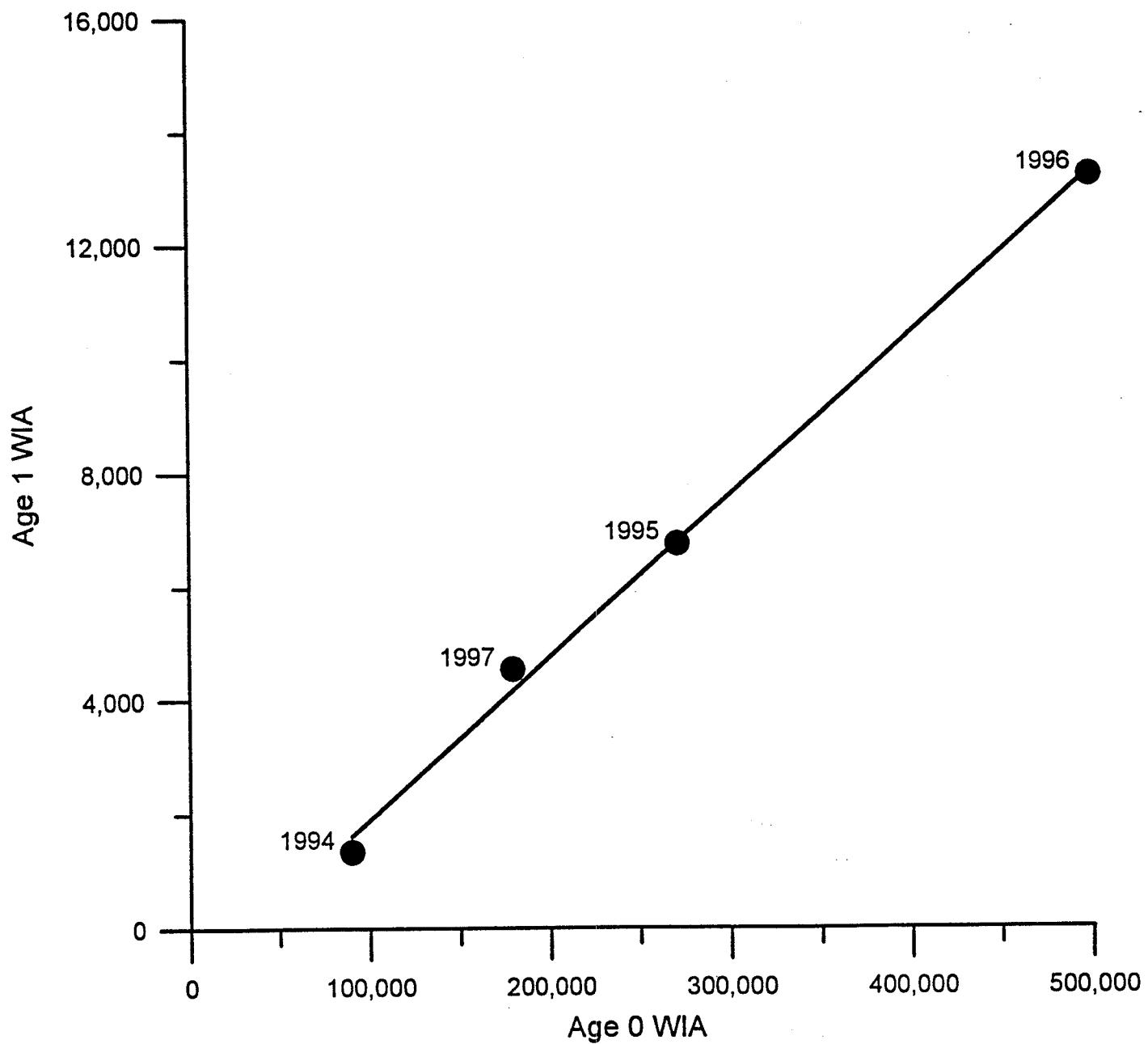


Figure 3. Comparison of the Weighted Index Area (WIA) indices for the 1994-1997 year classes at the larval stage (0-group) and at age one (1-group).

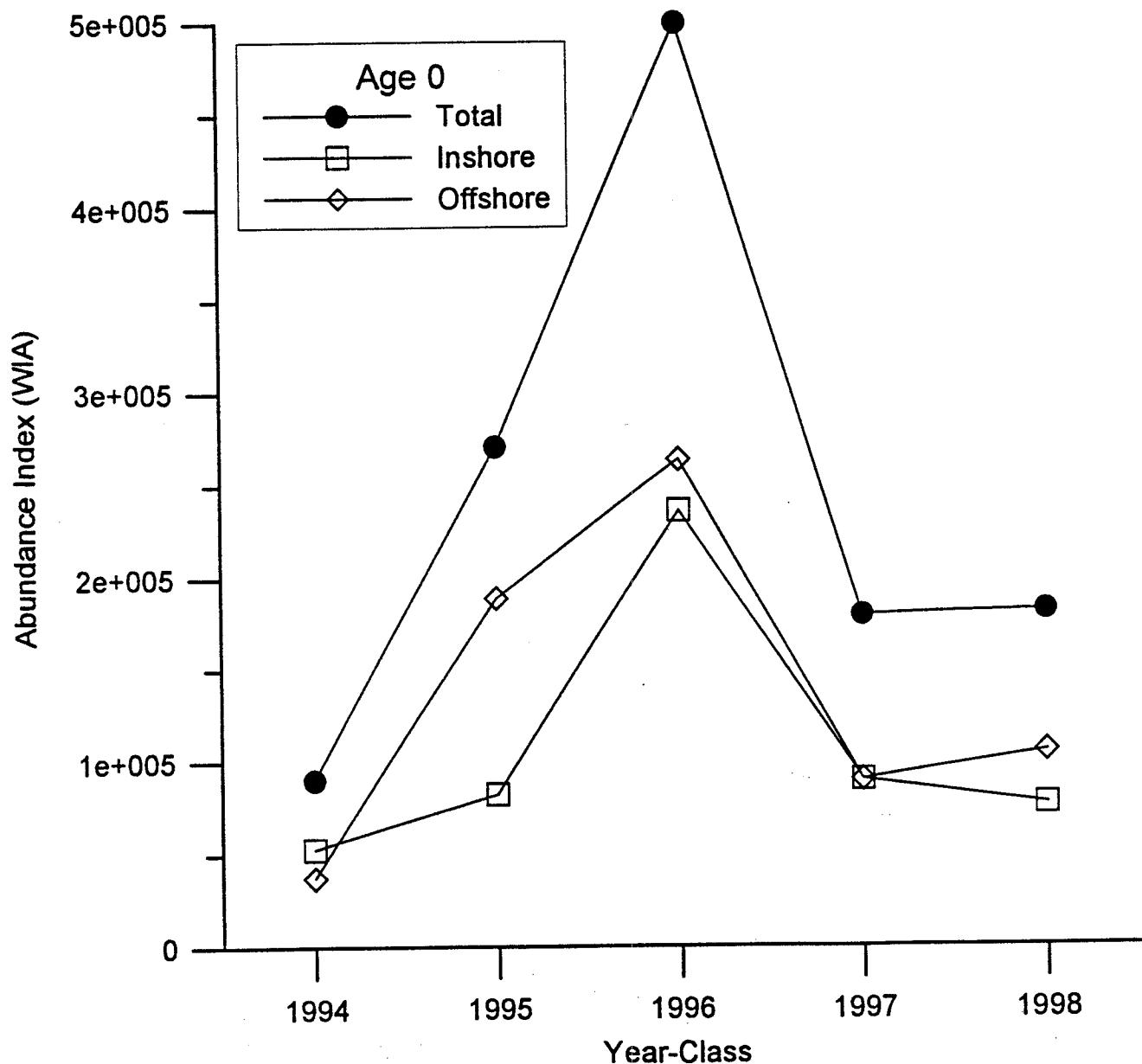


Figure 4. Abundance indices for larval (0-group) capelin based on the Weighted Index Area (WIA) method for the 1994-1998 year-classes.

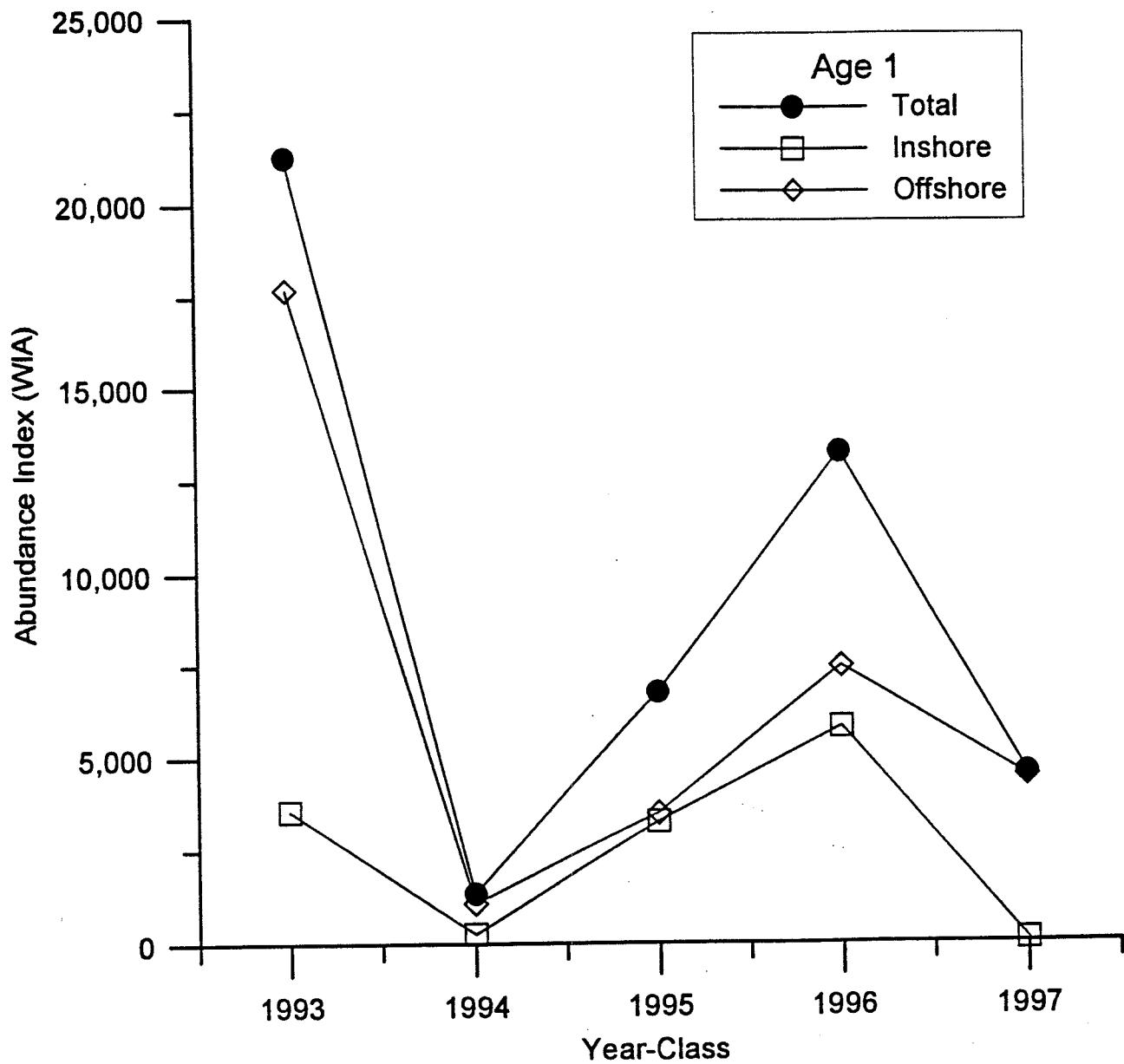


Figure 5. Abundance indices for age one (1-group) capelin based on the Weighted Index Area (WIA) method for year-classes 1993-1997.

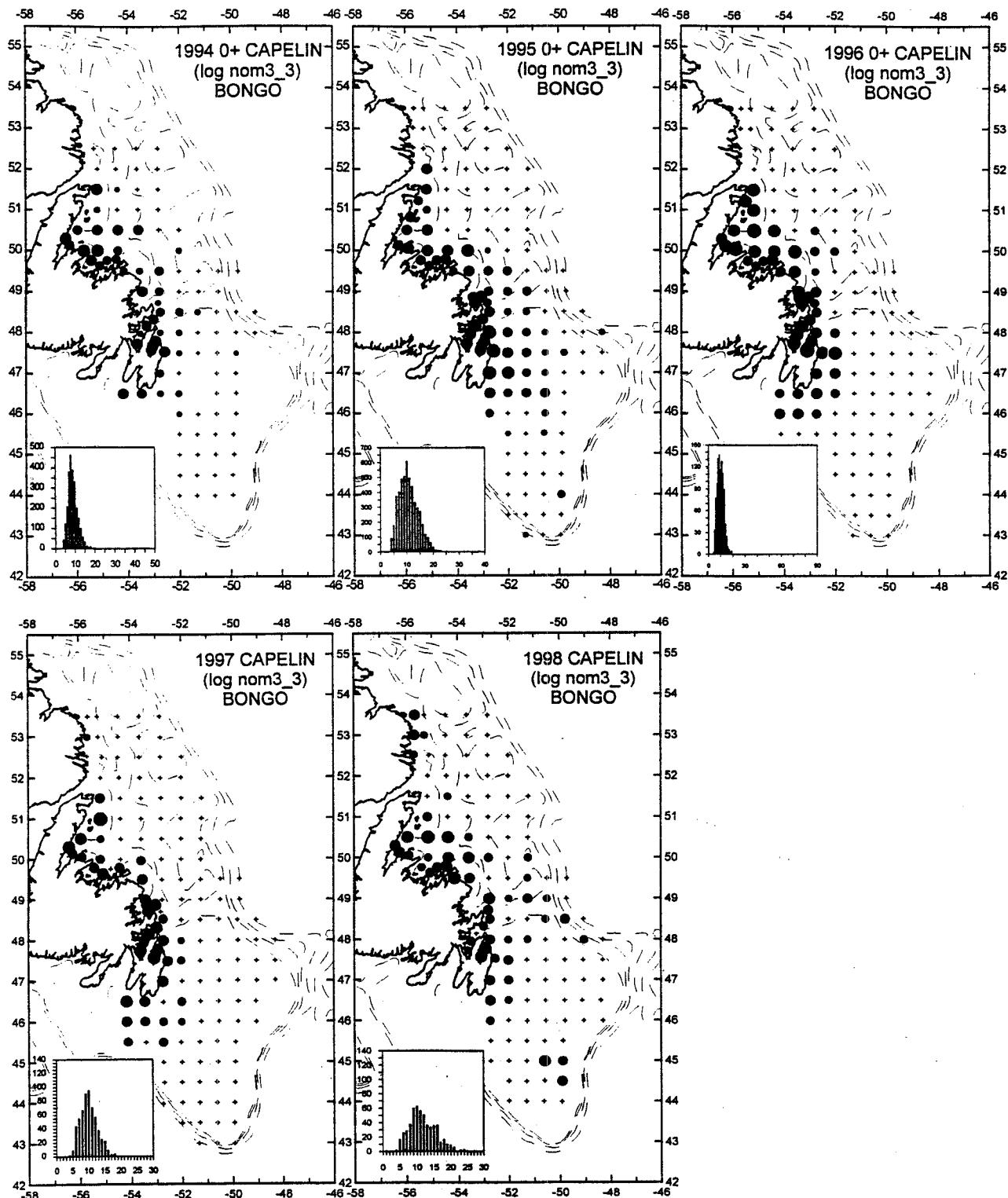


Figure 6. Distribution of larval capelin sampled by the bongo sampler in 1998. Abundance (log₁₀ number/m³) at each station is represented by an expanding symbol. Crosses (+) represent stations where capelin were not caught.

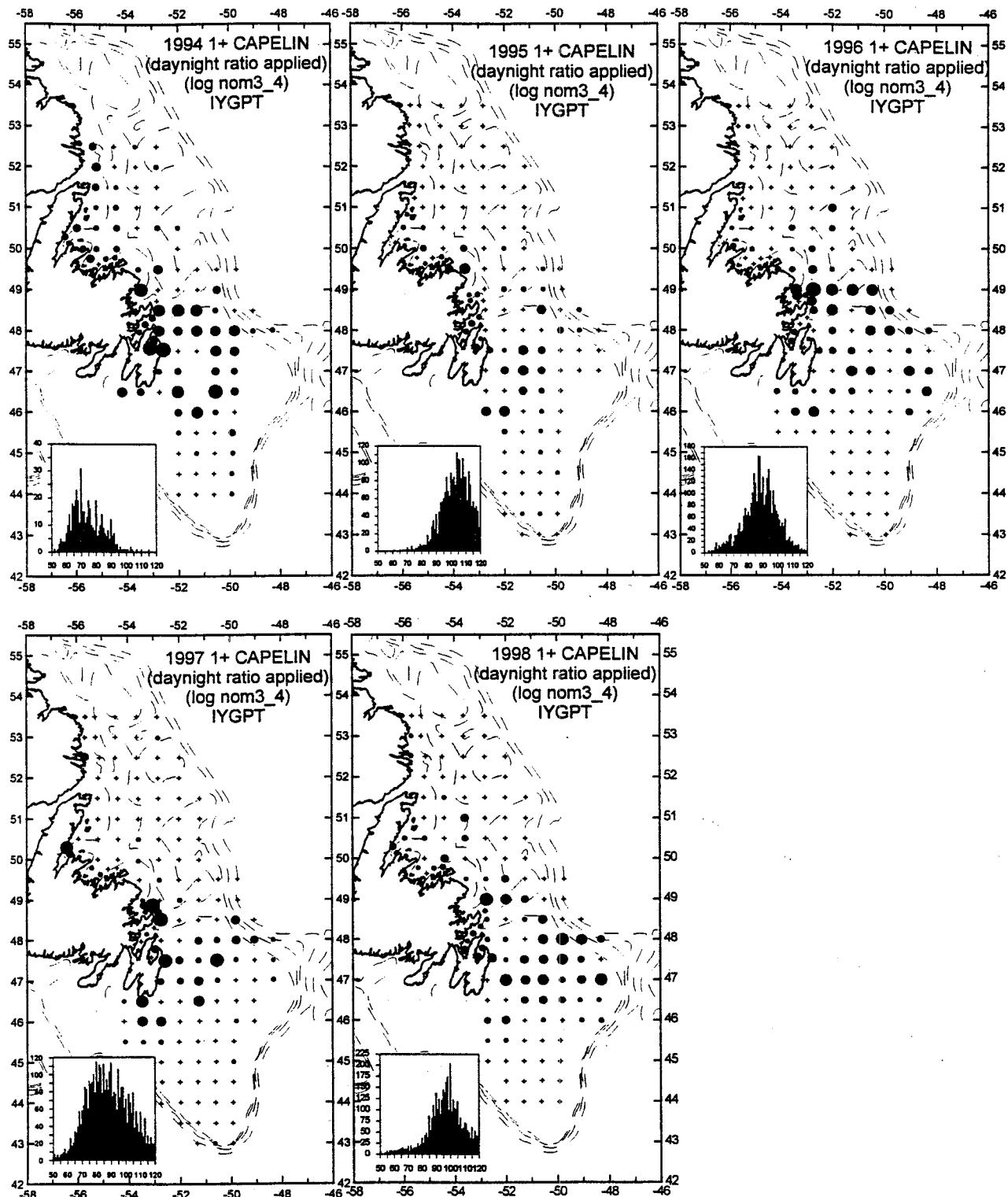


Figure 7. Distribution of one year old capelin sampled by the IYGPT trawl in 1998. Abundance (\log_{10} number/m) at each station is represented by expanding symbols. Crosses (+) indicate stations where capelin were not caught.

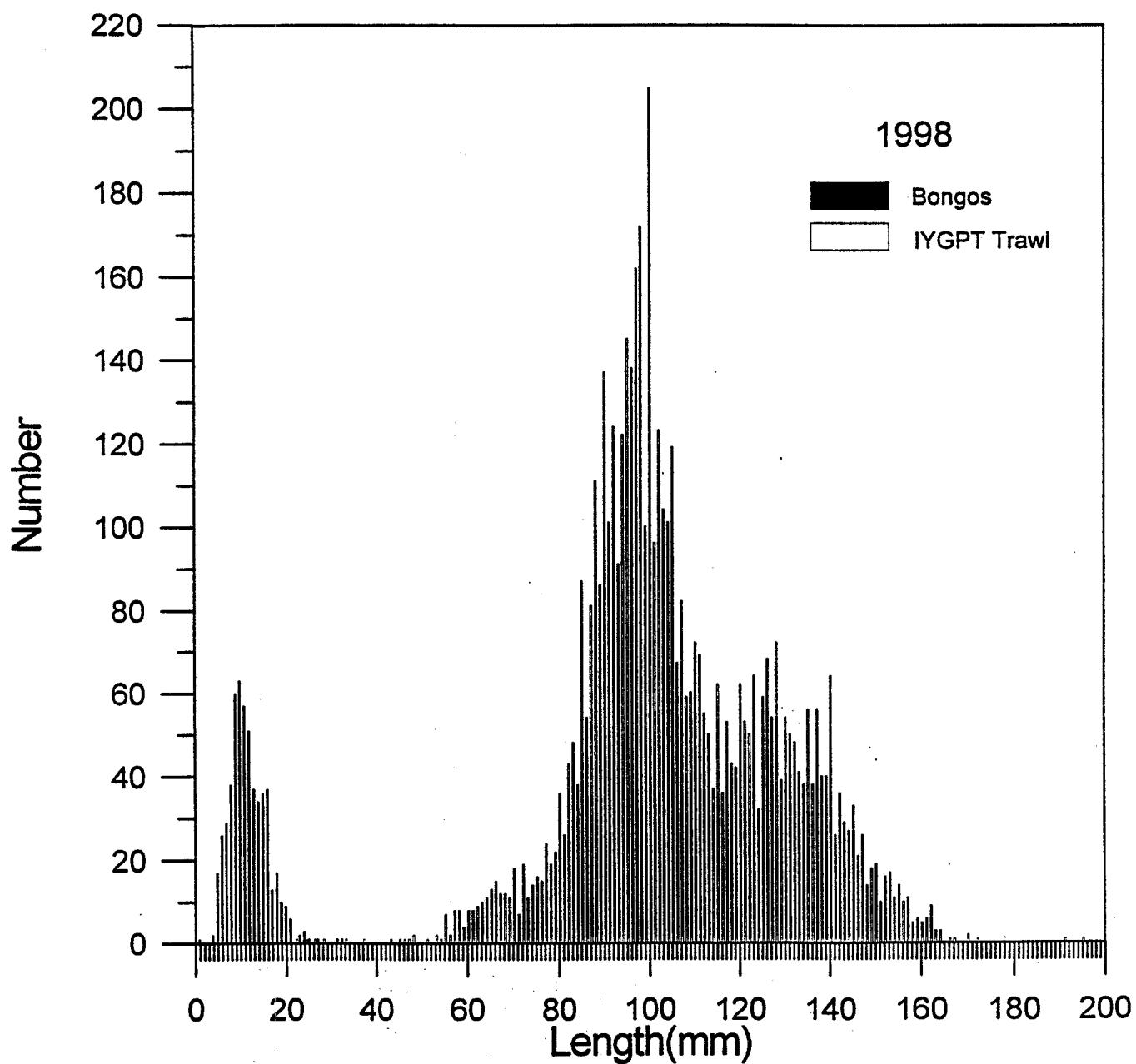


Figure 8. Length (mm) frequency distribution of capelin sampled by the bongo and IYGPT samplers in 1998.

Estimates of Consumption of Capelin

by

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Introduction

In the northern hemisphere, capelin (Mallotus villosus) plays a dual role, being both an important commercial and forage species. In the Northwest Atlantic, capelin appear to be key components in the diet of several commercial species of marine fish as well as marine mammals and seabirds. There are many feeding studies on various predators which list capelin as a key diet component. Several authors (e.g. Winters and Carscadden 1978, Lilly et al. 1991, Hammill and Stenson 1997) have taken the results of feeding studies and using population and/or production estimators, have calculated the total consumption of capelin by the predator of interest.

During the early 1970's, an offshore capelin fishery was rapidly developing and as a result, knowledge of capelin abundance was necessary for management. Estimates of capelin consumption by some major predators were calculated for that time period and these estimates were compared to those calculated for earlier periods, when predator stocks were much higher. It was assumed that the decline in total capelin consumption represented the potential biomass of capelin available to a commercial fishery (Winters and Carscadden 1978). This method was recognized as a crude technique to identify potential fishable biomass and several caveats to that effect were provided by the authors (Winters and Carscadden 1978), nevertheless the information was used as an early tool to provide scientific advice to management (Carscadden 1984).

In the intervening two decades, there has been a considerable amount of research, including food and feeding studies on capelin predators, estimation of total consumption of capelin and direct estimation of capelin abundance. Scientific advice to managers during the 1980's tended to be based on

direct measurements of capelin abundance from acoustic surveys as well as other indices of capelin abundance. However, during the 1990's, the provision of advice on capelin stock status has proven problematic. (It is not the intent to review the problems nor the potential causes since these have been discussed extensively in several assessment and other documents. For more information the reader should consult Anon. (1994, 1995, 1996, 1997, 1998a). In the 1998 assessment of stock status (Anon. 1998a) considerable concern was expressed about the indices used to assess the status of the Div. 2J3KL capelin stock, the multiplicative model used in the assessment and the fact that the scientific assessment was optimistic compared to the more pessimistic view of fishermen about capelin stock status. The problems in assessing capelin stock status coincide with changes in capelin biology (Carscadden et al. 1997, Frank et al. 1996, Nakasima 1996) and other changes in the ecosystem. Biological changes in the ecosystem include changes in abundance in other forage species (shrimp and crabs) as well as predator species (cod, seals, Greenland halibut).

With the changes in predator abundance and the unresolved differences in perception of capelin abundance, the time seems appropriate to revisit some of the earlier consumption calculations and update them. Although these estimates should be treated with caution in a management context, they may provide insight into the biological changes in the Newfoundland Shelf ecosystem. In this paper, I concentrate on cod, seals, and Greenland halibut simply because of the availability of previous consumption estimates which permits comparison to current estimates. However some additional information is provided for other predators.

Cod

There have been several estimates of consumption of capelin by cod in the Div. 2J3KL area (Turuk 1978, Minet and Perodou 1978, Winters and Carscadden 1978, Lilly et al. 1981).

All of these studies used values of consumption expressed as amount of capelin consumed annually per unit weight of cod. In addition, Lilly et al. (1981) used a production method but in this document I will use only the former method. Lilly et al. (1981) reviewed the method of estimation for each of the three earlier papers so only the salient points will be made here.

Turuk's (1978) data were collected during 1973 and 1976 from Div. 2GHJ and 3LNO (nothing from Div. 3L) and she combined estimates of feeding rate with observations on stomach contents. The sources of the feeding rates are unknown and one of her corrections is inappropriate and apparently incorrectly calculated (Lilly et al. 1981), nevertheless, Lilly et al. (1981) derived an average value of 2.38 for the weight of capelin eaten per unit of cod in Div. 2J3K and 3NO.

Minet and Perodou (1978) estimated that the average cod consumed 0.76 to 1.27 times its weight of capelin annually. These values were based on observed mean weights of capelin in the meal of an average cod, published gastric evacuation rates and the assumption that cod prey on capelin for only half the year (summer and winter). Because of the latter assumptions, the range is considered a minimum estimate since there is some predation during the other seasons and the inshore summer predation was not included (Lilly et al. 1981).

Winters and Carscadden (1978) used an indirect method to calculate consumption. This calculation involved several assumptions including proportion of capelin in the annual diet of cod (= 0.32) from Campbell and Winters (1973), total mortality (Z), gross growth efficiency (K), the production-biomass rate (P/B) equal to Z. They calculated that the annual consumption per unit weight of cod was 0.64 but increased this to 1.0 on the belief that cod abundance was lower during the period of interest (late 1960's).

These studies provide a range of estimates of capelin consumed per unit weight of cod. We can then perform a series of calculations similar to that performed by Lilly et al. (1981), that is, provide a range of capelin estimates consumed by cod during different time periods, using biomass estimates of cod and the multipliers discussed above. I have used 2+ biomass (P. Shelton, pers. comm.). Clearly, the consumption estimates will track the biomass estimates of cod, however, the exercise does provide a range of capelin consumption based on the available data (Fig. 1). The basic assumption in this exercise is that the amount of capelin consumed per unit biomass of cod is fixed over time and does not change with changes in abundance or any other biological factor (distribution, migration patterns, mean size) of either cod or capelin. It should also be emphasized that the exact trajectory of cod biomass is very uncertain during the late 1980's and early 1990's when the estimates from the sequential population analysis are not closely linked to other indicators of abundance (P. Shelton,

pers. comm.). However, the northern cod stock has been under fishing moratorium since 1992 because the stock size was extremely low. Therefore, estimates from 1992 to 1997 must be assumed to reasonably reflect the status of the cod stock, especially compared to historical estimates. At such low stock sizes (estimates from 1992 to 1997 range from a low of 4000 t to a high of 50,000 t, with an average of 14,000 t) total annual consumption must also be low relative to historical consumption.

With the cod stock so low in the mid 1990's it is interesting to examine historical consumption estimates and calculate the overall decline in capelin consumption by northern cod. I have chosen three years to illustrate the extent of the decline in consumption; 1962, the earliest available cod estimate and when the cod stock was high relative to the present; 1981, the year that Lilly et al. (1981) summarized the cod consumption data and a time when cod biomass was increasing; and, 1997, during the present period of extremely low abundance. The actual consumption estimates using the different consumption factors clearly demonstrate the decline in capelin consumption by cod (Table 1). During the early 1960's, capelin consumption might have ranged between 2 to 6.5 million tons of capelin, depending on the factor. By 1981, capelin consumption had probably declined such that capelin consumption could have ranged between 0.7 to 2.2 million tons, again depending on the factor used. With the recent collapse of the cod stock, annual capelin consumption by cod may be below 20,000 tons. If we adopt a factor in the middle of the range, say 1.0 -1.27, it is possible that cod consumption of capelin has decreased by approximately 1.0 million tons between the early 1980's, when the northern cod stock was increasing after the 1970's decline, and the present historical low cod abundance.

Greenland Halibut

Although Greenland halibut were known to prey on capelin (Lear 1969), they were not always highlighted as an important predator (Bowering and Lilly 1992), perhaps because they never enjoyed the historical importance as a commercial species. However, Bowering and Lilly (1992) provided estimates of capelin consumption by Greenland halibut of 105,000 t, 154,000 t and 208,000 t during 1981, 1982, and 1984 respectively in Div. 2J3K. The average of the three estimates is 156,000 t of capelin consumed. Although the authors considered the estimates conservative, it is clear that Greenland halibut were consuming considerable quantities of capelin.

The estimates were calculated by measuring total weight of capelin in the stomachs of Greenland halibut at the time of sampling and converting this to a daily feeding rate and daily consumption rate using observations from the Bering Sea. Annual consumption of capelin was then estimated by assuming that Greenland halibut feed on capelin for six months of the year. Bowering and Lilly (1992) provided several ways in which their estimates might be improved, one of which was a better knowledge of the catchability of the trawl. They assumed that the trawl catchability was 1.0 but noted that if the value were less than one, then both the population estimates of Greenland halibut and consumption estimates of capelin would be higher. This was well illustrated between 1981 and 1982, when the mean catch per tow of Greenland halibut increased, resulting in an increase in the total weight of prey in the stomachs.

Since the calculation of the consumption estimates (Bowering and Lilly 1992), the standard bottom trawl gear has changed to Campelen gear with higher catch rates. Thus, this should result in higher estimates of capelin consumption and the following discussion attempts to update those consumption estimates based on the new trawl estimates of abundance.

Bowering and Lilly (1992) reported that the major consumers of capelin were Greenland halibut in the 30-59 cm length range. For example, of 1755.3 tons of capelin eaten at the time of sampling in 1982, 1465.8 tons (84%) were eaten by Greenland halibut in that length range. These lengths correspond approximately to ages 4-10 (p. 604 in Bowering 1983) and these ages were used in the following comparisons. Conversions of abundance from the old trawl gear to the new trawl gear derived from comparative trawling experiments were length-based (Warren 1996) and these conversions were applied in subsequent assessments (Brodie et al. 1997). I compared the abundance estimates for ages 4-10 from Campelen estimates (Table 17, Brodie et al. 1997) to earlier unconverted estimates (Tables 14 and 15, Bowering et al. 1990) and found the new estimates were 1.58, 1.74 and 1.68 times higher in 1981, 1982, and 1984 respectively. Applying these factors directly to the consumption estimates yields revised annual estimates of 166,000 t, 268,000 t, and 349,000 t in 1981, 1982, and 1984 respectively. The average of these estimates is 261,000 t of capelin consumed.

Annual trawl estimates of abundance (ages 4-10) of Greenland halibut show year-to-year variation but the general trend is an increase to a peak during 1990 and 1991, then a

sharp decline to historically low values during 1994-96 (Fig. 2). If we assume that consumption of capelin is directly proportional to Greenland halibut abundance, then consumption during 1990 would have peaked at about 395,000 tons when compared to the average of 1981, 1982, 1984 Campellen estimates for ages 4-10. This is calculated by:

Average of 1981, 1982 and 1984 Campellen estimates, ages 4-10 x Average consumption
1990 Campelen estimates, ages 4-10
estimates 1981, 1982,
1984

$$\frac{(200951 + 281532 + 328035)}{3} \times 261,000 = 395,000$$

= 409065

However, Greenland halibut abundance, ages 4-10, declined after 1990. Thus, a similar calculation using the 1996 Campelen estimate (177964 individuals) would yield a consumption estimate of 172,000 t of capelin. This indicates that the decline in consumption of capelin between the early 1980's and 1996 was on the order of 89,000 t (261,000-172,000).

Although these calculations must be viewed as being very approximate considering the assumptions and approximations, they suggest that consumption of capelin by Greenland halibut has been substantial, perhaps at about 400,000 tons during 1989 and 1990. In contrast, this consumption probably dropped dramatically in the 1990's, possibly by about half, due to the decline in abundance of the ages 4-10 Greenland halibut, which prey on capelin. Overall, capelin consumption by Greenland halibut probably has declined between the early 1980's and 1996, by just under 100,000 t.

Harp Seals

In recent years, harp seals and their prey consumption have been under intense scrutiny. The most recent estimates of consumption show that 696,242 tons of capelin were consumed by harp seals in Div. 2J3KL during 1998, using average diets (G. Stenson, pers. comm.). These estimates have been made back to 1972 and are plotted with harp seal population estimates in Figure 3. It is clear that capelin consumption is closely linked to harp seal population size. The harp seal population trajectory, calculated in 1999 (G. Stenson, pers. comm.) goes back to 1972 but a comparison with an earlier estimate (Shelton et al. 1996) shows the two vectors are very close (Fig. 4). The

1996 estimates go back to the mid 1950's so it is reasonable to assume that the most recent estimates, if carried back, would follow the same pattern. Assuming capelin consumption has been directly related to harp seal abundance, this consumption was probably lowest in the late 1960's and early 1970's and highest during the most recent years.

It is interesting to compare consumption estimates from the most recent calculations with those calculated by Winters and Carscadden (1978). During the late 1970's, Winters and Carscadden (1978) noted that the population of harp seals was 1.3 million animals, which was about the same abundance used by Sergeant (1973) to calculate capelin consumption. Although Sergeant's calculations were crude, he estimated that about 400,000 tons of capelin were consumed in Canadian waters and roughly 300,000 tons in eastern Newfoundland and Labrador. Since populations of harp seals in the late 1970's were similar in abundance to those used in Sergeant's calculations, Winters and Carscadden (1978) used the estimate of 300,000 tons as a consumption estimate for that time period. However, the most recent estimates of harp seals (1999 estimates, G. Stenson, pers. comm.) show that 1975, 1976, 1977, and 1978 estimates as 2.12, 2.16, 2.22, and 2.30 million seals respectively. Thus, using the revised population estimates, the estimated consumption might have been calculated as

$$\frac{2.2 \text{ (1975-78 average seal abundance)} \times 300,000}{1.3 \text{ (capelin seal abundance estimate)}} = 508,000 \text{ tons}$$

However, the actual consumption for that 1975-78 period, based on the most recent calculations is 296,277 tons. Thus, although the harp seal population estimates for the mid to late 1970's are now higher, the capelin consumption estimates are similar to those presented by Winters and Carscadden (1978).

If we compare the years 1978 and 1998, the harp seal population has grown from 2.3 to 5.2 millions animals or an increase of 2.26 times. During that same time, capelin consumption has increased from 311,957 tons to 696,242 tons or a factor of 2.23.

If we compare the same time periods as we have for the other predators, i.e. early 1980's to the mid 1990's, we find capelin consumption has increased by about 333,220 tons ($696,242 - 363,022 = 1998 \text{ consumption} - 1982 \text{ consumption}$).

Other Predators

In the preceding sections, I have concentrated on predators that tend to consume large quantities of capelin and for which there are consumption estimates over a number of years. There are, however, consumption estimates for a few other predators and these are provided below.

Seabirds

There are several species of seabirds that consume capelin (Brown and Nettleship 1984) but few capelin consumption estimates for the Div. 2J3KL area are available. Most seabird studies have been conducted during the breeding time which generally overlaps the inshore spawning migration of capelin. Although capelin is clearly a key component of the chick and adult diet at this time, there are large gaps in our knowledge of seabird distribution and feeding at other times of the year. Brown and Nettleship (1984) estimated that about 7300 t of capelin were consumed by herring gulls, black-legged kittiwakes, common murres and Atlantic puffin between the 45 day period of 1 July-15 August. Their estimate of 3891 t of capelin by Atlantic puffins is comparable to a 5102 t estimate made by Rodway and Montevecchi (1996). Brown and Nettleship (1984) extrapolated their calculations to all seabirds throughout the year and concluded that the annual consumption of capelin by seabirds was on the order of 250,000 t.

Hooded Seals

Hammill and Stenson (1997) provided consumption estimates for four seal species, including hooded seals. For Div. 2J3KL they had feeding data for hooded seals from both inshore and offshore areas. The estimates of capelin consumption were lower than many other predators, ranging from a low of 2255 tons in 1990 to a high of 2994 tons in 1996 (the years of the study). Since the estimates of consumption are directly proportional to predator abundance, the increase between 1990 and 1996 reflects an increase in hooded seal abundance.

The authors also included consumption estimates for hooded seals in the Flemish Cap area. There were no feeding data from this area so Hammill and Stenson (1997) used stomach content data collected in Div. 2J3KL. As a result, there are estimates of capelin consumption in the Flemish Cap area, an area where capelin occur only rarely (Frank et al. 1996). Frank et al.

(1996) reported that capelin did occur on the Flemish Cap during the 1990's, which overlapped the time period examined by Hammill and Stenson (1997). It is therefore conceivable that hooded seals could have consumed capelin in that area during the 1990's but the estimates provided are equally likely to be artifacts of the methodology.

Baleen Whales

Winters and Carscadden (1978) estimated that capelin consumption in the mid 1970's by fin and minke whales was about 250,000 and 35,000 tons respectively. Consumption of capelin by these predators at population abundances prior to the predator's decline might have been 360,000 tons for fin whales and 50,000 tons for minke whales. These whales have not been hunted since the Winters and Carscadden's (1978) estimates so it is likely that predator abundance and consumption of capelin is now higher.

Humpback whales also consume capelin in Newfoundland waters during the summer and autumn. To my knowledge, capelin consumption by humpbacks has not been estimated. Whitehead (1981) estimated that approximately 2000 humpbacks occur in Newfoundland waters each year. Piatt et al. (1989) provided local estimates (Witless Bay) of capelin consumption estimating that the maximum consumption of capelin per day was 9.5 t (1982-85) with humpbacks consuming 79%. It is not possible however to extrapolate these estimates to the entire foraging area of humpbacks.

Cetaceans are also important consumers in Icelandic waters. Sigurjonsson and Vikingsson (1998) estimated that humpback whales near Iceland and north of 60°N consumed 236,000-290,000 t of fish annually, based on two methods of calculation. They did not provide an estimate for capelin only. They assumed 120 days of feeding per year and used feeding data from Canadian waters (Mitchell 1973). Their abundance estimate of 1796 whales came from sightings surveys.

Given that the abundance estimates for humpbacks in the Newfoundland area and Iceland area are similar, we could assume that the annual fish consumption of about 250,000 tons is also similar, however, the total consumption of capelin cannot be derived.

American plaice

Although capelin contribute to the diets of American plaice (Pitt 1973), there are no capelin consumption estimates available. American plaice stocks in Div. 3LNO have experienced dramatic declines. For example, based on research trawl data, the female spawning stock biomass in 1995 was 95% less than estimates from the mid 1980's (p. 86, Anon. 1998b). Assuming that overall capelin consumption is proportional to predator abundance, capelin consumption by American plaice has undoubtedly declined.

Salmon

The situation with salmon is similar to that of American plaice. Salmon consume capelin (Lear 1972) but no consumption estimates have been made. Salmon abundance is at a historical low (Anon. 1999) implying that capelin consumption is also very low.

Discussion

The North Atlantic ecosystem is a dynamic system and as such, predator-prey interactions are probably constantly changing. Recent extreme changes in some major predator populations (e.g. decline in northern cod and increase in harp seals) have probably resulted in dramatic changes in capelin consumption as well. As previously noted, the estimates of capelin consumption are very approximate and should be treated with caution. Furthermore, such simple single predator-single prey calculations do not account for more complex interactions that might be occurring between the major prey and predator species. Thus, all conclusions from the comparisons in this paper should be made with these caveats in mind.

A brief summary of likely population trends of major capelin predators and estimates of change in annual capelin production between the early 1980's and the present is given in Table 2. It is clear that for many species, there are no data available but taken together, they may account for significant annual capelin consumption. Of the three predator species for which historical capelin consumption estimates are available, two species, namely cod and Greenland halibut, have declined. Harp seals have increased in abundance. For Greenland halibut, the decline in consumption between the early 1980's and present has been in the order of 100,000 tons. For cod, the decline in consumption is much larger, in the order of 1,000,000 tons. For seals, the increase in capelin consumption over the same period

is just over 300,000 tons. Thus, even with the uncertainties associated with this type of exercise and comparison, it is probable that the increase in consumption of capelin by seals has not been as great as the decrease in consumption by groundfish predators.

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Table 1. Estimates of capelin consumption by cod (age 2+) using different factors.

Year	2+ cod biomass	Factor			
		0.76 1.27	1.0 2.38		
1962	2,722,099	2,068,795	2,722,099	3,457,066	6,4778,596
1981	957,399	727,623	957,399	1,215,897	2,278,610
1997	7,324	5,566	7,324	9,301	17,431

Table 2. Capelin predators discussed in the text, change in population abundance of the predators from the early 1980's and mid 1990's, and estimates of increase (+) or decrease (-) of capelin consumption during the same time period.

Predator	Change in Population Abundance	Increase (+) or Decrease (-) in Capelin Consumption (t)
Cod	Decrease	-1,000,000
Greenland halibut	Decrease	-89,000
Harp seals	Increase	+330,000
Seabirds	??	??
Hooded seals	Likely increase	Not significant - see text
Whales	Likely increase	??
American plaice	Decrease	Decrease
Salmon	Decrease	Decrease

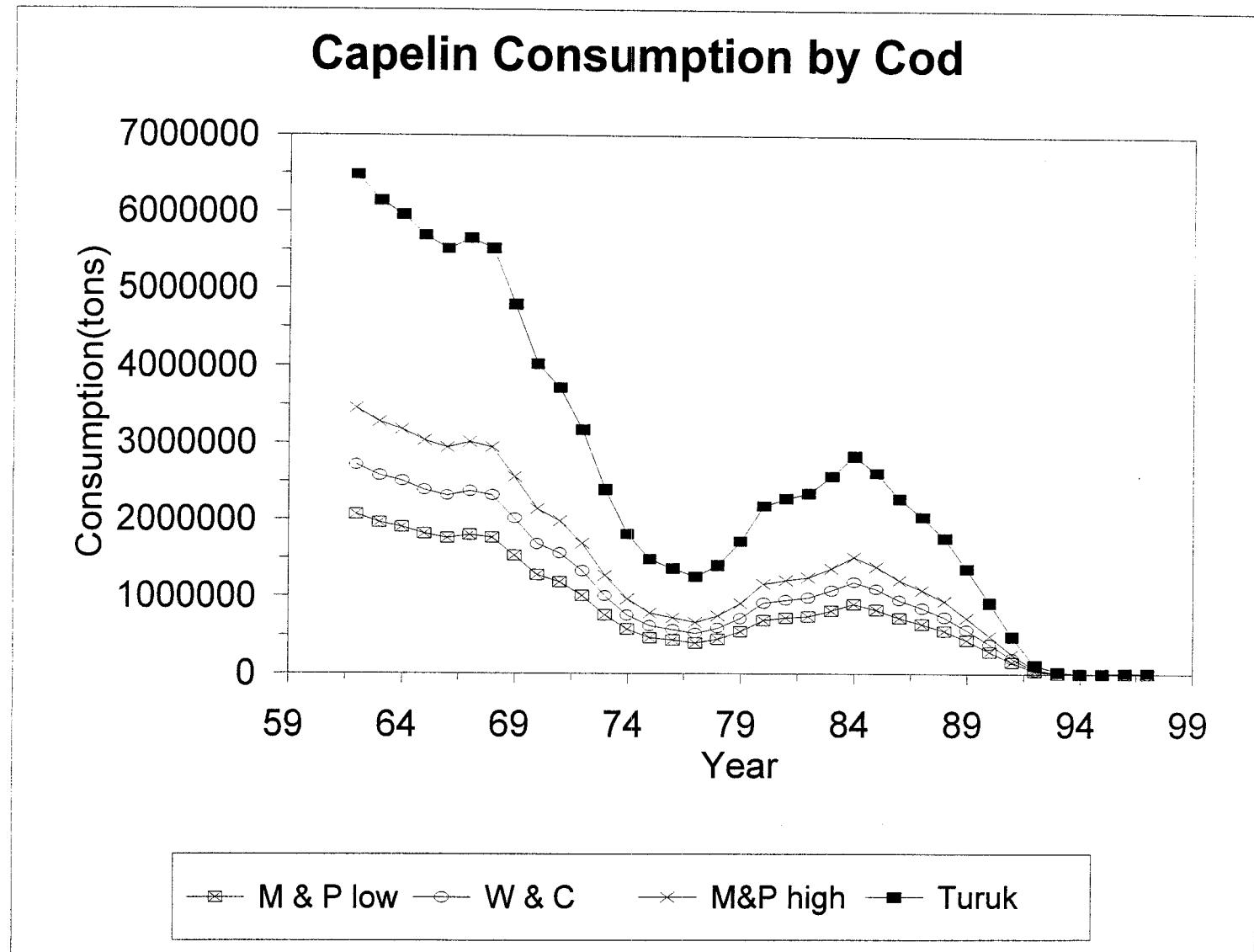


Fig. 1. Estimates of annual consumption by cod using different assumptions regarding biomass of capelin consumed per unit weight of cod. M + Plow is Minet and Perodou, low estimate; W + C is Winters and Carscadden; M + P high is Minet and Perodou, high estimate. See text for details.

Div 2J3K Greenland Halibut Campelen Units

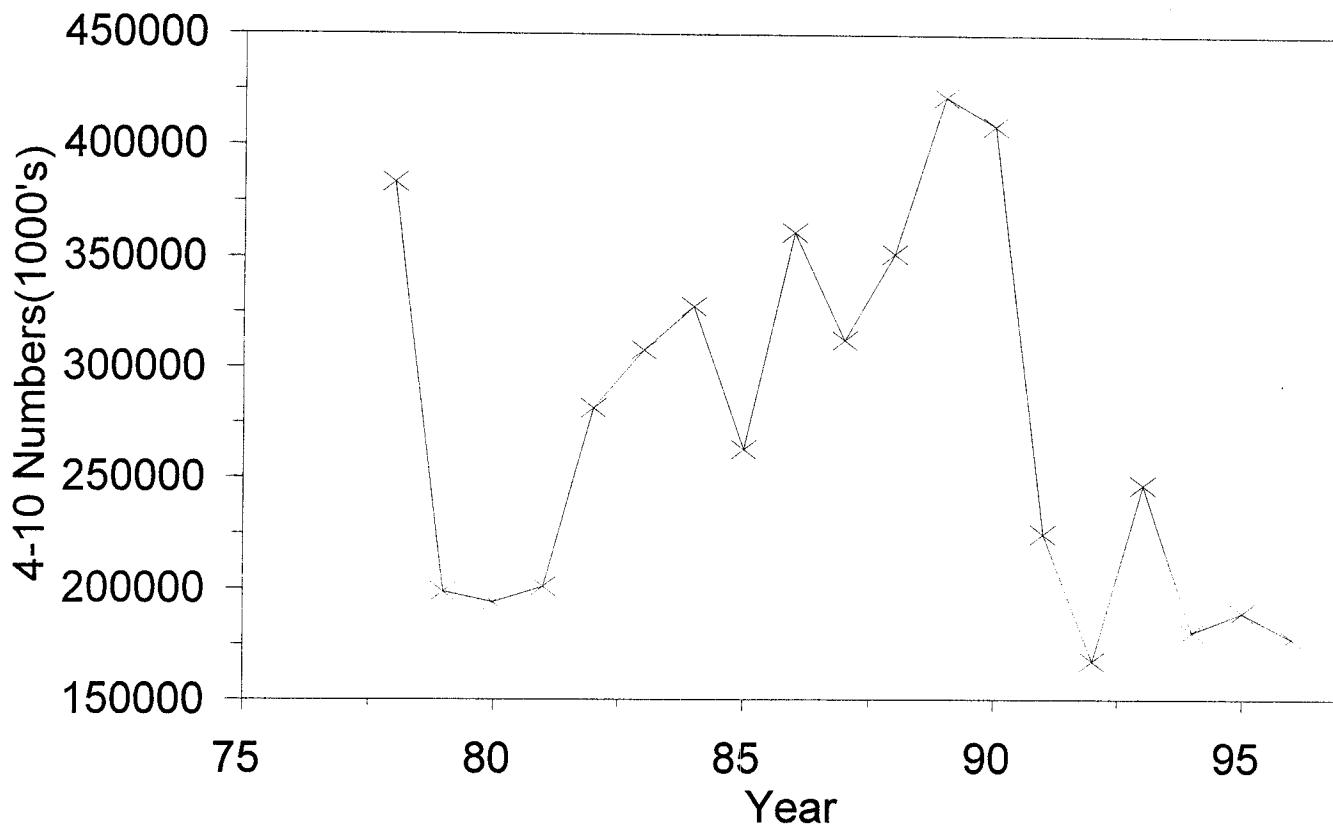


Fig. 2. Estimates of Greenland halibut numbers, ages 4-10, converted to Campelen equivalents.

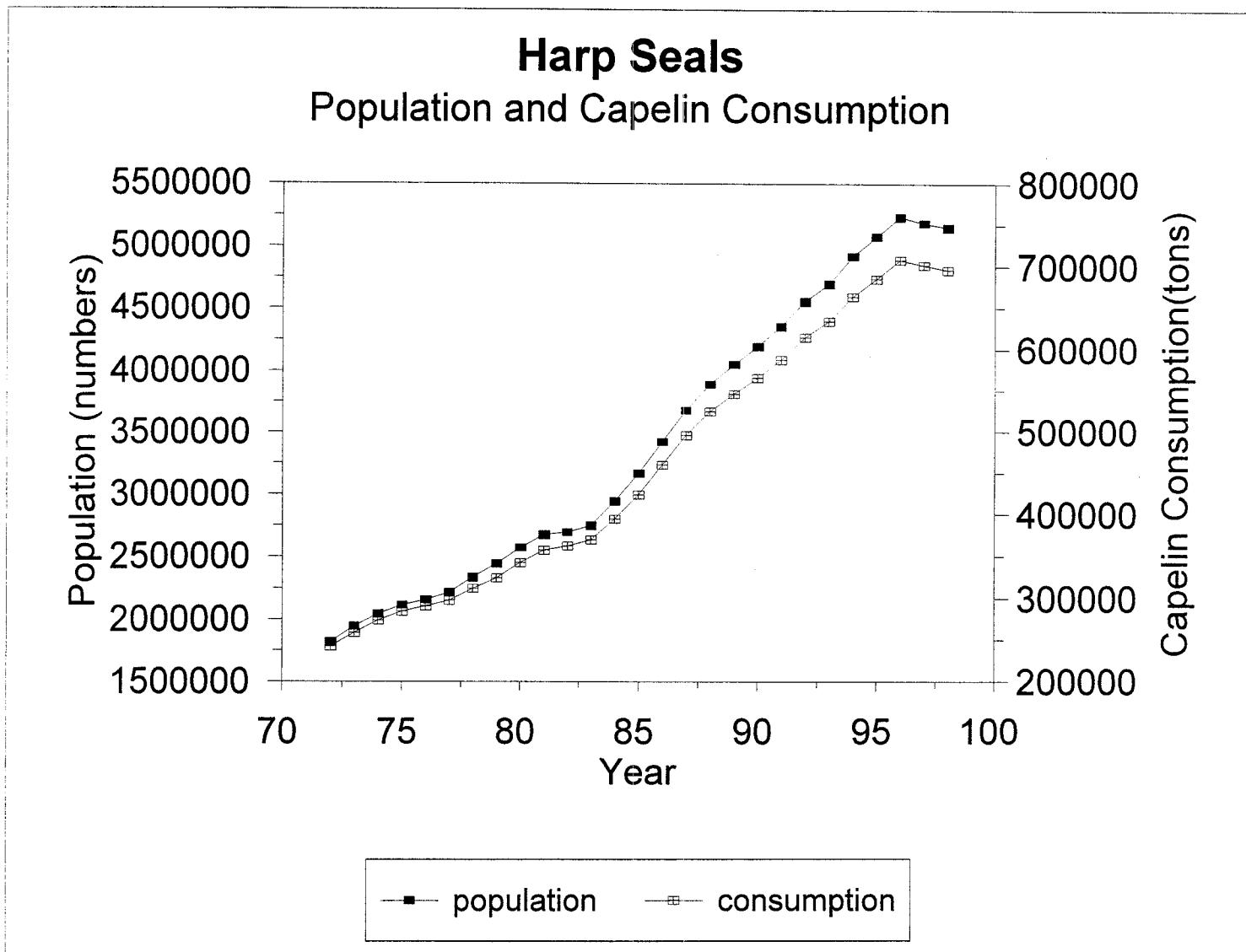


Fig. 3. Population numbers of harp seals and estimates of annual consumption of capelin by harp seals.

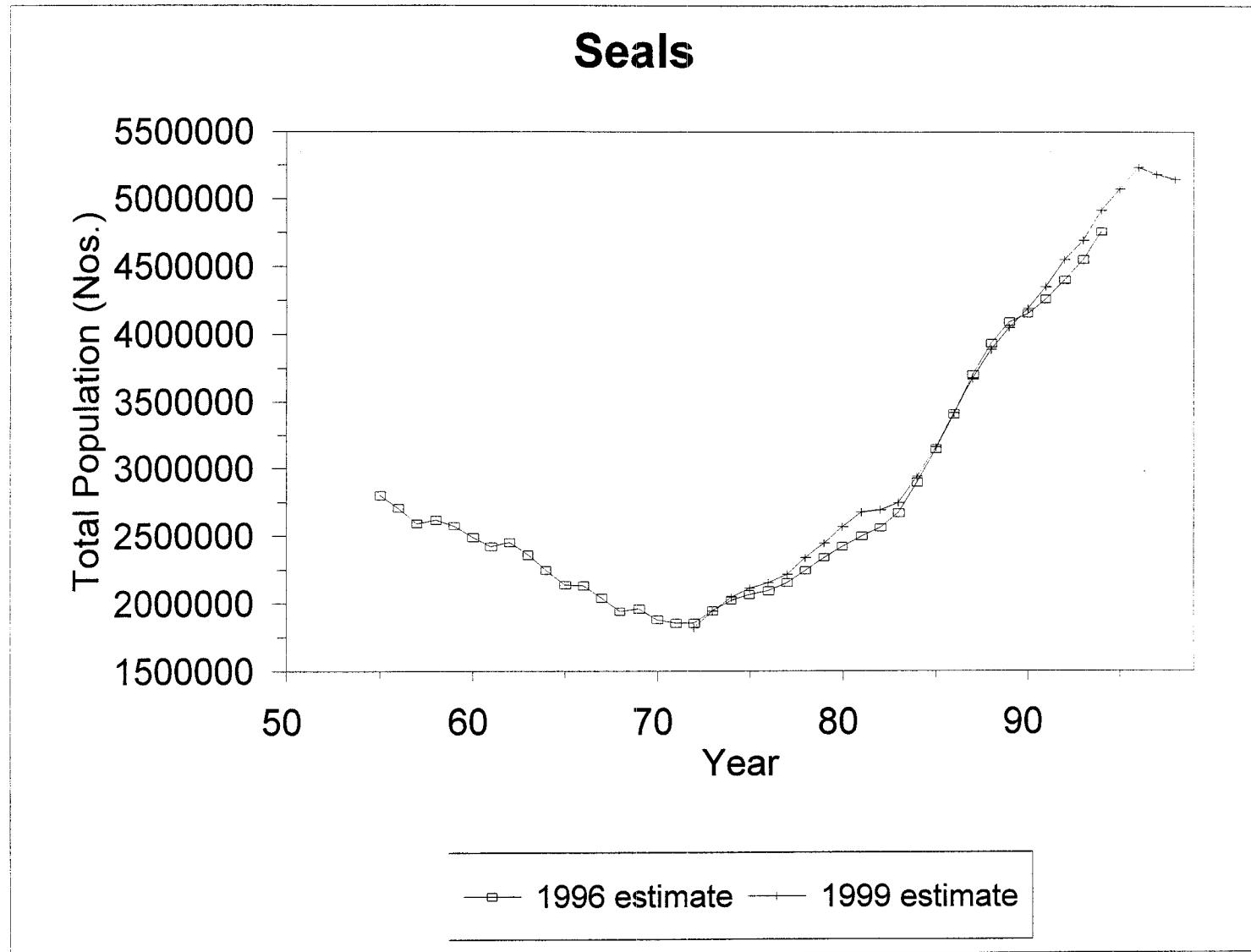


Fig. 4. Two trajectories of harp seal estimates. See text for discussion.

Predicting Mean Lengths of Female Capelin
In SA 2 + Div. 3KL

by

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Introduction

In past assessments, the positive relationship between mean lengths of maturing capelin from fall offshore surveys and the mean lengths of spawning capelin the following year have been used as a basis to predict the mean lengths of mature capelin during the assessment year (Carscadden 1995, 1996, 1997). During the 1997 assessment, the prediction for 1997 using data from the fall of 1996 proved optimistic (Carscadden and Evans 1998). A closer examination of the entire series of data indicated that two relationships might exist, one for the fall-summer mean length combination 1981/82 to 1989/90, and one from 1990/91 onward. In some cases, mean lengths in the fall in the 1990's period were smaller than the 1980's but in addition, the final mature mean lengths were smaller, indicating less growth during the latter period (see Fig. 1). Carscadden and Evans (1998) noted that growth between the fall of one year and spring of the following year could not be predicted. As a result, they provided two probability distributions using data from the 1980's and 1990's to provide insight in the likely mean lengths of females in the mature population in 1998, using the mean length observed in the fall of 1997. In this paper, we present the mean lengths of female capelin sampled in the 1998 fishery. In addition, we present another probability distribution analysis (Carscadden and Evans 1998) using historical mean length data and the observed mean lengths of female capelin during the fall of 1998.

The 1998 Analysis and Prediction

From capelin bycatch in the Campelen gear in the autumn 1997 groundfish survey in Div. 2J3KL, the mean length of maturing females was 144 mm. Using data from the 1980's and 1990's, probability distributions were presented. If growth increments (between fall 1997 and spring 1998) resembled those

observed in the 1990's, there was about a 60% probability that the mean length would be greater than about 151 mm. This mean length corresponds to approximately 50 count, thus, there would be about 60% chance that the average count would be 50 or less. On the other hand, if growth during the same time period was more typical of the 1980's, there was a 100% probability that the mean lengths would be greater than about 151 mm and counts 50 or less (Carscadden and Evans 1998).

The mean length of mature female capelin in the 1998 commercial fishery was 147 mm (Fig. 1). This point falls in the 1990's group, indicating that growth between the fall of 1997 and spawning season of 1998 was again low. The fishing industry reported that fish were smaller in Div. 3L than in Div. 3K. Our data support this report. The mean length of female capelin in Div. 3L was 0.5 mm smaller than in Div. 3K (Fig. 2).

Predicted Mean Length of Females in 1999

The only source of samples from the fall in 1998 is the bycatch in the Div. 2J3KL groundfish survey using Campelen gear. Sampling procedure in 1998 was the same as 1997, that is, lengths were recorded from all individuals in catches less than 200 fish. For larger catches, a random sample of 200 fish was collected and lengths recorded from this sample. The overall mean length of maturing female capelin in the fall of 1998 was 139 mm, one of the smallest estimates in the series (Table 1).

Using the non-parametric methods of Evans and Rice (1988) we present a probability distribution for the mean length in 1999, based on the mean length of 139 mm measured in the fall of 1998. Two distributions are present: one if the increments of the 1990's prevail, another (higher) if the system reverts to the increments of the 1980's. For reference we also illustrate the positions of lengths corresponding to the approximate 50 and 40 counts (Fig. 3). 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. However, they do offer guidance in evaluating the probable sizes of females in 1999. If growth is similar to that observed in the 1990's, there is virtually no chance that the average count will be less than 50 in 1999. If growth is similar to that of the 1980's, there is a 75% chance that the average counts will be less than 50.

These graphs (Fig. 3) 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 Figures 1 and 2 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

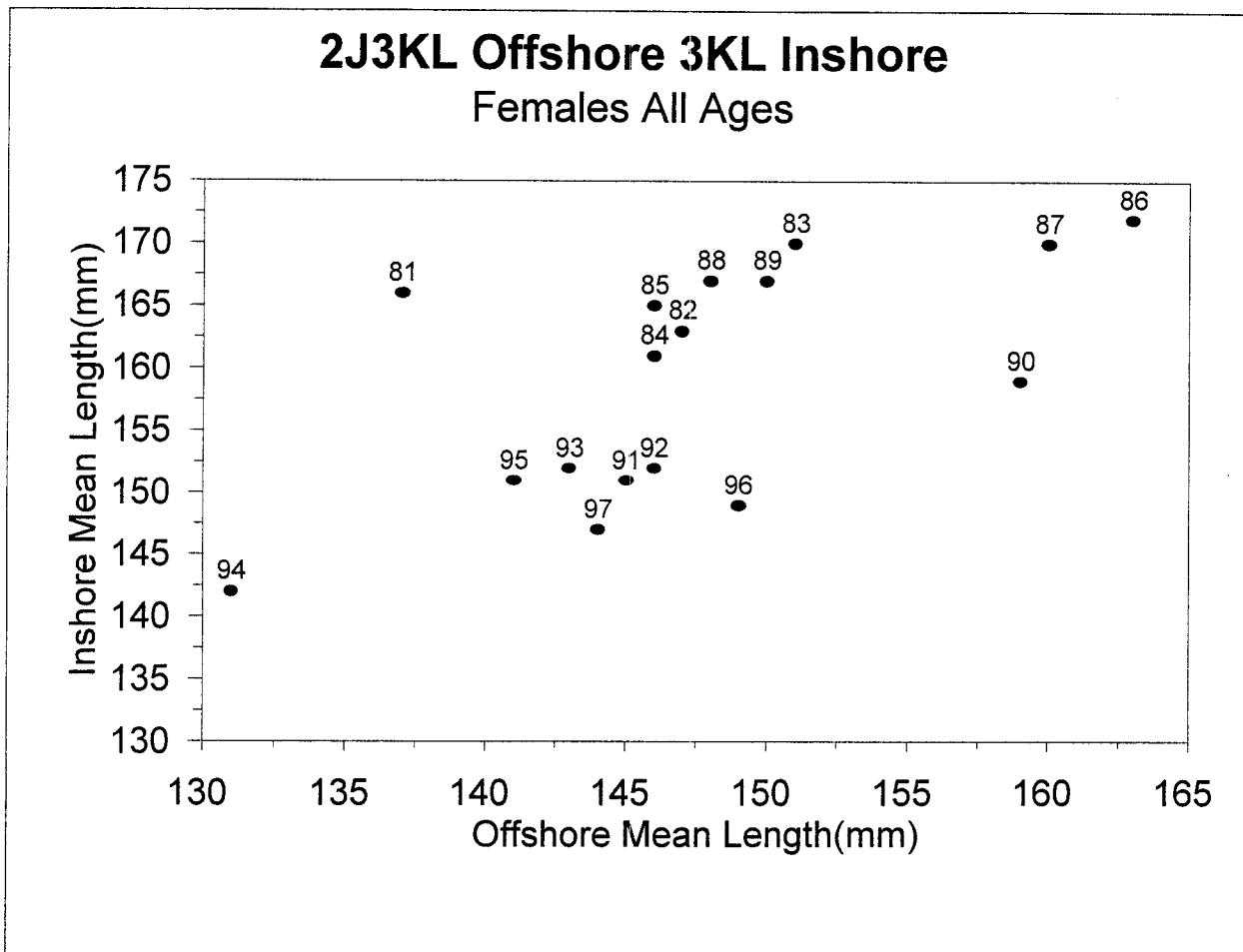


Fig. 1. Relationship between mean lengths of mature female capelin from fall offshore surveys and from inshore the following year, fall 1981 to inshore 1998. The labels (year) are the year the fall samples were collected (eg. 81 point is for fall 1981/inshore 1982).

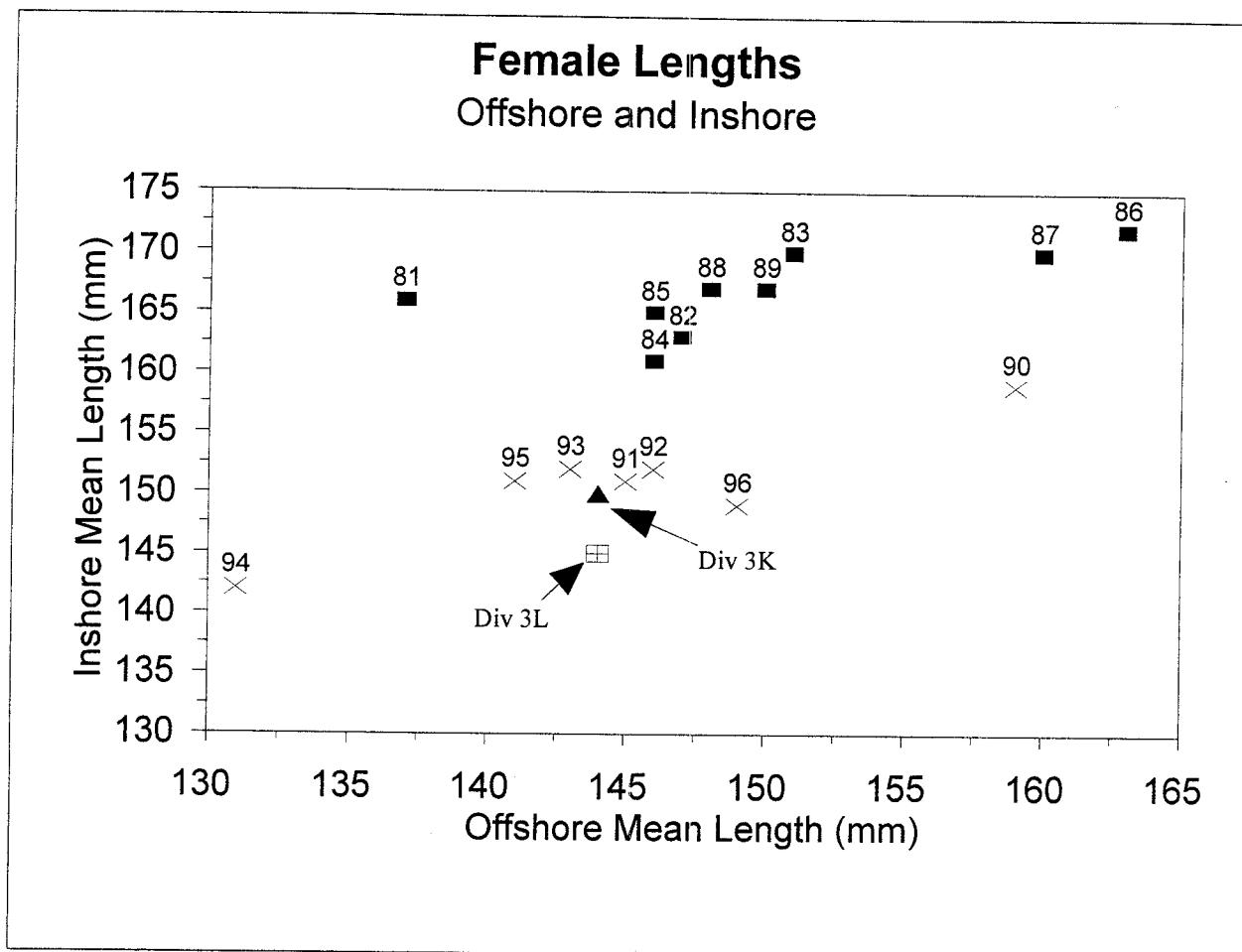


Fig. 2. The same data as in Figure 1 except the 1998 inshore samples have been split geographically to illustrate the differences in mean lengths between females from Div. 3L and Div. 3K.

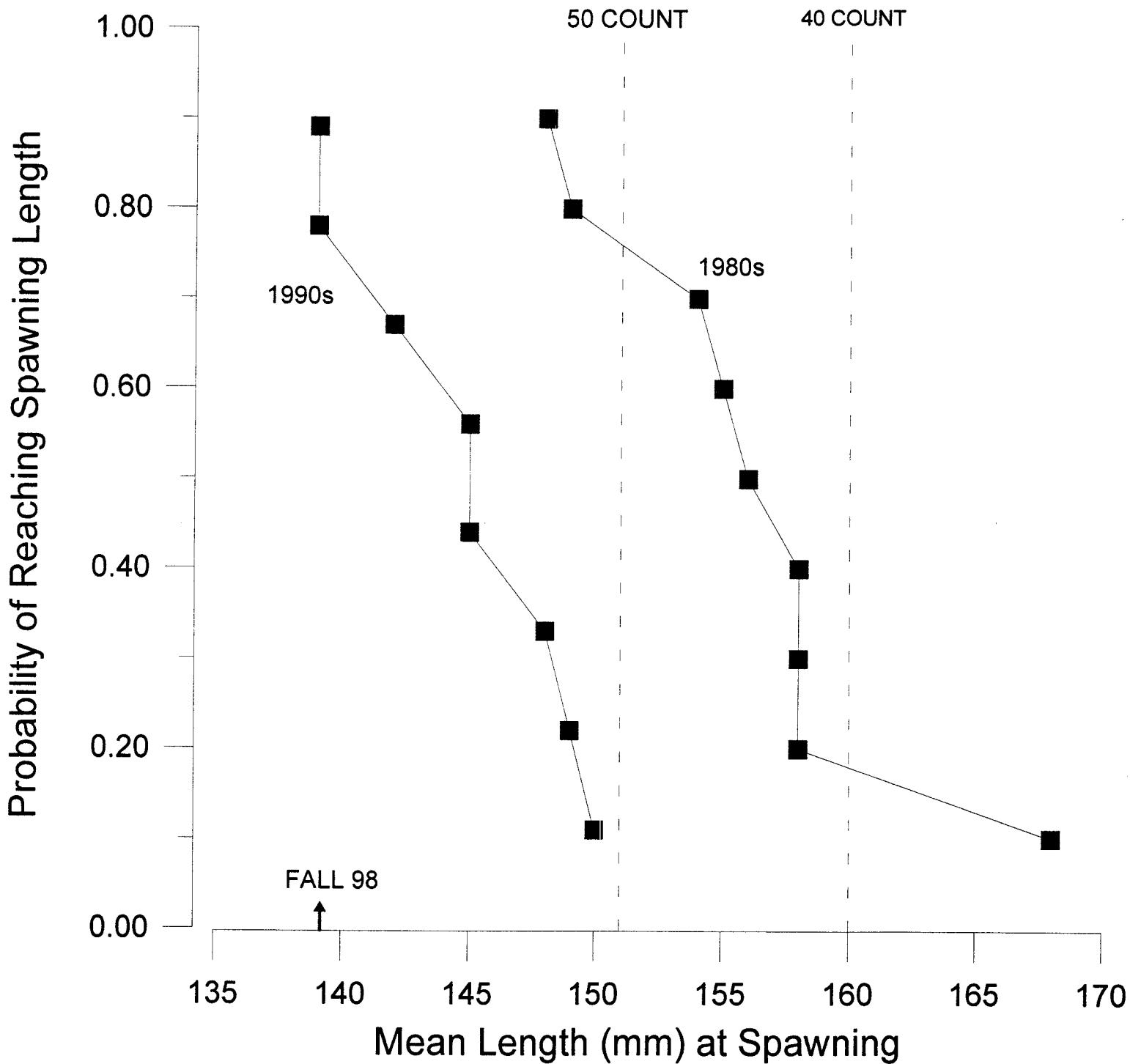


Fig. 3. Probabilities of reaching particular spawning lengths using growth increments observed during the 1980's and 1990's, and a fall mean length of 139 mm. The dotted lines identify the approximate mean lengths corresponding to 50 and 40 count (numbers of females per kg) capelin.

Yearclass Strength of Capelin (Mallotus villosus)
Using a Weighted Multiplicative Model

by

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Introduction

The multiplicative model provides an objective framework for combining indices from a variety of sources into a single compromise index (see Myers et al. 1993). This approach is particularly attractive for extraction of the yearclass effect because multiple estimates from several abundance indices can be combined over a life-span. The multiplicative approach was applied to capelin for the first time in the 1995 assessment (Anon. 1995). Now we drop the assumption of equal weighting of the indices. For the 1999 assessment, a weighted multiplicative model was developed to provide a standardized index of cohort strength.

Methods

The multiplicative cohort model assumes that the various types of abundance indices to be integrated retain their relativity throughout the time series, i.e. each index remains proportional to population abundance (and therefore each other) so that gaps and missing values can be filled in through standardization into a combined index.

The general multiplicative model took the form:

$$N_{ijkt} = I \cdot C_k \cdot S_j \cdot A_i \cdot \epsilon$$

where I = intercept

C_k = cohort effect

S_j = survey effect for $j = 1 \dots 12$

A_i = age effect for $i = 0 \dots 5$

ϵ = residuals from fitted model

and N_{ijkt} = number at age i from survey j belonging to cohort k to what is in year t .

All variables were log-transformed (i.e. multiplicative model becomes an additive model) and the estimated cohort strengths were obtained after exponentiation.

A multiplicative analysis was performed as in Anon. (1995). The variance of each index about the combined estimate was computed. For the group of indices comprising 1/3 of the total that had the smallest variances, the variance was replaced by the largest variance in the group. Thus exceptionally, possibly accidentally small variances were ignored. The multiplicative analysis was then repeated with each index weighted by the reciprocal of its variance.

For the most recent yearclass, a probability distribution for yearclass strength was developed combining the empirical distributions for expected yearclass strength and expected catchability of the few available indices, using Bayes rule.

To develop a standardized cohort index for the 1999 assessment, a multiplicative model was applied to twelve indices.

Seven of the indices were first accepted as the basis for the 1996 assessment, i.e. catch rates from purse seines and traps, the aerial survey index, egg deposition, the Russian 2J3K CPUE, and Canadian 2J3K and 3L fall bycatch indices from offshore groundfish surveys. Five indices that were the basis of a standardized recruitment index in the 1998 assessment (Nakashima 1998) were combined with the original seven indices for the 1999 assessment.

Results and Discussion

Indices

The multiplicative model was applied to the following indices as a basis for developing a cohort index for the 1999 assessment of capelin (Appendix A):

1. aerial survey index 1982-98, excluding 1991;
2. egg deposition index 1990-98;
3. purse seine catch rate index 1981-93, 1996;
4. integrated trap catch rate index 1981-93;
5. groundfish 3L fall bycatch 1985-94;
6. groundfish 2J3K fall bycatch 1985-94;
7. Russian 2J3K fall commercial catch rate index 1972-91;
8. Conception Bay sediment larval index 1987, 1989-93;
9. Bellevue Beach sediment larval index 1990-98;
10. Bellevue Beach emergent larval index 1990-96, 1998;
11. Offshore Div. 2J3KLNO 0-group index 1994-98;
12. Offshore Div. 2J3KLNO age 1 index 1994-98.

(a) Aerial survey index

The aerial survey in 1998 covered two transects (Nakashima 1999). We used a multiplicative analysis of the three transects (the transect covering the outer part of Conception Bay was last covered in 1996) as the aerial survey index. The 1998 estimate was partitioned using the age composition derived for Bellevue Beach spawners. The index assumes that the overall trend observed in the two bays is indicative of the whole stock area.

(b) Egg deposition index

Egg deposition (stages I-II, integrated for each beach) has been estimated since 1990 for several beaches on the northeast coast. Since 1996 only Bellevue Beach has been surveyed. Because it is unlikely that we will reactivate the closed sites, we decided to use only the Bellevue data series in this assessment. Past assessments (e.g. Nakashima 1998) employed a normalized series, however this assessment uses the actual estimates from the Bellevue site. To estimate the number of females we divided egg deposition by the mean female weight in gm. The estimate was then partitioned for the cohort model using the female age composition from biological samples collected at Bellevue Beach (Nakashima and Slaney 1999a). The egg deposition time series was first adopted as an index in the 1996 assessment (Winters 1996) and serves as an indirect measure of female spawner escapement. Retention of the index in the analysis assumes that observations at Bellevue Beach are indicative of the overall trend in beach spawning for Div. 3KL.

(c) Purse seine index

Data were available to estimate a purse seine catch rate (catch per fishing day) for the 1998 mobile fishery. Details concerning the purse seine fishery in 1998 are in Nakashima and Slaney (1999b). The purse seine catch rate for 1998 was not used in the standardized cohort model this year. The reduced effort and nature of the fishery created difficulties in evaluating the relevance of the current catch rate to those in the early part of the series.

(d) Integrated trap index

Data were unavailable from the research logbook survey to estimate an integrated trap index for 1998. The monitoring program to determine area openings and marketing constraints have changed fishing practices. Also catch rates for trap fishery were only

available from a small portion of the stock area (Southern Shore, Notre Dame Bay, and White Bay) with most of the data coming from the White Bay area (Nakashima and Slaney 1999b). No acceptable method was available to make the 1998 estimate compatible with estimates earlier in the time series. Consequently the 1998 estimate was not used in the analysis.

(e) Offshore indices

These include the Russian 2J3K CPUE series and the 2J3K and 3L bycatch (%) of capelin in the fall 2J3KL groundfish survey (see Lilly 1995). The Russian 2J3K CPUE series ended in 1991. The two fall groundfish bycatch indices ended in 1994 when the survey fishing gear was changed from an Engels 145 high-lift trawl to a Campelen 1800 shrimp trawl.

(f) Inshore 0-group indices

The inshore indices were based on very early estimates of 0-group fish. Sediment larvae are newly hatched capelin larvae resident in beach sediments for 1-5 days. When larvae are released from beach sediments into the water column they are then termed emergent larvae. Sediment larvae were estimated from 15 Conception Bay beaches in 1987 and 1989-93 (Winters et al. 1996) and from 1-6 beaches along the northeast coast since 1990. Emergent larvae were also enumerated at northeast coast beaches from 1990-96 and in 1998. For the 1999 assessment, the Conception Bay sediment larval index was retained. However, only the data from Bellevue Beach sediment larvae and emergent larvae were used in the 1999 assessment (Nakashima and Slaney 1999a). Similar to the egg deposition index, there is no expectation that sites studied in 1991-94 would ever be sampled again.

(g) Offshore 0-group and age 1 indices

An 0-group index and an age 1 index from annual offshore surveys conducted in August-September since 1994 (Anderson and Dalley 1999) were incorporated into the multiplicative cohort model for the first time. Previously both indices were part of a recruitment index (Nakashima 1998). 0-group capelin are collected by bongos and age 1 capelin are collected using an IGYPT trawl at the same stations during the offshore 0-group survey (Anderson and Dalley 1999). In the combined recruitment index (e.g. Nakashima 1998), these two indices began in 1991, however Anderson and Dalley (1999) argued that only since 1994 have the survey coverage and sampling methodologies been relatively consistent.

Accordingly, the time series for both indices used in the 1999 assessment was 1994-98.

Model Development

Indices used in the weighted model are displayed in Figure 1. A Bayes update to better estimate the most recent yearclass (1998 in this example) is shown in Figure 2. A comparison of outcomes assuming equal weighting as in previous assessments and the weighted version suggests small differences between the two (Fig. 3). The 1998 estimate is from the model results and not the Bayes estimate.

Summary

For the 1999 assessment, the weighted model was adopted to estimate standardized cohort abundance trends. The 1996 yearclass estimates at age 2 from the both the aerial survey and the egg deposition study show this yearclass is relatively strong. Even at the lower 95% confidence interval the estimate is one of the highest in the series. However, there is considerable variation and therefore uncertainty about the estimate. As the yearclass ages and estimates at older ages become available, the relative strength of the 1996 cohort will be better estimated.

Based on the weighted multiplicative analysis, the 1996 yearclass is the strongest yearclass in the time series and is likely to dominate the 1999 spawning stock. The 1996 yearclass was relatively strong in the recruitment series (Nakashima 1998). The 1997 yearclass is weaker than the 1996 yearclass, however estimates were only available at the 0-group and age 1 stages. The 1998 yearclass will not be part of the 1999 spawning biomass, however, early indications from 0-group estimates suggest this yearclass may be as weak as the 1991 yearclass. The high variation surrounding the estimates, especially since 1993 partly reflect a continuing reduction in the number of indices available.

Besides the problems and assumptions associated with each of the indices in this analysis, there are other assumptions that have not been evaluated but may be important to interpreting the model results. Some indices do not use an independently derived age composition. For example, the egg deposition and aerial survey indices use the same age composition derived from Bellevue Beach spawners since 1996. The results of the multiplicative analysis must be considered with caution in light of these and other assumptions whose effects have not been evaluated.

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previous indices updated

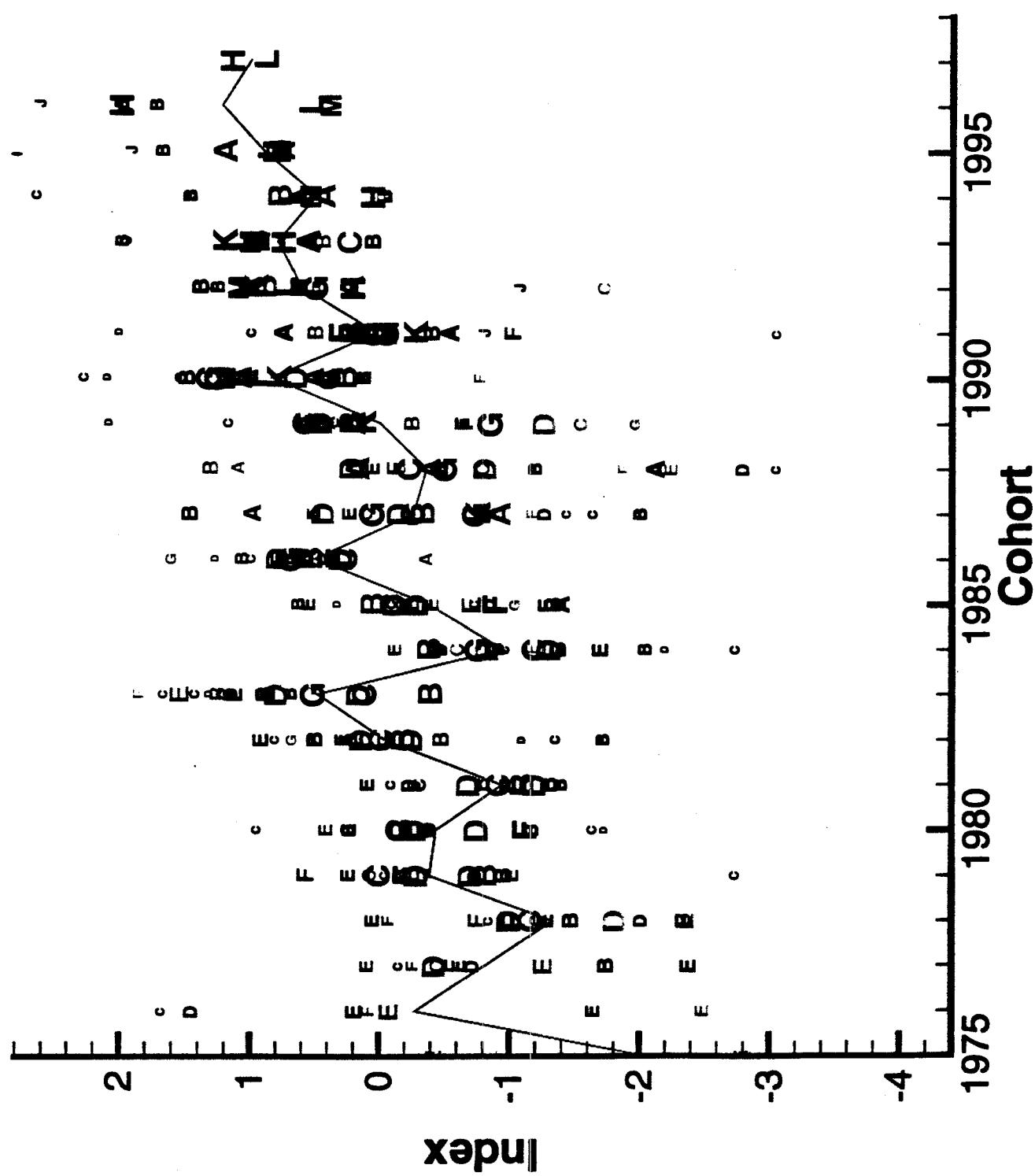


Fig. 1. The scatter of all indices used in the weighted multiplicative analysis. The letters refer to the indices in Appendix A. The larger the letter symbol the greater its contribution to the overall trend.

1998 yearclass

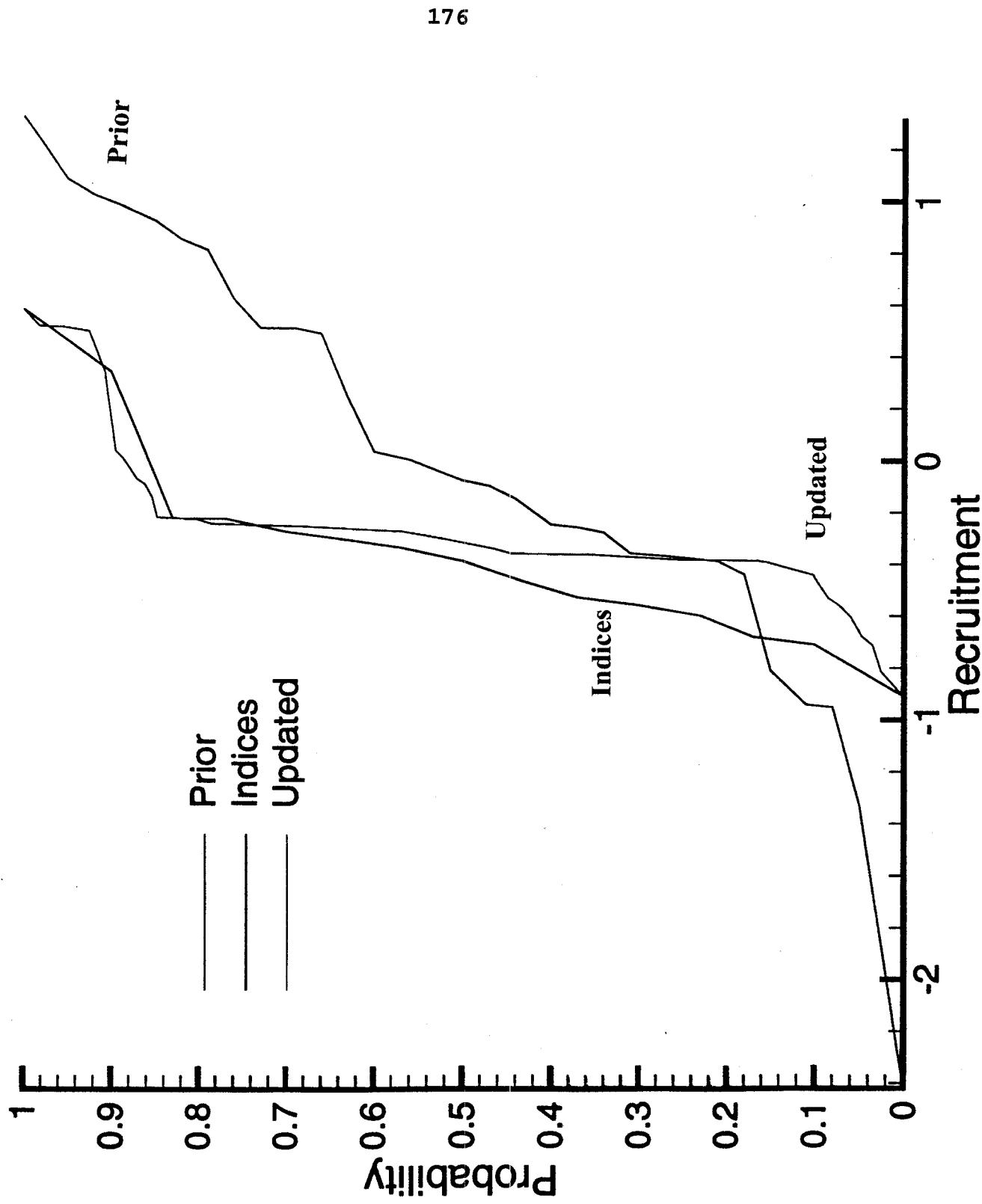


Fig. 2. Bayes update of the 1998 yearclass for the weighted multiplicative analysis.

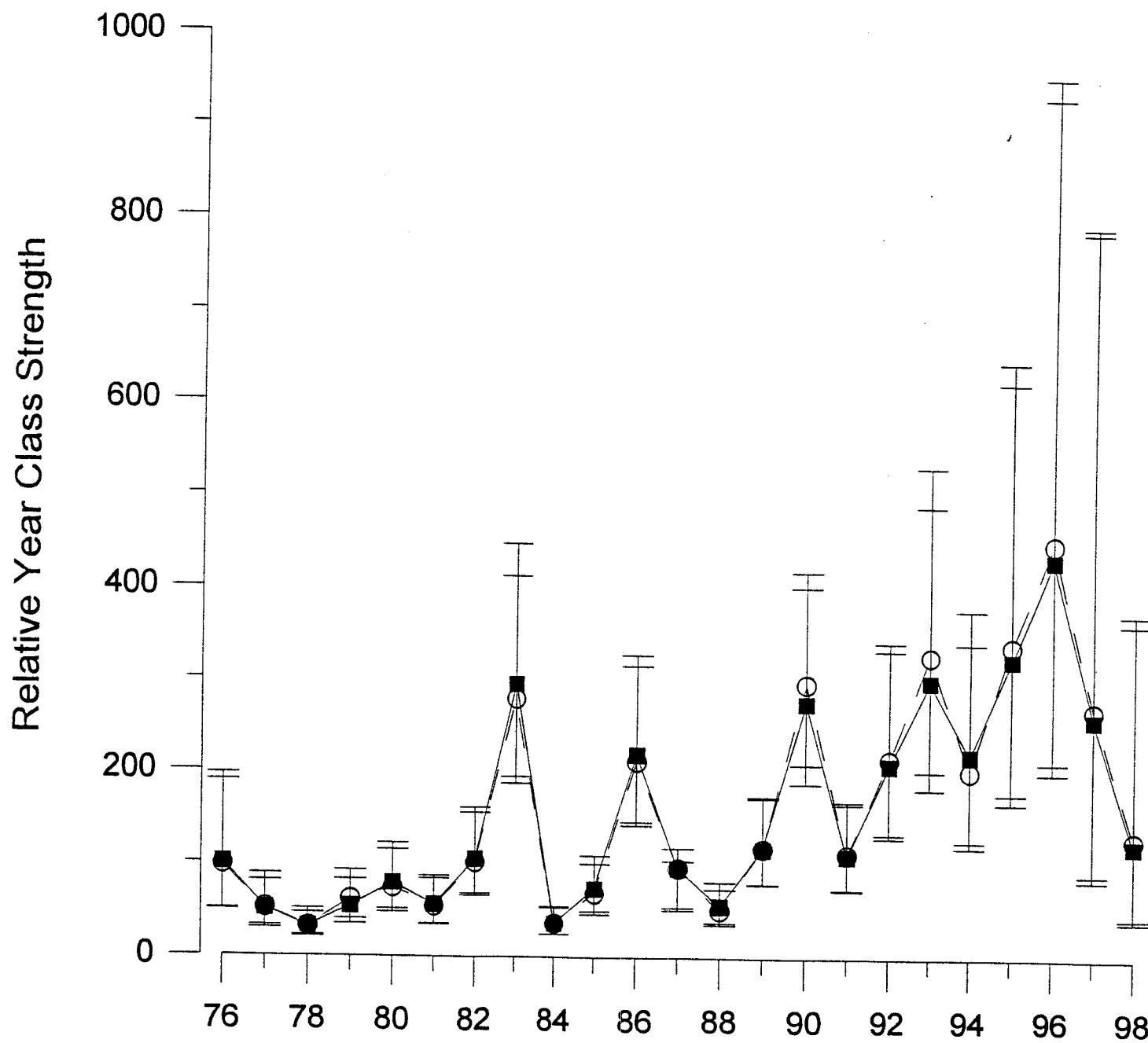


Fig. 3. A comparison of trends in standardized estimates of cohort abundance of capelin with 2 standard errors. Open circles use equal weighting and closed squares are from the weighted model.

Appendix A. Indices used in the standardized cohort abundance model.

Year	Age					
	0	1	2	3	4	
Egg Deposition Index (A)						
1990	-	-	79	821	696	53
1991	-	-	207	1620	1772	687
1992	-	-	482	1889	2561	476
1993	-	-	877	6609	1717	286
1994	-	-	347	1019	520	162
1995	-	-	1607	3955	1046	512
1996	-	-	812	3504	1246	120
1997	-	-	943	3213	1704	605
1998	-	-	729	1537	395	82
Aerial Survey Index (B)						
1982	-	-	55	939	125	36
1983	-	-	44	1783	1095	47
1984	-	-	32	712	885	79
1985	-	-	354	1775	582	143
1986	-	-	23	1438	803	56
1987	-	-	332	1456	4521	339
1988	-	-	515	2247	527	500
1989	-	-	24	3637	1011	52
1990	-	-	54	1524	1987	54
1991	-	-	-	-	-	-
1992	-	-	505	2660	4798	887
1993	-	-	226	2803	1013	130
1994	-	-	625	2678	1480	328
1995	-	-	1297	5227	2143	913
1996	-	-	768	5514	2074	137
1997	-	-	944	4662	3041	820
1998	-	-	1000	4745	1255	217
Purse Seine Catch Rate Index (C)						
1981	-	-	1	123	124	112
1982	-	-	3	395	58	18
1983	-	-	14	341	210	9
1984	-	-	4	158	248	20
1985	-	-	64	386	143	54
1986	-	-	1	441	215	16
1987	-	-	14	120	643	47
1988	-	-	42	358	107	111
1989	-	-	3	510	163	8
1990	-	-	10	304	413	10
1991	-	-	50	315	219	36
1992	-	-	150	705	89	5
1993	-	-	42	590	42	1
1994	-	-	-	-	-	-
1995	-	-	-	-	-	-
1996	-	-	217	500	35	1

Appendix A. Continued ...

Year	Age				
	0	1	2	3	4
Trap Catch Rate Index (integrated) (D)					
1981	-	-	1	941	943
1982	-	-	16	1908	237
1983	-	-	67	1202	719
1984	-	-	30	766	1095
1985	-	-	334	1998	731
1986	-	-	10	3013	1674
1987	-	-	124	697	3216
1988	-	-	323	2271	634
1989	-	-	38	3447	1083
1990	-	-	55	2198	3200
1991	-	-	723	3180	2248
1992	-	-	730	4056	648
1993	-	-	665	4902	413
Russian 2J3K Fall Commercial Catch Rate Index (E)					
1972	-	-	33	181	59
1973	-	-	83	99	132
1974	-	-	92	223	80
1975	-	-	400	179	53
1976	-	-	46	437	36
1977	-	-	12	124	248
1978	-	-	38	71	97
1979	-	-	105	14	3
1980	-	-	206	185	49
1981	-	-	248	49	15
1982	-	-	247	61	5
1983	-	-	215	256	39
1984	-	-	262	77	39
1985	-	-	464	200	19
1986	-	-	128	419	50
1987	-	-	340	150	248
1988	-	-	430	112	14
1989	-	-	248	332	26
1990	-	-	208	281	95
1991	-	-	104	18	0

Appendix A. Continued ...

Year	Age				
	0	1	2	3	4
Groundfish 2J3K Fall Bycatch Index (F)					
1980	-	-	34	31	7
1981	-	-	77	26	5
1982	-	-	31	97	6
1983	-	-	-	-	-
1984	-	-	-	-	-
1985	-	-	-	-	-
1986	-	-	-	-	-
1987	-	-	39	23	41
1988	-	-	131	37	2
1989	-	-	-	-	-
1990	-	-	-	-	-
1991	-	-	166	49	2
1992	-	-	248	29	1
1993	-	-	128	87	9
1994	-	-	173	20	3
Groundfish 3L Fall Bycatch Index (G)					
1985	-	44	220	28	-
1986	-	-	-	-	-
1987	-	-	-	-	-
1988	-	45	261	5	-
1989	-	57	140	71	-
1990	-	-	-	-	-
1991	-	352	56	12	-
1992	-	99	466	2	-
1993	-	154	125	66	-
Offshore 0-group Index (H)					
1994	37316	-	-	-	-
1995	188832	-	-	-	-
1996	263658	-	-	-	-
1997	89572	-	-	-	-
1998	105216	-	-	-	-
Offshore age I Index (J)					
1994	-	17698	-	-	-
1995	-	1083	-	-	-
1996	-	3485	-	-	-
1997	-	7451	-	-	-
1998	-	4460	-	-	-

Appendix A. Continued ...

Year	Age				
	0	1	2	3	4
Conception Bay Sediment Larval (K)					
1987	61	-	-	-	-
1988	-	-	-	-	-
1989	147	-	-	-	-
1990	285	-	-	-	-
1991	99	-	-	-	-
1992	340	-	-	-	-
1993	432	-	-	-	-
Bellevue Pre-emergent Larval Index (L)					
1990	262	-	-	-	-
1991	90	-	-	-	-
1992	183	-	-	-	-
1993	271	-	-	-	-
1994	174	-	-	-	-
1995	209	-	-	-	-
1996	152	-	-	-	-
1997	215	-	-	-	-
1998	62	-	-	-	-
Bellevue Emergent Larval Index (M)					
1990	212	-	-	-	-
1991	61	-	-	-	-
1992	193	-	-	-	-
1993	175	-	-	-	-
1994	110	-	-	-	-
1995	140	-	-	-	-
1996	94	-	-	-	-
1997	-	-	-	-	-
1998	45	-	-	-	-

Seasonal changes in abundance, distribution, and vertical
migration of capelin in Placentia Bay

by

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Abstract

The abundance and distribution of capelin (*Mallotus villosus*) in Placentia Bay, southeastern Newfoundland, were assessed during four acoustic surveys in January, March, and June 1998, and in January 1999. Most capelin observed were immature (75% < 130mm). Capelin biomass was highest in June 1998, with an acoustic estimate of 132,000t for outer Placentia Bay. Capelin biomass in the outer Bay was much lower in January 1998 (13,000t), March 1998 (2,100t), and January 1999 (390t), suggesting seasonal changes in spatial distribution. There were also seasonal differences in vertical distribution of capelin. In June capelin were close to the surface at night and near the bottom during the day. At other times no diurnal vertical migration was evident.

Introduction

No previous attempt has been made to estimate the abundance of capelin in Placentia Bay (NAFO Div. 3Ps). As part of ongoing work to monitor the distribution and abundance of cod in this area, we collected acoustic data on capelin during four surveys in 1998-99. This paper presents data on capelin biomass, distribution and vertical migration.

Acoustic surveys provide a direct method of estimating capelin abundance at sea (Toresen et al. 1998). 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 1990s (Carscadden & Nakashima 1997), and the reason for this decline was never fully

explained. Offshore acoustic surveys were discontinued in 1996. Currently, capelin abundance is monitored offshore only through groundfish bottom-trawl by-catch (Lilly 1998), and pelagic juvenile fish surveys (Anderson & Dalley 1998). Both these methods target a relatively narrow depth range and there is potential bias due to the vertical migration behaviour of capelin (eg Shackell et al. 1994).

Methods

Surveys were conducted from the research vessel *Teleost* during January 6-8 1998 (*Teleost* 59), March 28-30 1998 (*Teleost* 60), June 18-25 1998 (*Teleost* 65), and January 13-16 1999 (*Teleost* 77). Acoustic data was collected using a calibrated Simrad EK500 split-beam 38-kHz echo-sounder, and analysed using custom FASIT (Fisheries Assessment and Species Identification Toolkit) software. We distinguished signals from capelin based on signal characteristics (Rose & Leggett 1988, LeFeuvre et al. 1999) and information from fishing sets using IGYPT mid-water and Campelen bottom trawls.

For biomass estimation, we integrated data from 11m below the surface to the bottom in 100-m horizontal bins and scaled by acoustic target strength to give estimates of areal density of capelin (fish m⁻²) in each 100-m bin. Mean target strengths for each survey (Table 1) were calculated from fishing set length-frequency data using the relationship TS = 20logL - 73.1 where L = fish length in centimetres (Rose 1998).

The area covered varied between acoustic surveys (Fig. 1), but a region of outer Placentia Bay bounded by co-ordinates: 47°23'N, 54°29'W; 47°20'N, 54°01'W; 46°45'N, 55°31'W; 46°43'N, 54°19'W; was always surveyed with four or more transects (Fig. 1). We chose this region to compare biomass estimates between surveys. Capelin biomass was estimated from the equation:

$$B_A = w A \frac{\sum_{i=1}^{n_A} d_i}{n_A}$$

where B_A is the biomass of capelin in area A in kg
 w is the average weight of capelin from fishing sets in kg
 d_i is the areal density of capelin in the i th 100-m bin
 n_A is the number of 100-m bins in area A

Only data collected along transects were used to estimate biomass, although all data, including inter-transect bins are shown in Fig. 1. We estimated capelin biomass in the outer Bay in two ways. An estimate was calculated first for the entire region by averaging all acoustic density estimates collected along transects in the region and multiplying by the total area of the region. Second, biomass was calculated by sub-dividing the region into blocks surrounding each transect. The number and area of blocks was dependent on the number and spacing of transects (Fig. 1). Capelin biomass was then calculated independently for each transect block, and summed over the number of blocks to give an estimate of total capelin biomass in the outer Bay region (Table 2).

Surveys in January and March 1998 and in January 1999 also covered a circuit of inner Placentia Bay (Fig. 1). For these surveys we calculated an estimate of biomass in the inner Bay by averaging all acoustic density estimates north of our outer Bay region and multiplying by the total sea area of the inner Bay (Table 3). In January 1999 we observed a concentration of capelin in Paradise Sound, and calculated a separate biomass estimate for this area (Table 3). Survey coverage in the inner Bay and Paradise Sound was limited by the size of the research vessel, so biomass estimates for these areas are only general.

To examine capelin vertical distribution, we integrated acoustic signal from capelin in 5-m vertical bins (11-16m, 16-21m, 21-26m, down to the maximum depth) over a horizontal distance of 2km (~10min at survey speed of 8kts). The surface 11m was excluded because of transducer depth (6m), ship noise and near-field effects. Peak capelin depth was defined as the median depth of the vertical bin with the highest areal density of capelin. Peak capelin depth was then standardised relative to water depth according to the relationship:

$$\text{Relative capelin depth} = 1 - (\text{Peak capelin depth} / \text{Water depth})$$

Relative capelin depth provided a measure of capelin position in the water column. A value of 1 indicates capelin were at the surface. A value of 0 indicates capelin at the sea bottom. For display, we grouped acoustic data into hourly intervals and calculated the mean and standard error of relative capelin depth.

Results

Capelin biomass in outer Placentia Bay was highest in June 1998 (Table 2). Biomass in June (>130,000t) was an order of magnitude higher than the next highest estimate, from January 1998 (~12,000t). High densities of capelin were also observed offshore, south of Placentia Bay, in June 1998. Capelin biomass in the outer Bay in March 1998 (2,000-3,000t) and January 1999 (<400t) were low. Biomass estimates calculated by the two different methods (total area and transect blocks) were similar (Table 2).

Significant numbers of capelin were also observed in inner Placentia Bay, particularly in January 1999 (1,200t) and March 1998 (400t) (Table 3). In addition, a large concentration of capelin were observed in Paradise Sound in January 1999 (>1,400t), an area which we had not previously surveyed.

Capelin captured during the June survey (mean length = 125mm) were larger than those in other surveys (Fig. 2). However, the increase in capelin biomass in outer Placentia Bay from January to June was not due just to growth of individual fish. The average weight of capelin doubled over this period, from 5.03g in January to 10.34g in June, while the biomass increased by a factor of ten (Table 2). Most capelin captured in Placentia Bay were less than 130mm (Fig. 2). Larger fish only made up more than 10% of the total catch in June 1998 (Fig. 2). No information is available on capelin age or maturity from 1998 cruises, but preliminary analysis of results from January 1999 indicate that most capelin in Placentia Bay at this time were immature and ~18 months old.

A clear pattern of diurnal vertical migration was evident in acoustic data from June 1998 (Fig. 3). Capelin were close to the surface at night and near-bottom during daylight. There was little evidence of vertical movement in the other surveys. Capelin tended to be concentrated in the lower part of the water column during both day and night.

Discussion

Large numbers of capelin were observed in Placentia Bay, particularly in June. This should not be surprising, given the importance of the area as a feeding ground for seabirds, whales and cod. Most capelin in Placentia Bay were small (< 130mm), suggesting that this area is mainly used by immature fish,

rather than by pre-spawning adults. Work is ongoing to examine the feeding behaviour and age-structure of capelin in the region.

The decrease in capelin biomass in the outer Bay between January and March 1998, followed by the huge increase in June indicates that there is substantial movement of capelin in this system. It appears that most capelin move out of Placentia Bay in winter, returning in the spring. There is, however, a proportion of the population which over-winters, particularly in the inner Bay. This is different from the situation described by Winters (1969) in Trinity Bay, where he observed large over-wintering concentrations in February and March which dispersed in April and May.

Capelin biomass in Placentia Bay in January 1999 (<3,100t for outer Bay, inner Bay and Paradise Sound combined) was much lower than in January 1998 (~12,000t). The research survey in 1999 was one week later than in 1998, and it is possible that most capelin had already migrated out of the Bay in 1999. Also, capelin observed in 1998 are likely to have been dominated by the 1996 year-class, which was strong (Anderson & Dalley 1998). The 1997 year-class, which seem to be the major age-class in our catches in January 1999 (O'Driscoll unpublished data), was weaker and there may have been fewer fish available in 1999.

Diurnal vertical migration has commonly been reported for capelin (Winters 1969, Kovalyvov & Kudrin 1973, Bailey et al. 1977, Shackell et al. 1994). Our results indicate that the occurrence or extent of vertical movement varies seasonally, possibly related to seasonal changes in feeding (Chan & Carscadden 1976). This has important implications for attempting to assess capelin abundance using gear which samples a fixed depth window. In January and March, capelin tended to remain close to the bottom. This may increase their vulnerability to a bottom trawl survey (Lilly 1998), while decreasing their vulnerability to a pelagic survey (Anderson & Dalley 1998). In June, we expect diurnal changes in catchability with both bottom and pelagic gears, related to the diurnal changes in the vertical distribution of capelin.

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Table 1. Capelin target strength calculated from length-frequency data for surveys in Placentia Bay in 1998-99.

Survey	Mean σ (m^2)	Mean TS (dB)	Mean length (mm)
January 1998	7.458E-05	-52.27	110
March 1998	6.545E-05	-52.83	102
June 1998	9.846E-05	-51.06	125
January 1999	7.283E-05	-52.37	108

Table 2. Parameters and capelin biomass estimates for outer Placentia Bay (see text and Fig. 1 for region boundaries).

Survey	Transect block	No. of 100-m bins (n)	Min. capelin density	Max. capelin density	Mean capelin density	Variance capelin density	Mean capelin weight (g)	Transect area (m^2)	Number of capelin	Capelin biomass (tons)
January 1998	all	2186	0	23.54	0.4922	2.392	5.03	4.64E+09	2.28E+09	11,500
	1	734	0	23.54	0.8224	5.496	5.03	2.17E+09	1.78E+09	8,960
	2	739	0	8.667	0.6080	1.294	5.03	1.25E+09	7.61E+08	3,830
	3	530	0	0.639	0.0198	0.0018	5.03	8.76E+08	1.74E+07	87
	4	183	0.0013	0.323	0.0687	0.0046	5.03	3.11E+08	2.14E+07	107
	sum								2.58E+09	13,000
March 1998	all	2020	0	33.95	0.1228	1.156	5.32	4.64E+09	5.69E+08	3,030
	1	728	0	0.618	0.0203	0.0041	5.32	2.17E+09	4.40E+07	234
	2	634	0	0.878	0.0325	0.0069	5.32	1.25E+09	4.07E+07	216
	3	440	0	0.566	0.0459	0.0054	5.32	8.76E+08	4.02E+07	214
	4	218	0	33.95	0.8826	10.06	5.32	3.11E+08	2.74E+08	1,460
	sum								3.99E+08	2,130
June 1998	all	4163	0	143.0	2.8194	50.22	10.34	4.64E+09	1.31E+10	135,000
	1	1003	0	69.51	1.0734	6.999	10.34	9.01E+08	9.67E+08	10,000
	2	777	0	24.31	2.0290	8.259	10.34	1.45E+09	2.94E+09	30,400
	3	617	0	74.41	3.5667	30.01	10.34	9.01E+08	3.21E+09	33,200
	4	503	0	143.0	3.1067	93.67	10.34	3.68E+08	1.14E+09	11,800
	5	553	0	96.73	4.9612	151.8	10.34	4.49E+08	2.23E+09	23,000
	6	370	0	31.12	4.5151	32.94	10.34	4.01E+08	1.81E+09	18,700
	7	340	0	94.71	2.6661	78.46	10.34	1.65E+08	4.40E+08	4,550
	sum								1.27E+10	132,000
January 1997	all	2329	0	0.417	0.0162	0.0008	4.84	4.64E+09	7.50E+07	363
	1	761	0	0.111	0.0080	0.0002	4.84	1.02E+09	8.20E+06	40
	2	562	0	0.102	0.0205	0.0002	4.84	1.41E+09	2.89E+07	140
	3	412	0	0.178	0.0176	0.0006	4.84	1.21E+09	2.13E+07	103
	4	274	0	0.393	0.0233	0.0032	4.84	6.31E+08	1.47E+07	71
	5	320	0	0.417	0.0201	0.0011	4.84	3.62E+08	7.28E+06	35
	sum								8.03E+07	389

Table 3. Parameters and capelin biomass estimates for inner Placentia Bay.

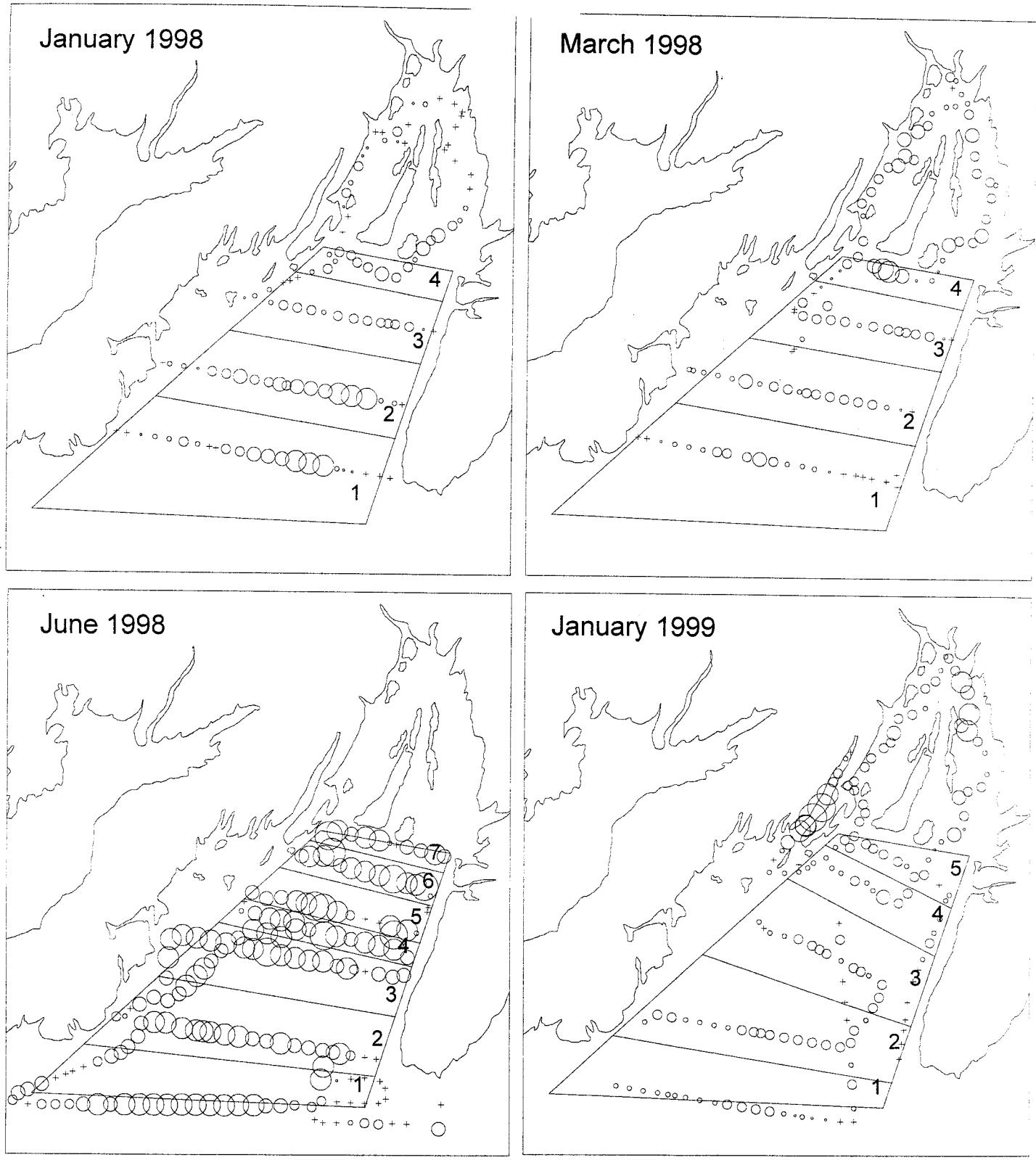
Survey	Transect block	No. of 100-m bins (n_i)	Min. capelin density	Max. capelin density	Mean capelin density	Variance capelin density	Mean capelin weight (g)	Transect area (m^2)	Number of capelin	Capelin biomass (tons)
January 1998	inner	1414	0	5.781	0.0133	0.0249	5.03	1.07E+09	1.43E+07	72
March 1998	inner	1469	0	7.999	0.0710	0.0768	5.32	1.07E+09	7.59E+07	404
January 1999	inner	1544	0	18.34	0.2313	1.492	4.84	1.07E+09	2.48E+08	1,200
	Paradise	688	0	31.57	4.5956	48.49	4.84	6.56E+07	3.01E+08	1,460

Figure Legends

Fig. 1. Expanding symbol plot showing capelin distribution in Placentia Bay during surveys in January, March and June 1998 and in January 1999. Acoustic data were averaged into 5-km segments for the purpose of display. '+' symbol indicates no capelin were detected in that segment. Circle sizes are proportional to $\log_{10}(\text{capelin density})$. The outer Bay region and transect blocks used for estimating biomass are indicated and numbered.

Fig. 2. Length frequency distributions of capelin sampled during acoustic surveys. The number of fish measured (n) is given. Capelin were measured to the nearest centimetre.

Fig. 3. Diel depth distribution of capelin observed during acoustic surveys. Relative position in the water column is a measure of the depth of peak capelin density standardised for water depth. A value of 1 indicates capelin were at the surface, while a value of 0 indicates capelin were close to the bottom. Hourly means and standard errors are shown as a function of Newfoundland Standard Time (GMT - 3.5h).

**Fig. 1.**

Capelin Density (fish/m ²)	
○	10 to 100
○	1 to 10
○	0.1 to 1
○	0.01 to 0.1
○	0.001 to 0.01
○	0 to 0.001

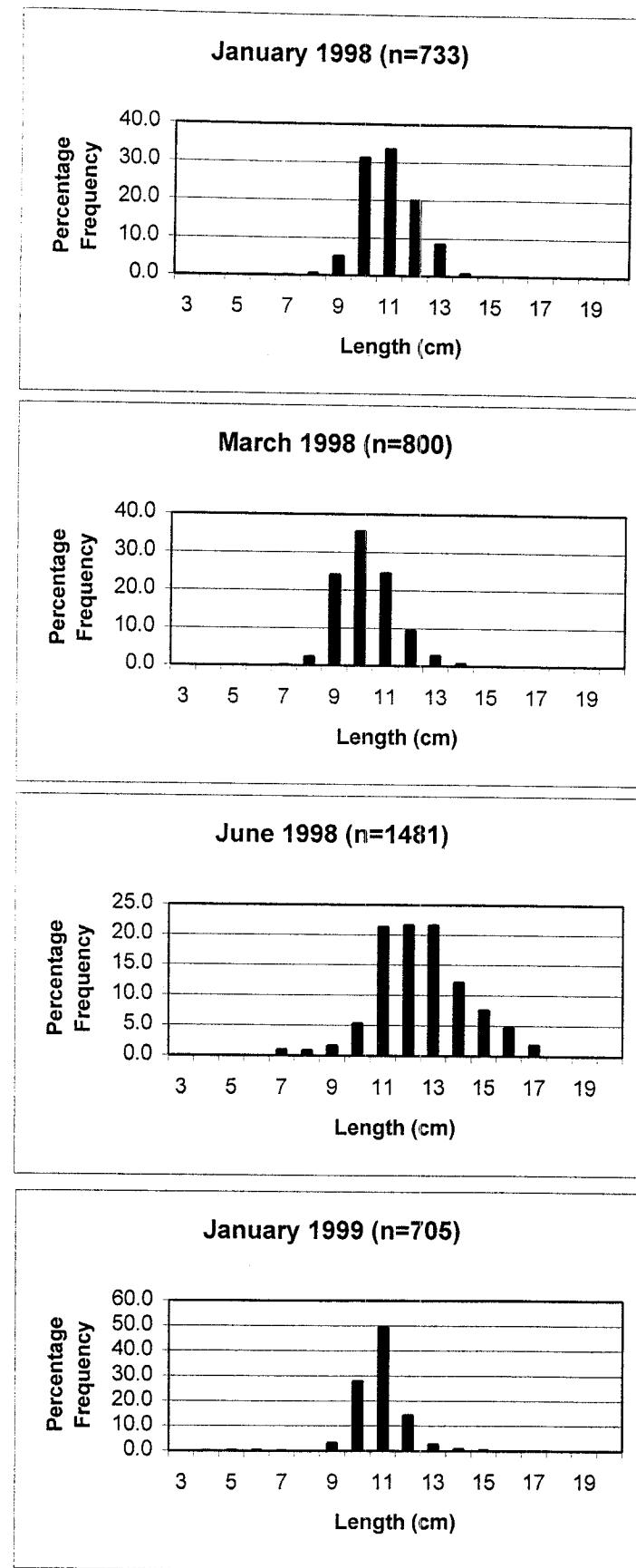


Fig. 2.

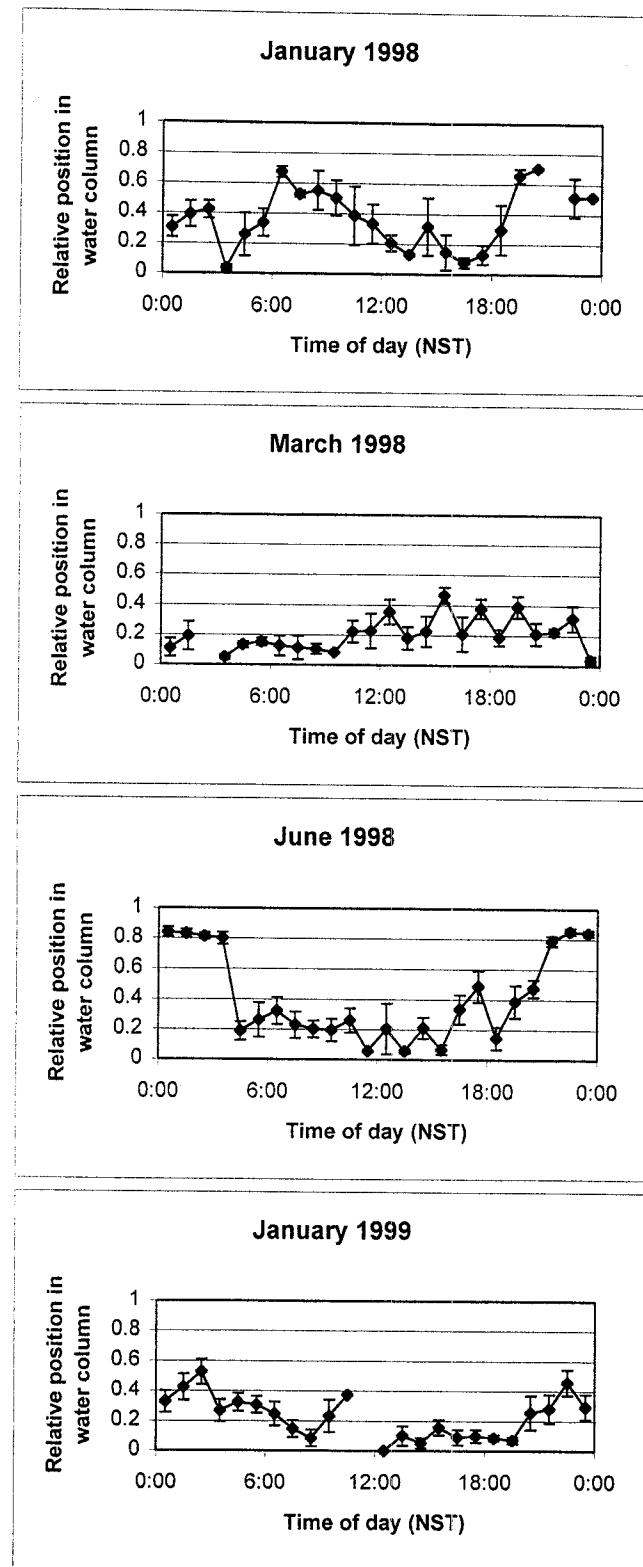


Fig. 3.