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DFO Atlantic Fisheries Research Document 95/70

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Capelin in SA2 + Div. 3KL

Science Branch
Department of Fisheries and Oceans
P. O. Box 5667
St. John's, NF A1C 5X1
Canada

[1]This series documents the scientific basis for the evaluation of fisheries resources in Atlantic Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the secretariat.

[1]La présente série documente les bases scientifiques des évaluations des ressources halieutiques sur la côte atlantique du Canada. Elle traite des problèmes courants selon les échéanciers dictés. Les documents qu'elle contient ne doivent pas être considérés comme des énoncés définitifs sur les sujets traités, mais plutôt comme des rapports d'étape sur les études en cours.

Les Documents de recherche sont publiés dans la langue officielle utilisée dans le manuscrit envoyé au secrétariat.

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Abstract

This document contains a number of discrete research results which were considered during a March 1995 assessment of capelin in SA2 + Div. 3KL. These results are arranged in fifteen chapters. In addition, a consensus meeting report, cross-referenced by chapter, is provided. The data available included the results of studies on inshore capelin, acoustic survey results, bycatches of capelin in groundfish surveys, predation studies, analyses of capelin distribution, lengths and ageing. Two alternate assessment techniques were also evaluated, one of which, the multiplicative model, formed the basis for the assessment.

Résumé

Le présent document contient des données discrètes de recherche qui ont été prises en considération durant une évaluation du capelan dans SA2 + div. 3KL réalisée en mars 1995. Les données en question sont organisées en quinze chapitres. Le document contient aussi un rapport consensuel de réunion à renvois par chapitre. Sont également présentés les résultats d'études sur le capelan côtier, les résultats de recherches acoustiques, des données sur les prises accidentelles de capelan dans les relevés de recherche sur le poisson de fond, des études sur la prédation ainsi que des analyses sur la distribution, la longueur et l'âge du capelan. On analyse aussi deux méthodes d'évaluation, dont l'une, appelée modèle multiplicatif, a servi à l'évaluation de mars.

Introduction

This document contains a number of discrete research results which were considered during a March 1995 assessment of capelin in SA2 + Div. 3KL. These results are arranged in fifteen chapters in this research document. In the past, each of these chapters would have formed a separate research document but beginning in 1994, all contributions were arranged into one research document with the aim of simplifying the extensive technical background to the assessment. In a further effort to provide a coherent presentation, a consensus meeting report, cross-referenced by chapter, is provided at the end of this document. A stock status report has been published elsewhere.

The data available for this assessment were extensive and varied. They included the results of studies on inshore capelin, acoustic survey results, bycatches of capelin in groundfish surveys, predation studies, analyses of capelin distribution, lengths and ageing. The last two chapters provide alternate types of assessments, one of which, the multiplicative model, formed the basis for the accepted assessment.

Results of a Telephone Survey of 1994 Fixed Gear Capelin License Holders

by

Brian S. Nakashima
Science Branch
Department of Fisheries and Oceans
P. O. Box 5667
St. John's, NF A1C 5X1

Introduction

A questionnaire was designed to quantitatively evaluate biological and fishery-related information obtained from capelin fishers in 1994. The survey was undertaken because concerns were expressed at a March 1994 capelin stock assessment meeting about the utility of qualitative information coming from comments made by some research logbook fishers. Questions were developed to supplement information collected by the research logbook and beach sampling programmes and to provide background data on the survey population of capelin fishers.

Methods

The survey population of 2159 was defined as all capelin fixed gear (traps and beach seines) fishers licensed to fish capelin in NAFO Div. 3Ps, 3L, and 3K in 1994. A list of names and telephone numbers was provided by the Resource Management Division, Fisheries and Habitat Management Branch, DFO. Employing a simple random sampling design and assuming an expected response rate of 75% a sample population of approximately 450 names was required to achieve a margin of error within ±5% at 95% confidence intervals (Gower and Kelly 1993). Questions relating to the fishery in 1994 were expected to have a low response rate due to low fishing effort requiring 128 responses to achieve ±10% margin of error. Because of time constraints the survey was conducted by telephone rather than as face-to-face interviews.

Earlier drafts were reviewed by Pelagic Section staff and by members of the MUN contact group chaired by L. Felt. A pretest was conducted by telephone in late January with eight fishers who are currently in the research logbook programme, for comments on the survey questions and overall intent of the survey. The questionnaire was revised as a result of their input with the final questionnaire as shown in Appendix A.

Telephone interviews commenced February 3, 1995 and were completed on March 19, 1995. As of February 28, 1995 responses were obtained from 204 fishers and four declined to participate in the survey. Interviewers were unable to contact 18 others despite five or more attempts to do so. Since the presentation of preliminary results at the regional assessment meeting on March 1-3, 1995 interviews continued until March 17, 1995 resulting in a final count of 371 responses received achieving a response rate of 82%. Of the 79 non-responses nine refused or were uncomfortable with participating and 70 could not be reached. Of the latter, 27 no longer had a telephone number as listed on the license, five had moved out of the province, and one was deceased.

Despite repeated attempts (maximum of five), interviewers were unsuccessful in reaching 33 license-holders in the sample population.

Results have been expressed in terms of final results (N) based on the 371 completed interviews and preliminary results (Np) from the first 204 completed interviews. The latter was provided because only this information was tabled at the assessment meeting. In general survey trends did not vary between the preliminary and final results.

Results and Discussion

Abundance Questions

Three questions (Appendix A) comparing abundance of capelin in 1994 to previous years were asked in the survey. Response rate of the preliminary (Np=204) and final results (N=371) were consistent and suggested low abundance in 1994. Over 50% of respondents in answering question 1 (Appendix A) ranked 1994 abundance on the lowest scale of '1' and 75% at '3' or less (Fig. 1a). Over 60% in answering question 2 (Appendix A) felt that capelin in 1994 were only half or less than half as abundant as in 1993 (Fig. 1b). When given three options in question 3 (Appendix A) respondents overwhelmingly indicated that capelin abundance in 1994 was lower than when they had first started to fish capelin (Fig. 1c).

Spawning Questions

Respondents of questions 4-13 (Appendix A) related to spawning generally indicated that spawning on beaches was lower in 1994 than in previous years, that spawning continued to be later than 'normal', and that spawning in deeper water away from beaches was more noticeable in 1994 than in other years. In general there are 1-10 spawning beaches near 70% of the respondents (Fig. 2a), however that percentage declined to 47% in 1994 with most reporting spawning on 1-5 beaches (Fig. 2b). There was also a substantial number of areas where no beach spawning was observed in 1994 (Fig. 2b). Questions 6 and 7 were answered by only those who had observed beach spawning in 1994 resulting in 115 preliminary and 184 final responses. Capelin spawned on more beaches in 1993 than in 1994 (Fig. 3). Not only were the number of spawning beaches reduced in 1994 the intensity of spawning was also very low. Over 70% of respondents indicated that spawning intensity was '3' or less on an increasing intensity scale of '1' to '10' in 1994 (Fig. 4). Spawning intensity in 1994 compared to 1993 was generally lower but over 30% thought it was the same or higher (Fig. 5). These results support the lower estimates of egg density at the six spawning beaches surveyed on the northeast coast in 1994 (Nakashima and Winters 1995).

There was evidence for capelin exhibiting off beach spawning behaviour in deeper water in 1994. In asking question 8 about spawning in deeper water 36% (Np=34%) didn't know, 18% (Np=17%) said 'no', and 46% (Np=49%) said 'yes'. In comparison to the perceived norm (Fig. 6) there appears to have been an increase in the incidence of capelin spawning off beaches in 1994. Question 9 (Appendix A) was asked of the 172 (Np=100) persons who responded in the affirmative to question 8 to explore reasons why capelin may not have spawned on beaches and spawned elsewhere in 1994. The majority suggested water temperatures (N=56%, Np=57%) as a likely possibility. Other possibilities were the presence of predators (N=5%, Np=8%), unsuitable beach habitat (N=4%, Np=5%), capelin only found offshore (N=4%, Np=2%), no 'capelin' weather in 1994 (N=2%, Np=1%), and low capelin abundance (N=1%, Np=2%). Approximately 28% (Np=25%) who indicated off beach spawning had occurred in 1994 could offer no reason why this may have occurred.

Spawning times were delayed compared to the 1980s and are similar to late spawnings experienced since 1991. Of those answering question 11a who recalled when spawning began in 1994 the majority suggested late June to late July (Fig. 7) with most responses from mid to late July. Comparing the start of the spawning season in 1993 to 1994 in question 11b most respondents who expressed a time indicated that it was the same in both years (Table 1). A lower percentage thought 1993 was earlier or later than 1994. There was a large percentage of non-responses. When asked to indicate the end of the 1994 spawning season the number of non-responses to question 12a was higher (Fig. 8) than for the start of the season (Fig. 7). The results suggest that spawning in 1994 ended between mid July and mid August (Fig. 8). Answers to question 12b suggested that the end of spawning was similar in 1993 and 1994 for 25% (Table 1). Approximately 15% thought spawning was later in 1993 and 10% thought it was earlier than in 1994. Over 50% were unable to estimate a time. Compared to when fishers started fishing capelin there was general agreement that spawning in 1994 has been later (question 13, Table 1). Nakashima and Winters (1995) have observed late spawning times on the northeast coast comparable to the ranges reported in this survey. The results continue a trend of delayed spawning seasons in the 1990s (Nakashima 1994).

Questions on the Fishery

Almost all licensed respondents intended to fish capelin in 1994 (question 14a: N=96%,Np=95%), however less than 45% (Np=59%) set traps or bothered to search (question 14b). Of the 168 (Np=120) who were asked question 15a 81% (Np=77%) fished only capelin traps, 5% (Np=4%) fished beach seines, and 14% (Np=19%) fished both traps and seines. Of the 156 (Np=111) trap fishers 49% (Np=42%) set one trap, 44% (Np=51%) set two, and 6% (Np=7%) tended more than two. Question 15c concerning the capacity of traps to hold capelin was answered poorly and could not be evaluated for this report. Most (N=85%, Np=86%) fishers had always fished the same gear type, however the 15% (Np=14%) who had changed went from beach seines to traps except one who converted from a trap to a beach seine. The dominance of traps as the fixed gear of choice in the survey population was also evident in the research logbook survey and in the proportion of fixed gear commercial landings attributed to traps and beach seines (Nakashima 1995).

About 75% of fishers (N=168, Np=120) intending to fish did not have any landings in 1994 (question 16) and very few reported landings greater than 20,000 lbs (Fig. 9). This reflected a very poor fishery in 1994 as reported in research logbooks and was obvious from the provisional low landings (Nakashima 1995). Discards were low for most fishers because the majority did not fish in 1994. Approximately 5% (Np=6%) reported discards in excess of 100,000 lbs (question 17, Fig. 10). The returns from the research logbook survey indicated that very few actually fished in 1994 and that for those who did discarding was high (Nakashima 1995). Research logbook fishers reported 100 % survival of discards in 1994 (Nakashima 1995). Of the 54 (Np=32) fishers reporting discards in the questionnaire survey 82% (Np=88%) responding to question 18 reported over 90% survival of capelin released (Fig. 11). Reasons provided for discarding in question 19 were small females (N=65%, Np=51%), fishery closures (N=8%, Np=10%), monitoring (N=8%, Np=7%), combination of two or more of the previous four reasons (N=10%, Np=17%), and redfeed (N=2%). The remainder who reported discards did not cite specific reasons for discarding capelin. Based on a few returned research logbooks catches of small females were the predominant reasons for discarding capelin in 1994 (Nakashima 1995). Fishers overwhelmingly indicated that the amounts discarded in 1994 were less than in 1993 (question 20a: N=61%, Np=75%) and less than other years fished (question 20b: N=75%, Np=89%). This is not surprising because many fishers did not catch any capelin in 1994 resulting in no discards.

Many fishers did not fish as mentioned earlier resulting in 72% (Np=74%) of 168 (Np=120) surveyed reporting no bycatch in 1994 (question 21). In response to question 22 asked of the 28% (N=47) who had bycatches there were 33 reports of cod, 9 of tomcod, 9 of salmon, 9 of herring, 6 of squid, 3 of mackerel, 2 of flounder, and 2 of lumpfish. In most cases fishers reported catching more than one bycatch species. Estimates of the amount of bycatch were unavailable. The condition of the bycatch was 92% (Np=94%) alive, 4% (Np=0%) dead, and 4% (Np=6%) mixture of live and dead (question 23). We asked question 24 (Appendix A) to fishers who reported bycatches of cod or tomcod in 1994. Over half thought their bycatches had no effect on cod populations while 16% felt the effects were significant or very significant (Fig. 12). Specific answers as to why a particular response was given when answering question 24 were few. From the reactions to questions 24 and 25 it was clear that these questions will have to be reworded for future surveys.

Questions on Climate and Ocean Conditions

The entire survey population of 371 (Np=204) was asked questions 26 and 27 (Appendix A) pertaining to general weather and ocean conditions during the summer of 1994. For question 26 most respondents tended to classify the weather into poor, average/fair, or good/perfect rather than using the three suggested categories posed by the interviewer. Consequently 92% (Np=91%) reported good/perfect weather in 1994 compared to 2% (Np=2%) who experienced bad weather and 6% (Np=7%) said fair conditions. Respondents were asked specifically to classify ocean conditions. The responses were similar to what one would expect with good weather conditions. Generally most reported no ice (N=89%, Np=99%) and none or few storms (N=Np=97%). A majority noted water temperatures were warm (N=57%, Np=55%) while 21% (Np=19%) said temperatures were cold. Almost one quarter could not recall relative water temperatures. No ice, few storms, and warm water are indicative of favourable weather throughout the south and northeast coasts. The contrast between cold and warm water along the coast may be related to where respondents live. Nakashima and Winters (unpublished data) noted that beaches such as Bellevue and Hampden experienced cooler (<5C) water temperatures into late July in 1994, whereas water temperatures near other beaches at Arnolds Cove, Chapel Cove, Eastport, Cape Freels, and Twillingate were much warmer (>8C) by late June to early July.

Characteristics of Survey Population

All respondents were asked questions 28-31 to help characterize the survey population of fixed gear fishers and to be able to relate in a subsequent analyses responses to areas fished and experience in the fishery. The distribution of responses to question 28 indicates that 30% began fishing capelin in the late 1970s when the Japanese roe fishery started (Fig. 13a), more entered from 1984 to 1989, and very few began in the 1990s. Most fishers are in the age 40-55 range followed by the 25-39 range (Fig. 13b). Fishing vessel lengths varied from 17-52 feet with the majority less than 35 feet (Fig. 14a). Estimated vessel capacity for capelin was less than 18,597 kg (41,000 lbs) for most fishing vessels used in the fixed gear capelin fishery (Fig. 14b). Responses were distributed along the south and northeast coasts with the highest number from Notre Dame Bay (Fig. 14c).

Summary

Results from the telephone survey of fixed gear capelin fishers support many of the observations made from beach spawning and research logbook programmes. In 1994 capelin spawned later than in the 1980s, spawned on fewer beaches at a low intensity, and spawned subtidally away from beaches more so than in previous years. Most licensed fishers intended to fish in 1994 but many did not due mainly to monitored areas remaining closed because of small fish. The weather was generally considered favourable for being out on the water and water temperatures were considered warm. Overall respondents felt capelin abundance was low in 1994 and lower than in previous years. The reported results of the telephone survey for most questions were considered accurate for the survey population within ±5% to ±10%, 19 times out of 20 depending on the number of responses. For questions 18,19,22, 23, and 24 the number of responses was too low to fall within acceptable levels of error.

A variety of comments were provided by ⅔ of respondents at the end of the interview (Table 2). The most frequent comment was to close the capelin fishery, however, it was uncertain whether this referred to 1994, 1995 or all years. Future surveys can incorporate specific questions to resolve the nature and extent of the comments provided. The quality of responses can be improved by rewording questions which were poorly understood and by conducting the survey soon after the capelin fishery is closed.

Acknowledgements

The development of the questionnaire benefited greatly from suggestions by J. Carscadden, B. Slaney, B. Neis, A.-M. Powers, the MUN contact group chaired by L. Felt, and by several fishers. A. Murphy, L. Chafe, and J. Mitchell conducted the telephone interviews. I am also indebted to D. Lawrence of Statistics Canada for advice.

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Nakashima, B. S. 1995. The inshore capelin (Mallotus villosus) fishery in NAFO Div. 3KL in 1994. DFO Atl. Fish. Res. 95/ .

Nakashima, B. S., and G. H. Winters. 1995. Results from monitoring six spawning beaches on the northeast coast of Newfoundland. DFO Atl. Fish. Res. 95/ .

Table 1. Responses to survey questions 11b, 12b, and 13. Prelimlinary (N_p) results are based on 204 responses and final (N) results are from 371 responses.

Question No.	Response (%)							
	Later		Same		Earlier		No answer	
	N	N_p	N	N_p	N	N_p	N	N_p
11b	10.0	10.3	28.0	35.8	12.9	13.2	49.1	40.7
12b	13.5	14.7	23.2	29.9	8.6	7.4	54.7	48.0
13	67.7	76.0	5.1	5.9	3.0	5.4	24.2	12.7

Table 2. Summary of comments in response to survey question 34. Miscellaneous comments are unrelated to any of the comments listed.

Comment	N = 371	Np = 204
Close capelin fishery	34.5	31.4
Capelin declining/gone	4.6	0
Capelin small	4.3	2.9
More monitoring/improve quota management	4.3	4.9
Seals eating capelin/increase hunt	4.0	7.4
Keep capelin fishery open	3.0	3.4
Seiners/trawlers destroying capelin	1.6	2.0
Water temperatures affect abundance	1.4	1.0
Comments on the questionnaire	3.5	4.4
Miscellaneous comments	5.9	2.5
No comments expressed	37.2	40.1

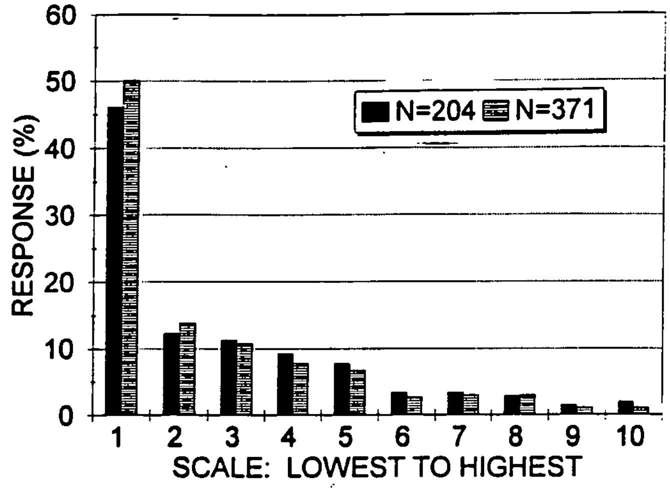

Fig. 1a. Response to question 1 on the abundance of capelin in 1994.

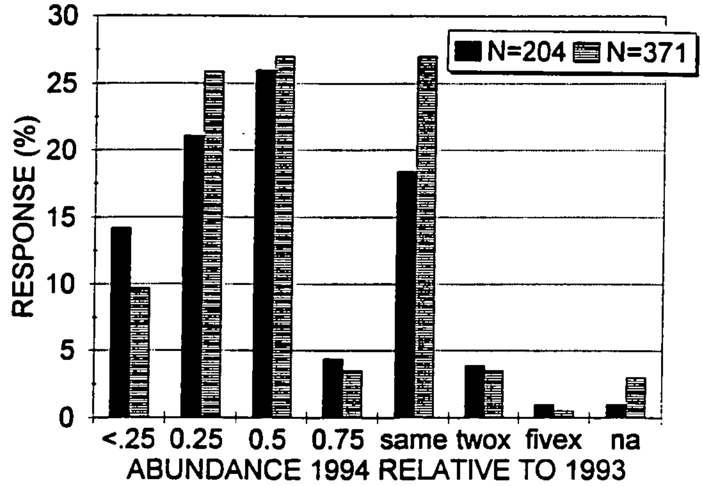

Fig. 1b. Response to question 2 on the abundance of capelin in 1994 compared to 1993. Not able to answer (na).

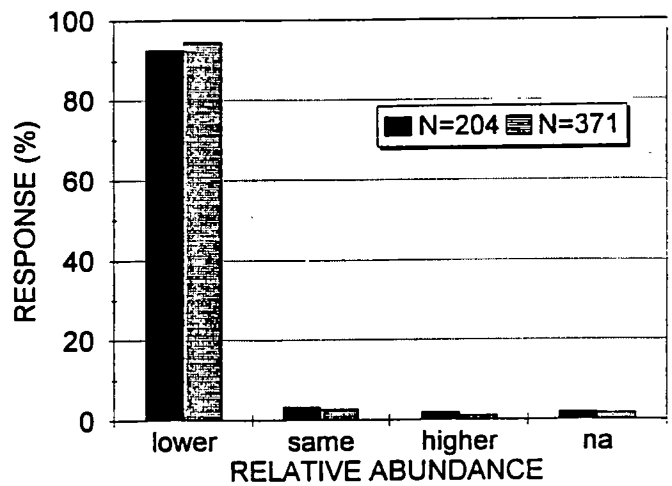

Fig. 1c. Response to question 3 concerning abundance in 1994 compared to first started fishing capelin. Not able to answer (na).

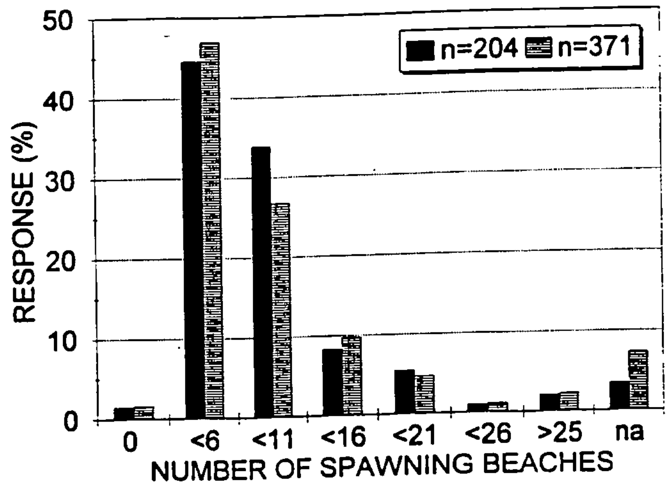

Fig. 2a. Response to question 4 concerning the number of capelin spawning beaches. No answer given (a).

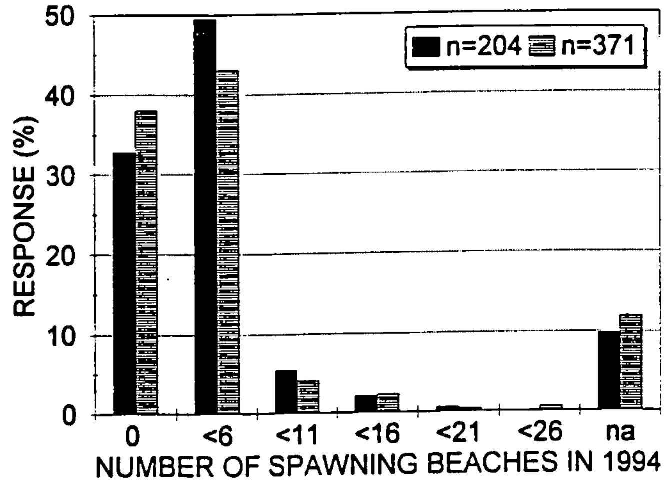

Fig. 2b. Response to question 5 concerning the number of capelin spawning beaches in 1994. No answer given (na).

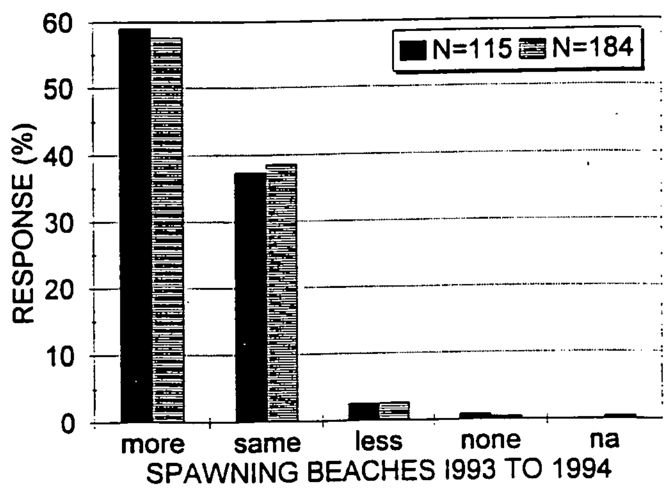

Fig. 3. The difference in the number of beaches where capelin spawned in 1993 compared to 1994 for question 6. No answer given (na).

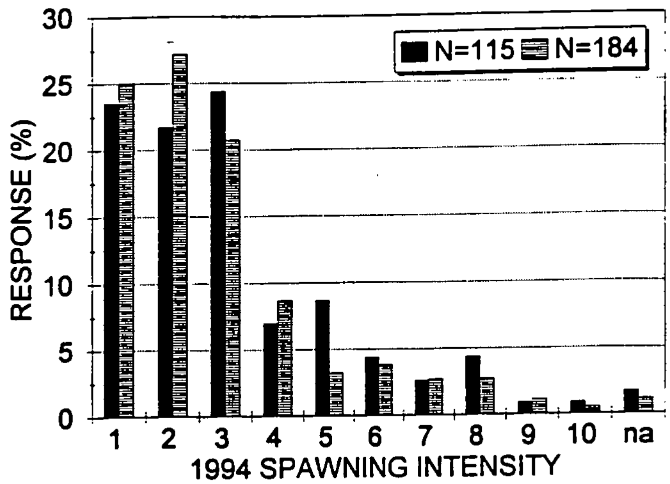

Fig. 4. Responses to question 7a describing the intensity of spawning in 1994 on an increasing scale of 1 to 10. No answer given (na).

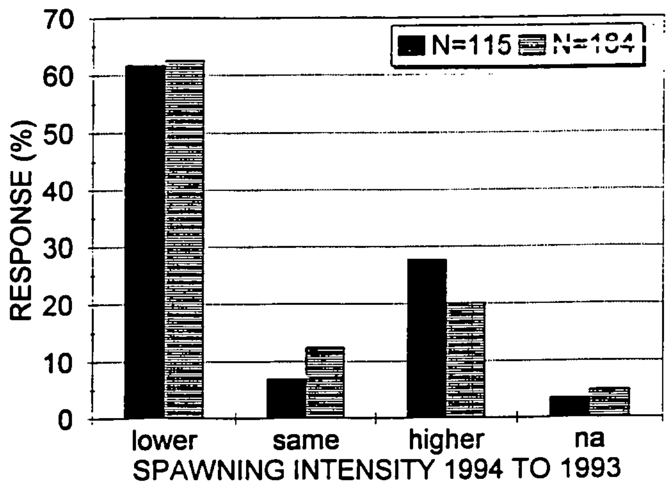

Fig. 5. Response to question 7b comparing the spawning intensity in 1994 relative to 1993. No answer given (na).

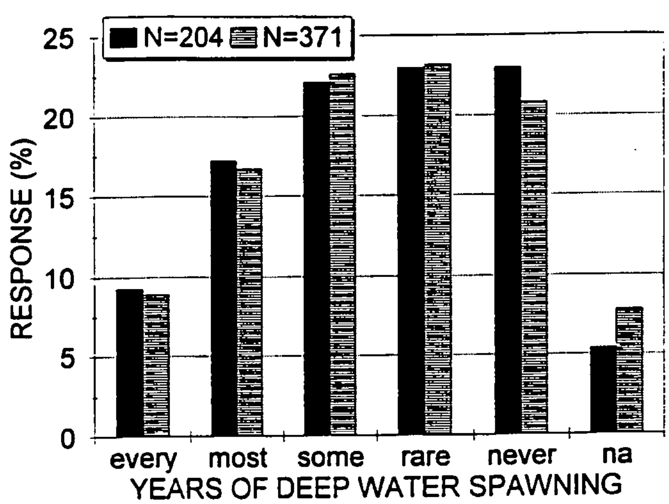

Fig. 6. General observations on the frequency of subtidal and deep water spawning for question 10. No answer given or unknown (na).

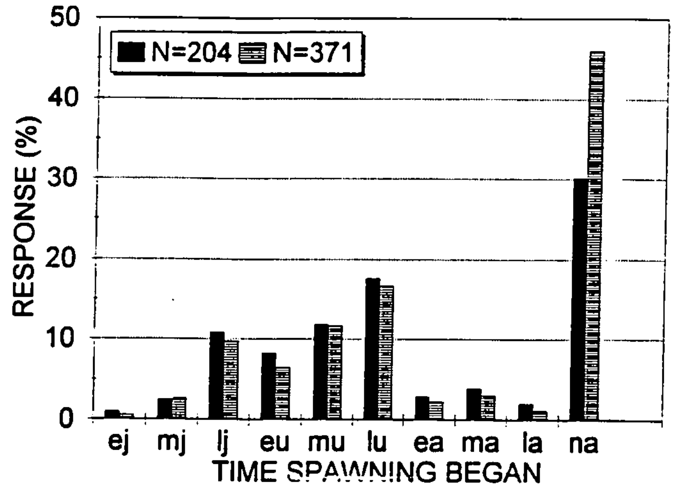

Fig. 7. Range of times when spawning began in 1994. Symbols in the x-axis are early June = ej, mid June = mj, late June = lj, early July = eu, mid July = mu, late July = lu, early August = ea, mid August = ma, late August = la, and unknown = na.

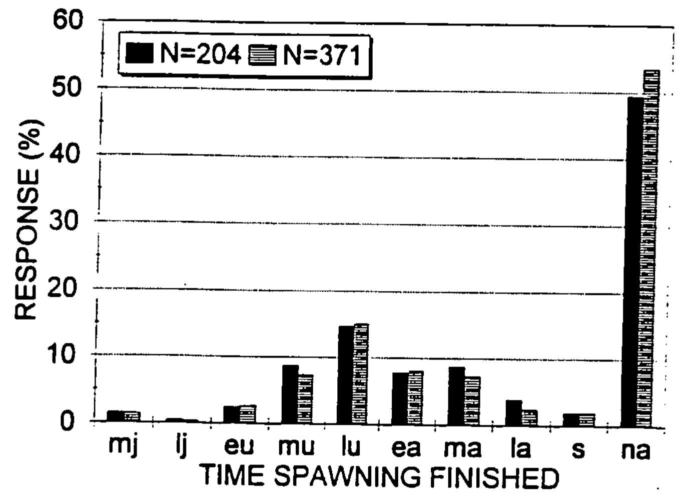

Fig. 8. Range of times when spawning ceased in 1994. Symbols are early June = ej, mid June = mj, late June = lj, early July = eu, mid July = mu, late July = lu,early August = ea, mid August = ma, late August = la, September = s, and unknown = na.

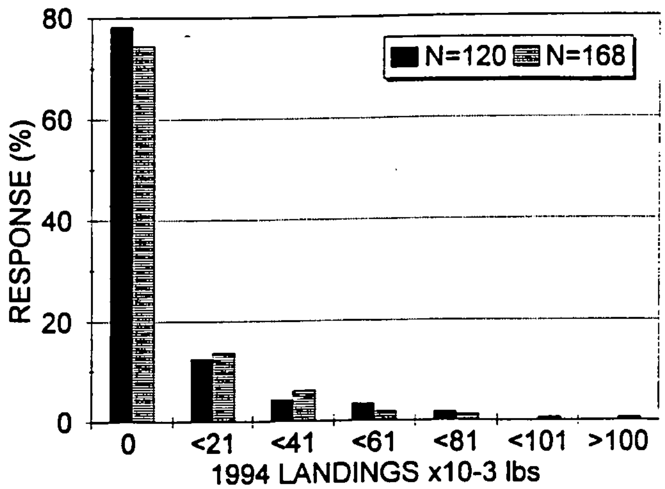

Fig. 9. Estimated landings by respondents to question 16 in 1994.

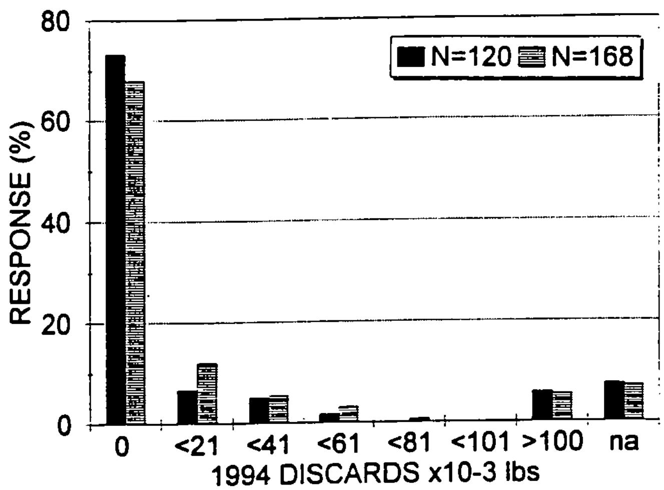

Fig. 10. Estimated discards by respondents to question 17 in 1994.
No estimate available (na).

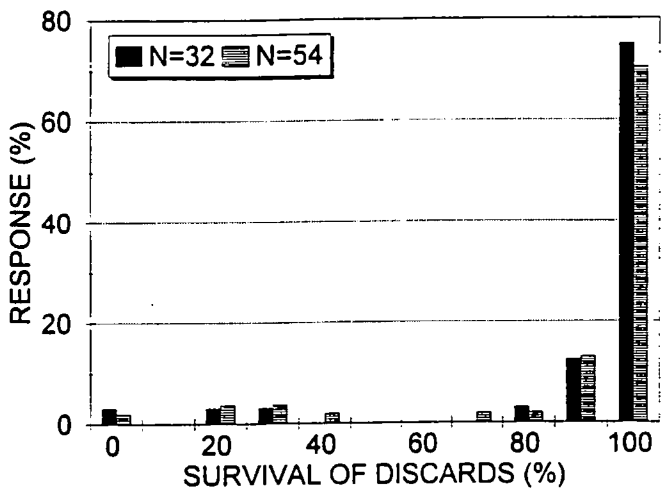

Fig. 11. Percent survival of discarded capelin in 1994.

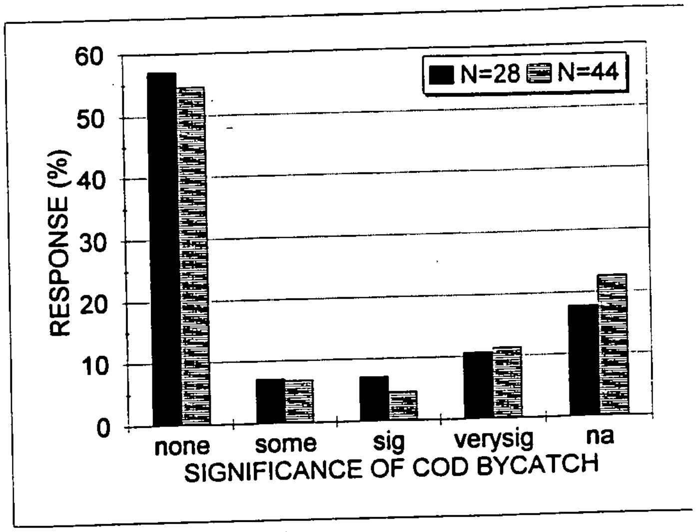

Fig. 12. The effect of small cod bycatch on cod populations in 1994.
No answer given (na).

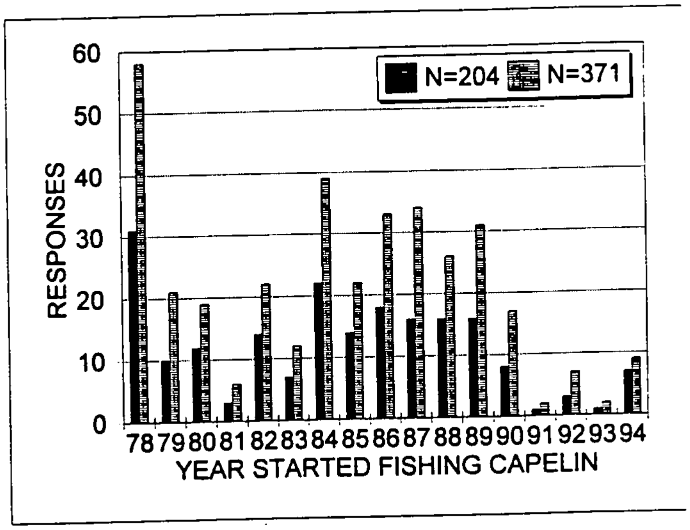

Fig. 13a. Distribution of year started fishing capelin (question 28).

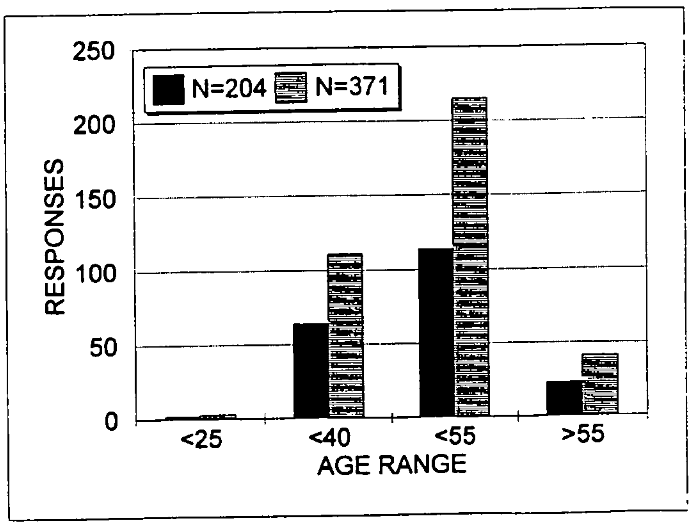

Fig. 13b. Age range of capelin fishers (question 31).

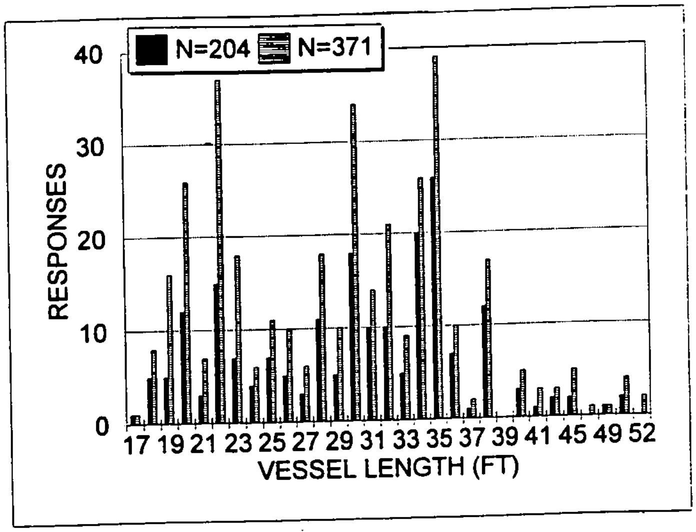

Fig. 14a. Distribution of vessel lengths involved in the fixed gear capelin fishery (question 29).

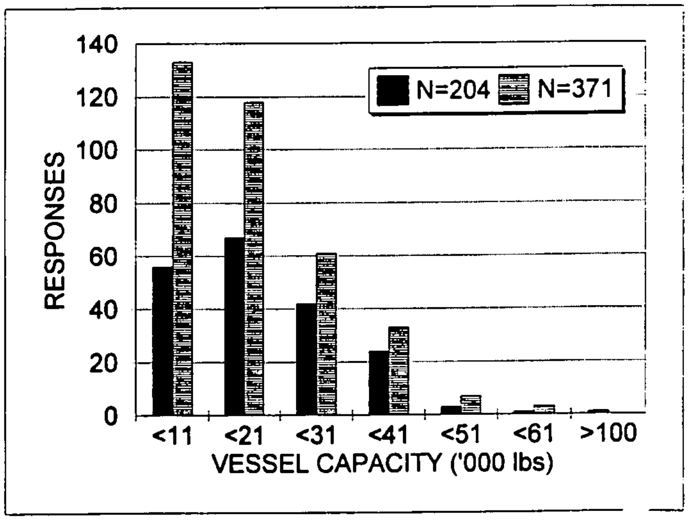

Fig. 14b. Distribution of estimated vessel capacity for capelin (question 29).

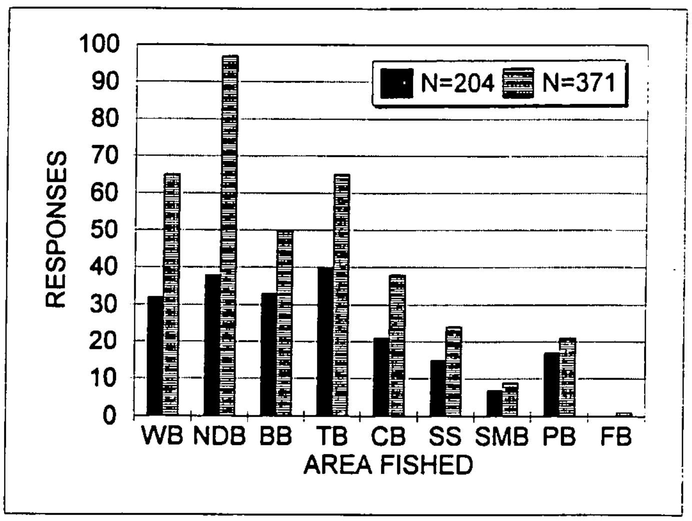

Fig. 14c. Distribution of area fished by survey respondents (WB = White Bay, NDB = Notre Dame Bay, BB = Bonavista Bay, TB = Trinity Bay, CB = Conception Bay, SS = Southern Shore, SMB = Trepassey and St. Mary's Bay, PB = Placentia Bay, FB = Fortune Bay).

Appendix A

SURVEY QUESTIONNAIRE OF FIXED GEAR CAPELIN FISHERS

Questions on Abundance.

1. Using a scale of 1 to 10 with 1 being the lowest and 10 the highest how abundant (ie numbers of fish) were capelin in your area in 1994?
Ans: 1 2 3 4 5 6 7 8 9 10

2. How abundant were capelin in 1994 compared to 1993?
Ans: 1/4 1/2 same 2X 5X ________ don't know

3. How would you describe the abundance of capelin compared to when you first started fishing capelin?
Ans: lower the same higher don't know

Questions on Spawning.

4. Approximately on how many beaches in your area do capelin usually spawn?
Ans: none ________________ don't know

5. Approximately on how many beaches did capelin spawn in 1994?
Ans: none ________________ don't know

If 'none' or 'don't know' go to Ques. 8

6. Compared to 1994 how many beaches did capelin spawn on in 1993?
Ans: more same less none don't know

7a. On a scale of 1 to 10 with 1 being low and 10 being high how intense was capelin spawning in your area in 1994?
Ans. 1 2 3 4 5 6 7 8 9 10

7b. What was the intensity of capelin spawning in 1994 compared to 1993?
Ans: lower same higher don't know

8. Did capelin spawn off beaches in your area in deeper water?
Ans: yes no don't know

If yes go to Ques. 9
If 'no' or 'don't know' go to Ques. 10
If no spawning on beaches or in deep water go to Ques. 14

9. Why do you think capelin spawned in deeper water in 1994?
Ans:

Appendix A - Continued

10. How often since you started fishing have you observed capelin spawning off beaches in deeper water?
Ans: every yr most yrs some times rarely never

11a. When did capelin first spawn in 1994?
Ans:

11b. Did spawning start at the same time in 1993 as in 1994?
Ans. later same earlier don't know

12a. When did capelin finish spawning in 1994?
Ans:

12b. Did spawning finish at the same time in 1993 as in 1994?
Ans: later same earlier don't know

13. How does the timing of capelin spawning (beginning and end) in 1994 compare to when you first started fishing capelin?
Ans: later same earlier don't know

Questions on Fishery Data.

14. Did you intend to fish for capelin in 1994?
Ans: Yes No

If 'yes' continue if 'no' go to Ques. 26

14b. Did you set your fishing gear or go out and search for capelin in 1994?
Ans. Yes No

If 'yes' continue if 'no' go to Ques. 26

15a. What type of fishing gear did you use in 1994?
Ans: trap beach/bar seine purse seine

If a 'trap' go to Ques. 15b if other gear types go to Ques. 15d

15b. How many traps did you fish in 1994?
Ans: one two more than two

15c. How much capelin does your trap(s) hold (ie maximum amount)?
Ans.

15d. Did you always fish this gear type or have you fished other types in the past?
If fished other types what were they?

Ans:

16. Approximately how much capelin did you and your crew land in 1994?
Ans: lbs

17. Approximately how much capelin (live or dead) did you and your crew discard (ie did not land or sell) in 1994?
Ans: lbs

If discarding >0 continue if discarding is '0' go to Ques. 21

18. What percent of the discarded capelin do you think survived?
Ans: 0 10 20 30 40 50 60 70 80 90 100

19. Why were the capelin discarded? Please give reasons in order of importance.
Ans:

20a. How does the amount you discarded in 1994 compare to 1993?
Ans: less same more don't know

20b. How does the amount discarded in 1994 compare to all the other years you've fished capelin?
Ans: less same more don't know

21. While fishing capelin did you and your crew catch any other species (ie bycatch)?
Ans: yes no

If 'yes' continue if 'no' go to Ques. 26

22. What species were they and approximately how many of each?
Ans:

23. What was the condition of the bycatch when released?
Ans: alive some dead/some alive dead

24. How much of an effect do you think your bycatch of small cod (less than 17") in 1994 had on cod populations in your area?
Ans: none some significant very significant don't know

25. Why?
Ans.

Questions on Climate/Ocean Conditions.

26. Weather plays an important role in the biology of capelin. While overall weather patterns are similar over the entire island there are instances when local conditions may be different from average conditions. Please describe the weather in your area during the summer (June to early Sept) of 1994.
Ans: Winds:
Air Temperature:
Sun-Overcast:

27. Similar to the weather, ocean conditions can sometimes vary between areas. Please describe the general ocean conditions in your area during the summer (June to early Sept) in 1994.
Ans: Ice:
Stormy:
Water Temperature:

General Information

28. In what year did you start fishing capelin?
Ans:

29. What is the length and capacity (how much capelin) of your vessel?
Ans:

30a. Have you always fished for capelin in the same location?
Ans: Yes No

If 'no' continue if 'yes' go to Ques. 31

30b. Where else have you fished capelin?
Ans.

31. How old are you?
Ans: less than 25 25-39 40-55 over 55

32. Do you wish to receive a summary of the results of this survey when the analyses are completed?
Ans: yes no

33. If there is a capelin fishery in 1995 would you consider keeping a diary of your fishing activities in a capelin research logbook if asked?
Ans: yes no

34. Thank you for your patience and your time. Are there any comments you wish to make on the questionnaire or in general?
Ans:

The Inshore Capelin (Mallotus villosus) Fishery in NAFO Div. 3KL in 1994

by

Brian S. Nakashima
Science Branch
Department of Fisheries and Oceans
P. O. Box 5667
St. John's, NF A1C 5X1

Introduction

Reported landings in 1994 were 938 t in Div. 2J3KL compared to a market-based quota allocation of 32,280 t. Landings were the lowest in the series (Table 1). A summary of the 1994 commercial capelin roe fishery, the age composition of the catch, trends in mean lengths and weights, and the information compiled in research logbooks given to commercial fishers is presented.

Materials and methods

Commercial samples were collected by fishers and at fish plants by reliable collectors at the rate of two samples per gear type per week per statistical section (Fig. 1). From each sample, length, sex, and maturity stage were measured on 200 fish and a stratified sample of 2 otoliths per sex per 1/2 cm length was taken for ageing.

Research logbooks were mailed to 44 purse seine and 133 fixed gear licensed fishers residing in Div. 3KL. Of these four purse seine and nine fixed gear logbooks have been returned to date. Twenty-five purse seiners and 90 fixed gear fishers in the programme did not fish in 1994. Information was not available for 15 purse seiners and 34 fixed gear fishers. The records of five fishers who fished traps and three with purse seine were used in this analysis. Records from beach seines were not presented in this report.

Fishing effort was estimated from research logbook records for both purse seines and capelin traps. Fishing days for purse seines are defined as those days when the vessel was out searching for capelin schools. Similarly fishing days for traps were defined as those days (24-hour basis) when the trap was fishing. In 1994, two trap fishers fished one trap each and three fishers fished two traps per trap crew. Trap logbook records were only available from the Southern Shore and St. Mary's Bay areas in 1994.

Mean lengths and weights for Div. 3K and 3L were estimated from commercial samples for each gear type and combined weighted by landings.

Results and discussion

<u>The Inshore Fishery</u>

The inshore fishery in Div. 3KL is prosecuted by purse seines, capelin traps, and beach seines and has been regulated by quota management since 1982. Quotas by area and gear type are presented in Appendix A. Opening and closing dates varied considerably in 1994 (Appendix B). Monitoring programs in most areas were set up to close and reopen areas to fulfill market demands. Small fish (50 females/kg) was the main reason areas were never opened or opened for brief periods (Appendix B). Area and gear sector allocations were not reached in 1994.

Age Composition of the Commercial Catch

In 1994 11 biological samples were processed from commercial catches throughout Div. 3KL (Table 2). The mean number of otolith pairs per sample was less in Div. 3K than in Div. 3L (Table 2).

The 1994 catch in numbers was dominated by the 1991 year-class as three-year-olds (46.3%) followed by the 1992 year-class as two-year-olds (31.1%) and the 1990 year-class as four-year-olds (19.7%) (Table 3). Some interesting patterns arise. The 1991 year-class was suspected to be poor due to poor larval emergence patterns and appears to be as three-year-olds despite the high proportion of mature two-year-olds in 1993 (Nakashima and Winters 1995).

Mean Lengths and Weights in Div. 3K and Div. 3L

In Div. 3K (Fig. 3) there is no apparent trend in mean length at age 2. For ages 3 and 4 and all ages combined, there has been a general decline in the mean length from 1991-93 followed by an increase in 1994 especially evident at age 3.

The mean lengths-at-age in Div. 3L during 1981 were small (Fig. 4). For age 2, the 1982-90 mean lengths did not vary much or exhibit any trends then declined slightly during 1991-93 with an increase in 1994. For ages 3 and 4, mean lengths showed only small variations between 1982 and 1988 but have shown a gradual decline since then. For all ages combined, the decline seemed more severe during 1991 and 1992 with an apparent increase in 1994.

The interpretation of the estimated lengths-at-age in 1994 must be considered with care due to the very small sample sizes involved and the limited spatial and temporal distribution of the samples.

Age 2 females have contributed more to the spawning stock than age 2 males especially since 1991 (Table 3). In most years, Div. 3L two-year-old females were smaller than Div. 3K females. This was true since 1991 when age 2 fish made a significant contribution to the spawning stock and contributed to the decline in overall mean size (all ages combined) of females in the population. Females in Div. 3L at age 3 were only slightly smaller than females at the same age in Div. 3K except in 1992 when the difference was larger. At age 4, females in Div. 3L and 3K were approximately the same length until 1993 when Div. 3L females were smaller than in Div. 3K.

The sample mean weights from the inshore fishery are given in Table 4. For Div. 3K the sample mean weights-at-age are only available since 1984.

Research Logbook Survey

The predominant reasons reported by fishers for discarding capelin in 1994 were small females with redfeed also important to traps in St. Mary's Bay (Table 5).

Discarding as a percentage of landings for traps in 1994 in Div. 3L was 67% of the Southern Shore and 293% in St. Mary's Bay (Table 6). For purse seines most of the catch was let go (Table 7). Discarding rate was the highest since 1981 when estimates were available for traps (Table 8) and for purse seines (Table 9). According to information provided in the research logbooks 99% of trap and 100% of purse seine discards were released alive at sea. In the analyses presented in Tables 6-9 discards are defined as all capelin caught but not landed by the fishers who caught them and includes both live and dead fish. The amount of reported discarding in 1994 was low because catches and fishing effort were negligible.

The average fishing effort in 1994 decreased for traps and for purse seiners in 1994. Traps averaged 7.5 fishing days and were hauled 9.8 times in 1994 compared to 5.1 days and 11.1 hauls per trap in 1993 (Table 8). Purse seiners had 2.7 searching days and made 13 sets per vessel in 1994 compared to 8.0 searching days and 13.9 sets in 1993 (Table 9).

Catch/effort (CPUE) estimates were available since 1981 for capelin traps and for purse seines (Tables 8 and 9). All catch rates are very low in 1994 except for the catch/set for purse seines. The 1994 CPUEs are not comparable to previous years and may not be indicative of stock status due to low numbers of completed research logbooks and responses limited to a very small portion of the island. Trap catch rates in 1994 could not be analyzed as suggested by Winters (1994).

Conclusions

Because many areas were closed to fishing and others only opened for short periods of time, the interpretation of the 1994 commercial fishery data (commercial samples and research logbooks) must be considered anomalous. These circumstances emphasize the value of having fishery independent evaluations of stock status.

Acknowledgements

We especially are grateful to the fishers who have diligently reported their fishing activities in our research logbooks. The inshore commercial sampling programme was organized by

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Table 1. Inshore capelin landings (t) by fishing gear (vessels <21 m in length) by area (White Bay = WB, Notre Dame Bay = NDB, Bonavista Bay = BB, Trinity Bay = TB, Conception Bay = CB, Southern Shore = SS, St. Mary's and Trepassey Bays = SMB) and by NAFO Div.

Year	Div.	Area	Purse seine	Beach seine	Trap	Total
1985	2J		**0**	**1**	**0**	**1**
		WB	1114	16	1541	2671
		NDB	2834	819	1044	4697
	3K		**3948**	**835**	**2585**	**7368**
		BB	2286	115	1593	3994
		TB	1624	545	6816	8985
		CB	3649	211	6804	10664
		SS	33	9	348	390
		SMB	1284	12	121	1417
	3L		**8876**	**892**	**15682**	**25450**
1986	2J		**0**	**3**	**0**	**3**
		WB	1675	465	3684	5824
		NDB	2547	2069	1459	6075
	3K		**4222**	**2534**	**5143**	**111899**
		BB	3323	199	3197	6719
		TB	4005	648	12142	16795
		CB	7454	133	9589	17176
		SS	37	52	1362	1451
		SMB	5685	34	337	6056
	3L		**20504**	**1066**	**26627**	**48197**
1987	2J		**0**	**4**	**0**	**4**
		WB	619	193	2719	3531
		NDB	1921	1539	1948	5408
	3K		**2540**	**1732**	**4667**	**8939**
		BB	2140	76	2139	4355
		TB	1644	193	6780	8617
		CB	1317	120	3084	4521
		SS	106	32	633	771
		SMB	712	0	0	712
	3L		**5919**	**421**	**12536**	**18976**
1988	2J		**0**	**2**	**0**	**2**
		WB	3309	517	6751	10577
		NDB	6414	3213	6636	16263
	3K		**9723**	**3730**	**13387**	**26840**
		BB	3664	157	3960	7781
		TB	4275	164	15417	19856
		CB	7064	210	10586	17860
		SS	220	33	3194	3447
		SMB	3636	228	605	4469
	3L		**18859**	**792**	**33762**	**53413**
1989	2J		**0**	**3**	**304**	**307**
		WB	3276	643	9513	13432
		NDB	3235	2793	7938	13966
	3K		**6511**	**3436**	**17451**	**27398**
		BB	2704	111	4426	7241
		TB	4822	172	14845	19839
		CB	8662	75	8579	17316
		SS	207	11	3048	3266
		SMB	3327	1	643	3971
	3L		**19722**	**370**	**31541**	**51633**

Table 1. Continued ...

Year	Div.	Area	Purse seine	Beach seine	Trap	Total
1990	2J		**0**	**1**	**0**	**1**
		WB	4462	318	11820	16600
		NDB	5842	3403	9294	18539
	3K		**10304**	**3721**	**21114**	**35139**
		BB	3171	90	5619	8880
		CB	6852	41	11373	18266
		SS	31	45	2897	2973
		SMB	610	0	1016	1626
	3L		**15072**	**284**	**32636**	**47992**
1991	2J		**0**	**1**	**0**	**1**
		WB	239	227	12045	12511
		NDB	426	2709	4291	7426
	3K		**665**	**2937**	**16336**	**19937**
		BB	33066	70	3180	6316
		TB	4450	154	6474	11078
		CB	1889	20	2925	4834
		SS	0	7	0	7
		SMB	69	0	3	72
	3L		**9474**	**251**	**12582**	**22307**
1992*	2J		**0**	**0**	**0**	**0**
		WB	3390	124	8242	11756
		NDB	3014	1290	2293	6597
	3K		**6404**	**1414**	**10535**	**18353**
		BB	1073	29	63	1165
		TB	95	173	70	338
		CB	899	57	240	1196
		SS	0	5	21	26
		SMB	223	3	42	268
	3L		**2290**	**267**	**436**	**2993**
1993*	2J		**0**	**1**	**0**	**1**
		WB	1583	197	5108	6888
		NDB	1447	2503	2323	6273
	3K		**3030**	**2700**	**7431**	**13161**
		BB	1734	92	1920	3746
		TB	1989	365	4568	6922
		CB	4712	50	3377	8139
		SS	57	31	1480	1568
		SMB	2102	4	404	2510
	3L		**10594**	**542**	**11749**	**22885**
1994*	2J		**0**	**0**	**0**	**0**
		WB	0	20	0	20
		NDB	23	23	1	47
	3K		**23**	**43**	**1**	**67**
		BB	0	2	0	2
		TB	23	54	4	81
		CB	0	4	9	13
		SS	0	16	701	717
		SMB	0	3	55	58
	3L		**23**	**79**	**769**	**871**

* provisional

Table 2. Summary of the commercial samples processed and aged from the 1994 inshore capelin fishery in Div. 3KL.

Gear type	No. of LSM/strat. samples	No. of otoliths aged (N)	Mean no. otoliths ± SD per sample
Div. 3K			
Purse seine	1	29	
Beach seine	0	0	
Capelin trap	0	0	
TOTAL	1	29	
Div. 3L			
Purse seine	0	0	
Beach seine	0	0	
Capelin trap	10	401	40.1 ± 4.1
TOTAL	10	401	

Table 3. Age compositions (%) of capelin from the inshore commercial capelin fishery, Div. 3KL. Data available from Div. 3L only in 1979-81.

Year/Sex	Age 2	3	4	5	6
Males					
1979	0	47.6	36.3	15.1	0.9
1980	0	39.0	57.8	2.9	0.3
1981	0	28.3	40.2	29.7	1.9
1982	+	90.5	8.7	0.7	+
1983	0.3	60.8	38.5	0.3	0
1984	0.3	36.0	62.9	0.8	0
1985	4.9	65.4	27.9	1.7	+
1986	0.2	56.7	42.5	0.5	0
1987	0.2	11.4	86.8	1.5	0
1988	3.7	70.2	23.1	3.0	0
1989	0.3	76.8	22.8	0.1	0
1990	0.4	33.6	65.7	0.2	0
1991	9.2	47.8	41.6	1.4	+
1992	7.9	81.4	10.5	0.2	0
1993	5.9	88.4	5.6	0.1	0
1994*	23.8	56.7	19.5	0	0
Females					
1979	0.8	59.1	25.4	11.3	3.4
1980	0.3	41.1	58.3	0.2	0.1
1981	+	38.7	31.4	28.9	1.1
1982	1.5	77.9	12.4	6.4	1.8
1983	5.8	58.8	33.4	2.0	+
1984	2.6	41.0	48.0	8.1	0.3
1985	13.4	57.3	18.5	10.3	0.5
1986	0.2	65.5	29.5	3.7	1.1
1987	4.8	19.1	67.1	8.5	0.4
1988	11.6	51.8	12.1	23.0	1.5
1989	1.3	70.7	23.4	2.0	2.6
1990	1.4	44.1	51.9	2.5	+
1991	12.6	49.5	29.4	8.4	0.1
1992	17.6	67.8	12.9	1.7	+
1993	10.4	82.1	7.3	0.2	+
1994*	33.4	43.1	19.7	3.8	0
Sexes combined					
1979	0.2	50.3	33.8	14.2	1.5
1980	0.2	40.4	58.1	1.1	0.2
1981	0	34.6	34.7	29.2	1.4
1982	0.7	84.6	10.5	3.4	0.8
1983	3.3	59.7	35.7	1.3	+
1984	1.5	38.6	55.2	4.5	0.2
1985	10.1	60.4	22.1	7.0	0.4
1986	0.2	62.1	34.5	2.5	0.7
1987	2.9	15.9	75.5	5.5	0.2
1988	8.4	59.1	16.5	15.1	0.9
1989	0.8	73.5	23.1	1.2	1.4
1990	1.0	39.7	57.8	1.5	+
1991	11.1	48.8	34.5	5.5	0.1
1992	13.3	73.9	11.8	1.0	+
1993	8.5	84.8	6.6	0.1	+
1994*	31.1	46.3	19.7	2.9	0

* may not be representative of population due to low landings and restricted sampling of landings.

Table 4. Mean weights (gm) for commercial samples in Div. 3K and Div. 3L, sexes combined.

Year	Age 2	3	4	5	6	All
Div. 3K						
1984	14.7	30.5	37.0	34.5	32.3	35.0
1985	15.3	26.3	34.1	31.7	33.6	29.2
1986	11.3	27.4	34.4	32.9	35.3	30.1
1987	17.0	30.7	37.9	34.8	35.8	36.8
1988	17.2	31.2	42.6	36.4	38.9	34.1
1989	14.5	31.3	38.2	36.9	38.8	33.2
1990	16.4	26.1	32.6	31.3		30.2
1991	18.9	23.1	27.2	26.4	31.7	24.8
1992	15.7	25.0	27.4	26.7	37.5	24.6
1993	20.1	24.5	29.4	30.5		29.2
1994	18.1	29.9	32.9	30.4		30.5
Div. 3L						
1981	7.8	22.3	29.8	32.3	36.4	28.1
1982	12.6	32.5	37.0	37.2	39.9	33.0
1983	13.9	27.7	33.8	34.0	27.6	29.1
1984	13.9	27.6	34.7	30.5	33.6	31.3
1985	12.0	25.4	35.9	32.6	33.1	26.7
1986	18.0	26.2	34.2	33.7	36.8	29.1
1987	14.2	27.4	36.3	33.5	38.1	33.1
1988	14.3	29.9	39.6	36.4	38.8	30.7
1989	14.5	29.3	36.5	36.6	37.9	30.8
1990	16.0	25.4	32.7	32.1	37.1	29.2
1991	12.6	21.2	29.2	27.8	35.7	22.6
1992	12.9	18.7	25.2	25.0		17.1
1993	15.0	24.1	25.7	27.8	28.5	23.5
1994	16.8	23.8	27.7	28.1		22.4

Table 5. Percent contribution by weight of reasons for discarding capelin in 1994. This analysis excludes capelin given to other fishers.

Area	Redfeed	Low % females	Small females	Males picked out	Females spawned out	No market/ quota filled	Misc.	Not given
<u>Traps</u>								
Southern Shore	0	0	98	2	0	0	0	0
St. Mary's Bay	38	0	62	0	0	0	0	0
<u>Purse seine</u>								
Bonavista Bay	0	0	100	0	0	0	0	0
Southern Shore	0	0	100	0	0	0	0	0
St. Mary's Bay	0	0	100	0	0	0	0	0

Table 6. Capelin landings (t), discards (t), and catch/effort from research logbook records for capelin traps in Div. 3KL in 1994.

Area	No. fishers	No. traps	Landings	Discard logbook	Bycatch		No. days fished (D)	No. times hauled (H)	L = Landings		C = Landings + discards	
					Cod	Herring			L/D	L/H	C/D	C/H
Southern Shore	4	7	28.3	18.9	0.2	0	56.4	73	0.5	0.4	0.8	0.6
St. Mary's Bay	1	1	4.1	12.0	0	0	3.9	6	1.1	0.7	3.9	2.7

Table 7. Capelin landings (t), discards (t), bycatch (t), and catch/effort compiled from purse seine logbooks for Div. 3KL in 1994.

						L = Landings		C = Landings + discards	
Area	No. of fishers	Landings by logbook	Discards by logbook*	No. days fished	No. sets made	L/D	L/S	C/D	C/S
Bonavista Bay	1	0	9.1	1	1	0	0	9.1	9.1
Southern Shore	1	0	18.1	3	1	0	0	6.0	18.1
St. Mary's Bay	3	0.2	29.3	4	2	0.1	0.1	7.4	14.8

* includes capelin given to other fishers

Table 8. Capelin landings (t), discards (t), bycatch (t), and catch/effort from research logbook records for capelin traps in Div. 3KL, 1981-94. Data available from Div. 3L only for 1981 and 1982.

Year	No. fishers	No. traps	Landings	Discard logbook	Bycatch		No. days fished (D)	No. times hauled (H)	L = Landings		C = Landings + discards	
					Cod	Herring			L/D	L/H	C/D	C/H
1981	35	41	1281.0	417.7	5.8	0	577	680	2.2	1.9	2.9	2.5
1982	60	81	4366.5	605.2	60.4	0	1630	1996	2.7	2.2	3.1	2.5
1983	50	71	3051.2	1338.0	23.6	32.8	1277	1460	2.4	2.1	3.4	3.0
1984	67	89	4172.5	634.1	48.3	1.8	1615	2442	2.6	1.7	3.0	2.0
1985	60	80	3011.3	1850.1	31.0	0.1	1108	1508	2.7	2.0	4.4	3.2
1986	64	91	5056.4	2436.4	17.8	0.4	1567	2095	3.2	2.4	4.8	3.6
1987	68	93	3150.6	2437.5	11.8	0	622	1104	5.1	2.9	9.0	5.1
1988	86	125	6792.6	1500.4	28.0	0.2	1353	2415	5.0	2.8	6.1	3.4
1989	102	154	6275.8	2188.1	53.0	+	1314	2431	4.8	2.6	6.4	3.5
1990	106	167	6638.1	2986.6	100.4	0.7	1041	1825	6.4	3.6	9.2	5.3
1991	59	76	2793.0	2287.5	23.7	1.4	860	1325	3.2	2.1	5.9	3.8
1992	28	34	1225.8	567.1	1.5	5.7	297	666	4.1	1.8	6.0	2.7
1993	59	78	2261.1	297.0	52.3	10.7	400	863	5.6	2.6	6.4	3.0
1994*	5	8	32.4	30.9	0.2	0	60	79	0.5	0.4	1.1	0.8

* small and localized sampling

Table 9. Capelin landings (t), discards (t), and catch/effort from research logbook records for purse seines in Div. 3KL, 1981-94.

Year	No. fishers	Landings	Discards logbook	No. days fished (D)	No. sets made (S)	L = Landings		C = Landings + discards	
						L/D	L/S	C/D	C/S
1981	23	2705.3	810.4	376	707	7.2	3.8	9.4	5.0
1982	61	11541.9	2484.8	859	1670	13.4	6.9	16.3	8.4
1983	48	6439.0	4551.3	626	1155	10.3	5.6	17.6	9.5
1984	46	8185.5	1517.2	679	1305	12.1	6.3	14.3	7.4
1985	35	4191.0	2314.3	396	696	10.6	6.0	16.4	9.3
1986	36	8654.5	2745.2	605	991	14.3	8.7	18.8	11.5
1987	29	2100.5	869.1	169	267	12.4	7.9	17.6	11.1
1988	41	8282.7	1247.1	476	927	17.4	8.9	20.0	10.3
1989	46	7463.5	1687.1	421	863	17.7	8.6	21.7	10.6
1990	32	5081.4	2327.4	344	630	14.8	8.1	21.5	11.8
1991	9	699.0	413.7	74	95	9.4	7.4	15.0	11.7
1992	17	1719.8	254.0	95	146	18.1	11.8	20.8	13.5
1993	21	2448.7	291.5	169	292	14.5	8.4	16.2	9.4
1994*	3	0.2	56.5	8	4	+	+	7.1	14.2

* small sample size

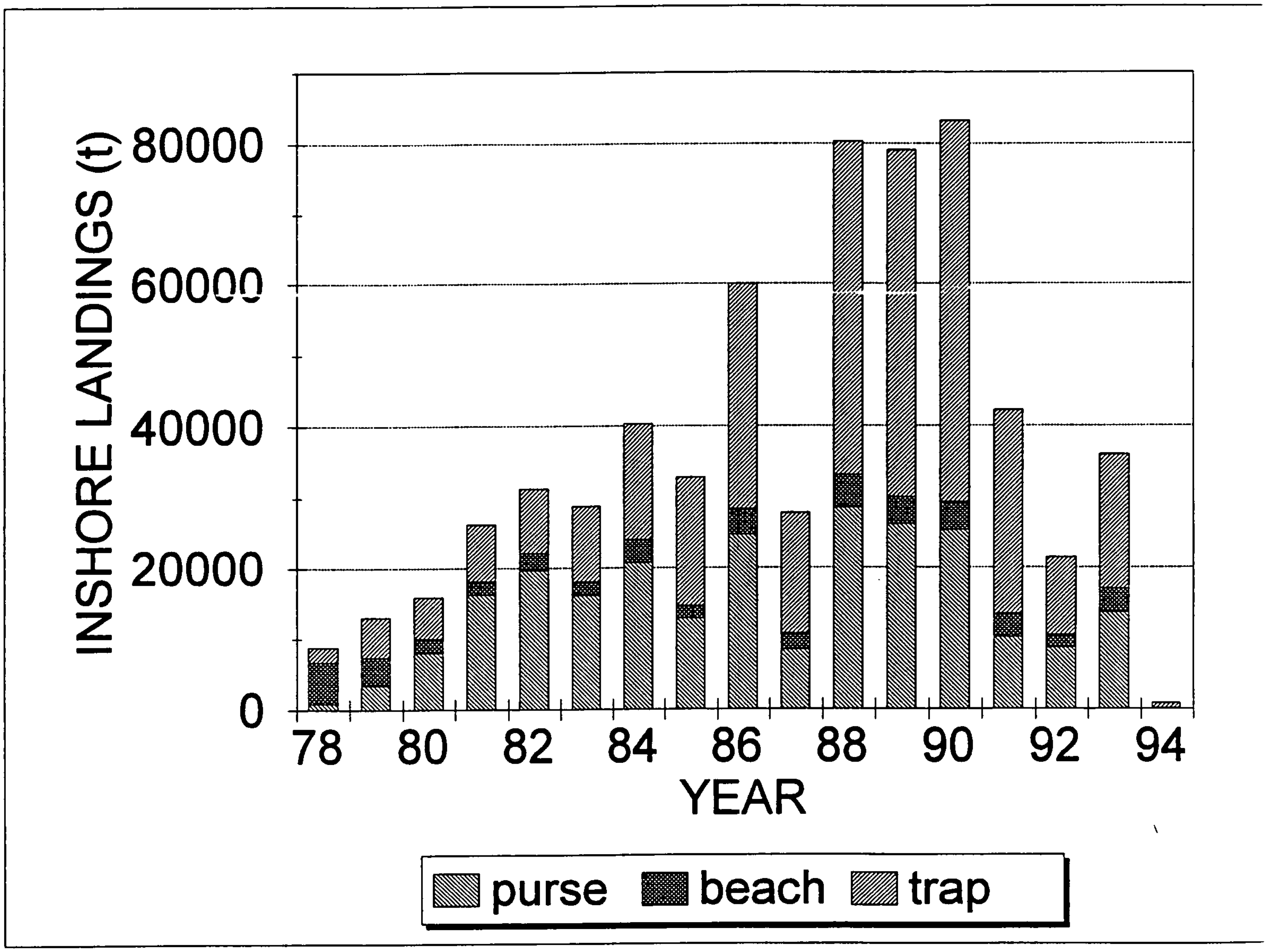

Fig. 1. Capelin landings in Div. 3KL.

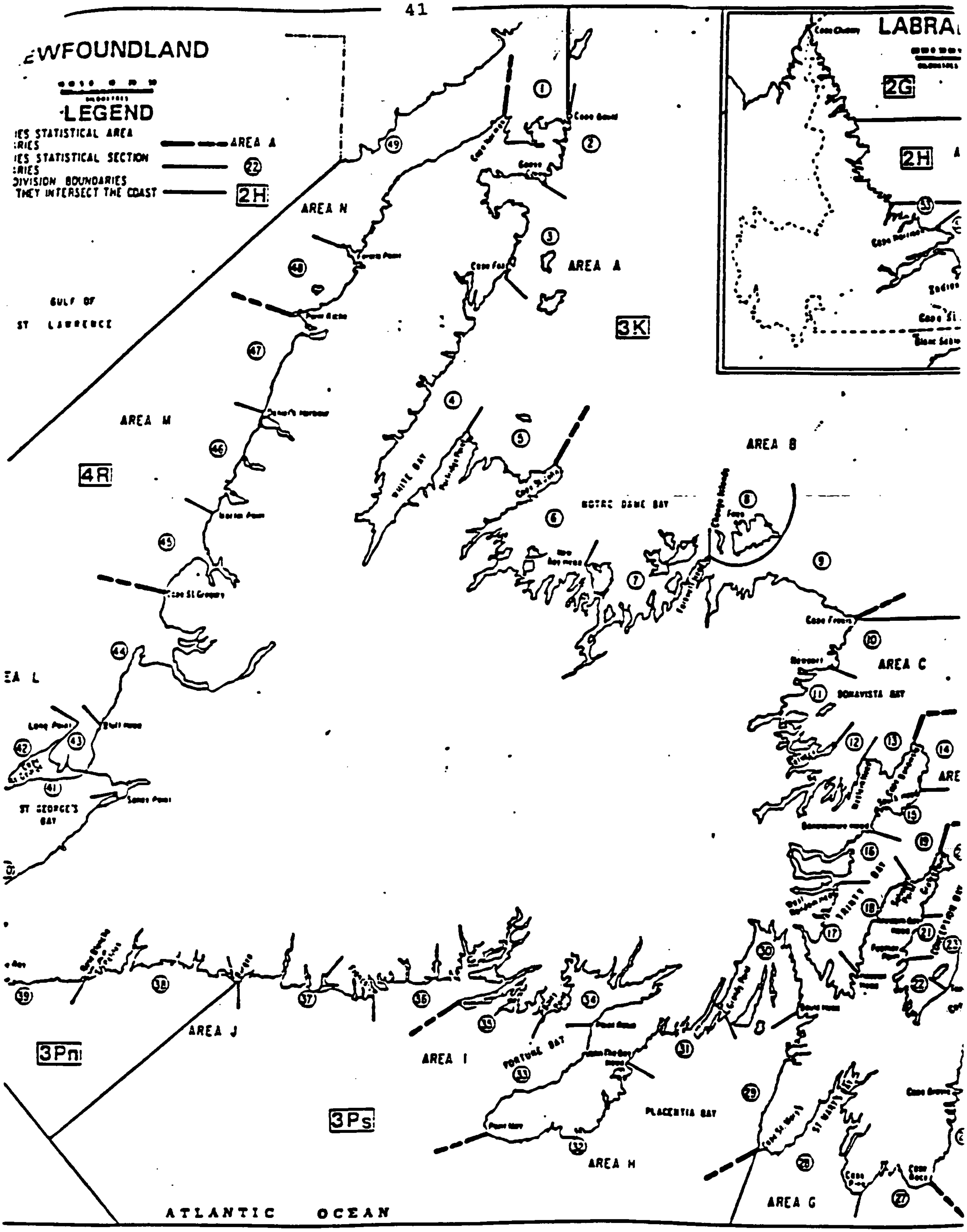

Fig. 2. Statistical areas in Div. 3L and Div. 3K.

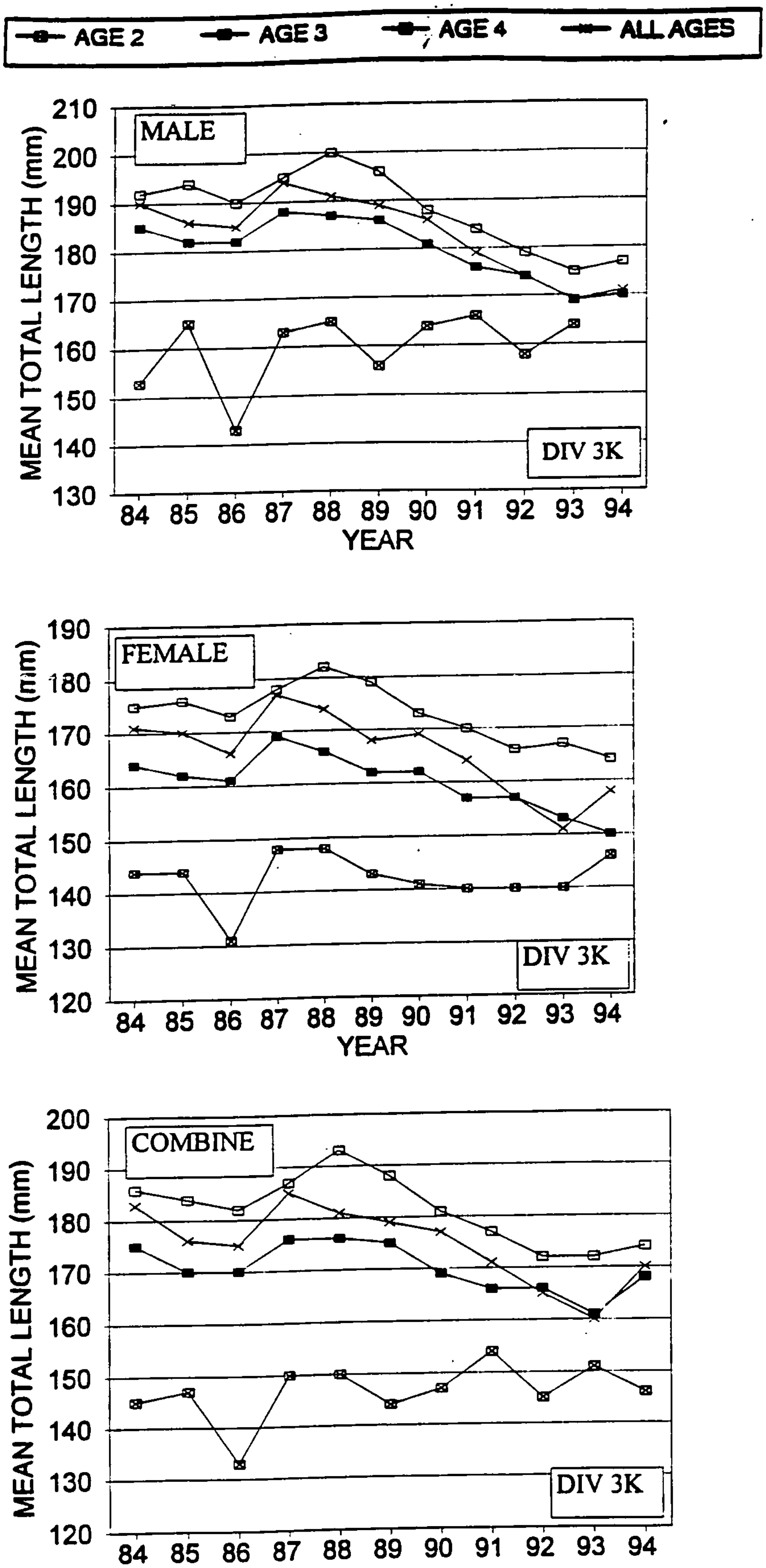

Fig. 3. Mean total length-at-age for males, females, and sexes combined for Div. 3K.

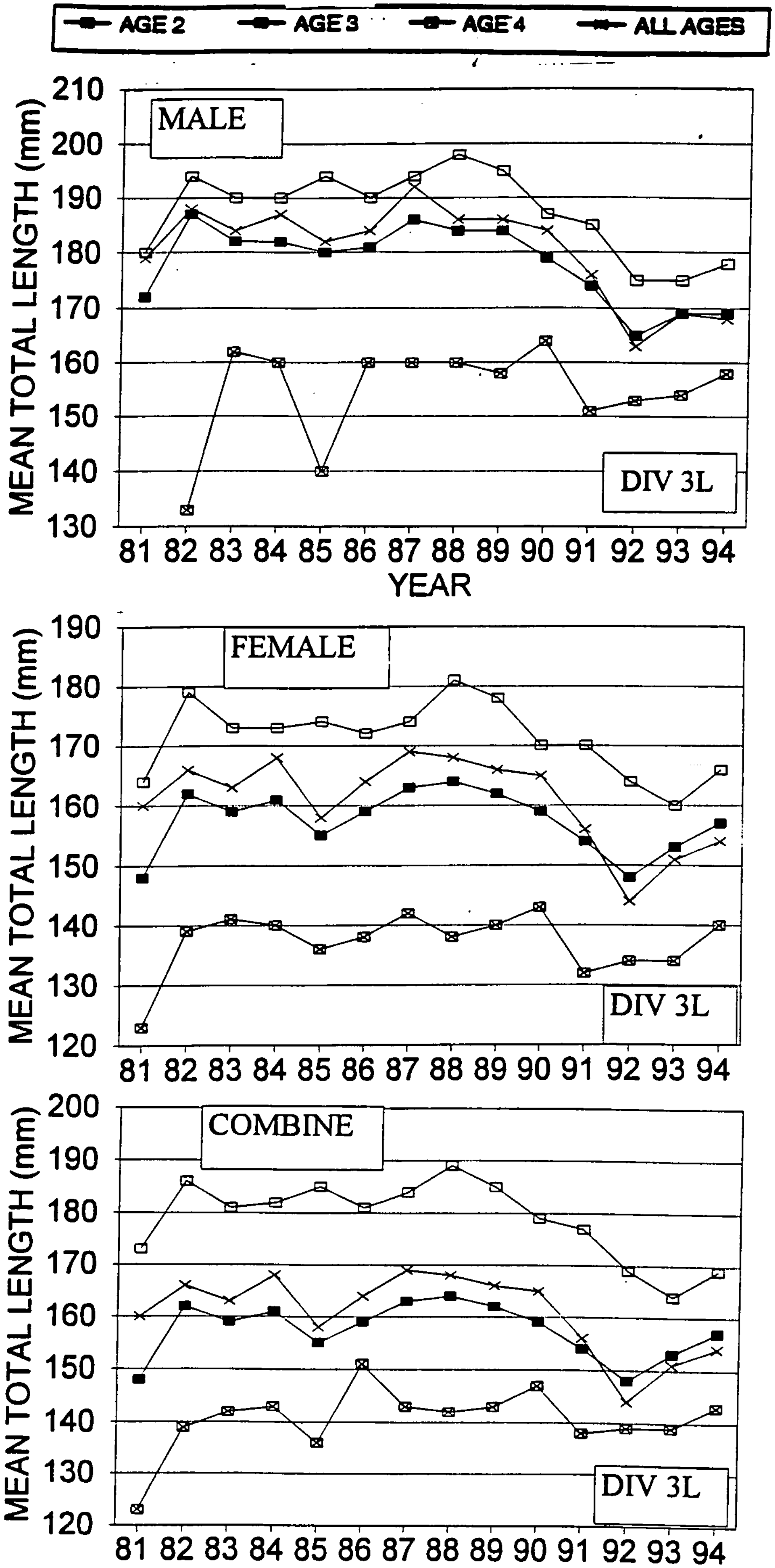

Fig. 4. Mean total length-at-age for males, females, and sexes combined for Div. 3L.

Appendix A

1994 CAPELIN ALLOCATIONS

NAFO AREA	AREA	FIXED GEAR	PURSE SEINE	TOTAL
2J	LABRADOR	150		150
3K	WHITE BAY (1)	4,475	1,500	5,975
	NOTRE DAME BAY (1)	3,925	1,500	5,425
	TOTAL	8,400	3,000	11,400
3L	BONAVISTA BAY	2,245	1,425	3,670
	TRINITY BAY	4,490	1,870	6,360
	CONCEPTION BAY	3,710	3,370	7,080
	SOUTHERN SHORE (1) (2)	2,300	190	2,490
	ST. MARY'S BAY	450	1,680	2,130
	TOTAL	13,195	8,535	21,730
3Ps	PLACENTIA BAY	1,740	260	2,000
	FORTUNE BAY AND WEST (3)	510	30	540
	TOTAL	2,250	290	2,540
4R3Pn	WEST COAST (1) (4)	4,000	6,000	10,000
	NFLD PROVINCE TOTAL	27,995	17,825	45,820
	4ST			1,725
	ATLANTIC COAST TOTAL			47,545

NOTES TO ALLOCATION TABLE:

1. Sub-divisions of the fixed gear quota in White Bay, Notre Dame Bay, Southern Shore and 4R3Pn ar detailed on the attached table.

2. Trepassey Bay from Cape Pine to Cape Race is included in the Southern Shore quota area for fixe gear only.

3. The fixed gear quota includes 450 t for an experimental fishery in the Hermitage/Harbour Breton area

4. The purse seine quota in 4R3Pn is further sub-divided with 3,500 t for vessels over 65 feet and 2,50 t for vessels less than 65 feet.

Appendix A - continued

1994 CAPELIN FIXED GEAR SUB-DIVISIONS

BAY	AREA	QUOTA
WHITE BAY	CAPE BAULD TO FISCHOTT ISLAND	965
	FISCHOTT ISLAND TO CAPE FOX	325
	CAPE FOX TO CAPE ST. JOHN	3,185
NOTRE DAME BAY	CAPE ST. JOHN TO NORTH HEAD	1,105
	NORTH HEAD TO DOG BAY POINT	2,300
	DOG BAY POINT TO CAPE FREELS	520
SOUTHERN SHORE	CAPE ST. FRANCIS TO LONG POINT	600
	LONG POINT TO CAPE NEDDICK	400
	CAPE NEDDICK TO CAPE PINE	1,300
4R3Pn	SOUTH OF BROOM POINT	640
	BROOM POINT TO POINT RICHE	445
	POINT RICHE TO BIG BROOK	1,430
	BIG BROOK TO CAPE BAULD	775
	LABRADOR	710

Appendix B

1994 Opening and Closing Dates

White Bay
- monitoring never opened in 1994

Notre Dame Bay
- opened Dog Bay Point to Cape Freels area on June 20 for fixed gear
- opened Notre Dame Bay on June 20 for mobile gear
- closed on June 22 for mobile gear due to small females

Bonavista Bay
- monitoring never opened in 1994

Trinity Bay
- opened on June 15 for fixed and mobile gears
- closed June 29 for fixed gear
- closed July 14 for mobile gear due to small females

Conception Bay
- monitoring never opened in 1994

Southern Shore
- Cape St. Francis to Long point
  opened June 21 for fixed gear
  closed July 18 for fixed gear due to small females

- Long Point to Cape Neddick
  opened June 11 for fixed gear
  closed July 15 for fixed gear due to small females
  re-opened July 17 for fixed gear
  closed July 18 for fixed gear due to small females

- Cape Neddick to Cape Pine
  opened June 11 for fixed gear
  closed July 6 for fixed gear due to small females
  re-opened July 8 for fixed gear
  closed July 11 for fixed gear due to small females

St. Mary's Bay
- opened June 11 for fixed and mobile gears
  closed June 24 for mobile gear

Chapter 3

Results of the 1994 CASI Aerial Survey of Capelin (*Mallotus villosus*) Schools

by

Brian S. Nakashima
Science Branch
Department of Fisheries and Oceans
P. O. Box 5667
St. John's, NF A1C 5X1

Introduction

Areal estimates of capelin (Mallotus villosus) schools conducted since 1982 have been used as an index of inshore abundance of mature capelin in NAFO Div. 3L (eg. Nakashima 1994). From 1982 to 1989 school areas were measured from aerial photographs (Nakashima 1990). Since 1990 school areas have been estimated from digital imagery data collected by the Compact Airborne Spectrographic Imager (CASI). The digital images collected using the CASI and processed by image classification techniques were easier to interpret than aerial photographs (Nakashima et al. 1989, Borstad et al. 1990, Borstad et al. 1992).

This report presents the results of the 1994 CASI aerial survey.

Materials and methods

Instrument Operation

The CASI is an imaging spectrometer which uses a two dimensional (612 x 288) charge couple device (CCD) and a diffraction grating to collect image and spectral data. The CASI operates in the range of 423-946 nm. A 512 pixel width spatial image is formed in "pushbroom" fashion by reading out the cross track information as the aircraft moves forward. The remaining elements are used to obtain dark and electronic offset reference values. The spectral resolution of each element is 1.8 nm and the spatial resolution of each element is 1.2 rad. Integration times are a function of ambient light levels, aircraft speed, and band selections.

In spatial or imaging mode the CASI operates like other pushbroom imagers except that band widths, positions and number are programmable during the flight. High spatial resolution imagery is collected in several spectral bands which can be programmed as narrow as 1.8 nm or wider. Different spectral band widths were used for sunny days and for overcast days:

Light condition	Band widths			
	1	2	3	4
Overcast	450-510	525-591	640-691	735-755
Sunny	476-501	525-590	651-671	744-755

These bands selections were used in 1993 (Nakashima 1994).

Survey Method

Particulars of previous aerial surveys including aircraft type, equipment used, survey time, and altitudes flown are listed in Table 1. Weather conditions in 1994 were almost always favourable allowing CASI surveys to be flown at 1220 m to obtain a swath width comparable to aerial photographs taken at 457 m. The 1994 survey covered three transects as often as possible; the inside of Trinity Bay from Masters Head to Hopeall Head, the outside of Conception Bay from Bay de Verde to Harbour Grace Islands, and the inside of Conception Bay from Bryant's Cove to Portugal Cove (Fig. 1).

During each flight capelin schools were detected by experienced spotters prior to digital recording of the area. If there was any doubt as to the presence of schools imagery was collected and examined later. Flight tapes and survey records were examined following each flight or shortly thereafter to assess the quality of the imagery.

Analytical Methods

CASI imagery data were transferred to a PC-based image processor for classification and analysis. Data were calibrated and set up as PCI image files. An algorithm, first tested in 1989 to estimate school areas from the digital survey data (Borstad et al. 1990), was used to analyze the 1994 data. Schools on the imagery were identified by an experienced observer. For each transect flown, the mean and median surface areas of capelin schools, the total number of schools, and the total surface area of all schools observed along a transect were estimated.

The school surface area index for each year was estimated by summing the highest total school surface area observed on each of the three transects. I assumed that the peak in school surface area was indicative of inshore abundance for each transect for that year (Nakashima 1985). In transect three there were two occasions when the survey had to be spread out over two days due to cloud cover over part of the survey area on both days. Visual inspection of the area not imaged indicated that on both occasions the distribution of schools was similar on adjacent days.

I did not adopt the method suggested by Winters (1994) because the problem of multiple counting of the same schools over several days was not resolved and the survey time used included transit time between the airport/seaport and transects. Survey times reported in Table 2 are best estimates of actual survey time.

Results and Discussion

In 1994, the aerial survey provided frequent coverage of both Conception Bay transects and Trinity Bay. Complete data were collected in Trinity Bay eight times (Table 2a), along the outside transect of Conception Bay six times (Table 2b), and the inside of Conception Bay ten times (Table 2c). A visual reconnaissance survey flight on July 2 found few capelin schools in the survey area (Tables 2a, b, c). Four days (July 11, 24 and 25 and August 4) were not flown because of poor weather conditions. In Trinity Bay the highest school area estimate was observed on July 15 (Table 2a). In Conception Bay the highest total for both transects occurred on July 12-13 (Tables 2b, c). The total school surface area taken from the highest estimates in Conception and Trinity Bays was 675,727 m^2 which is the second highest in the series (Table 3, Fig. 2). The estimate in Trinity Bay was the highest ever observed, whereas the school area in Conception Bay was the second lowest excluding the 1991 estimates (Table 3, Fig. 2). The index in 1994 was dominated by the presence of several large schools in Trinity Bay (Fig. 3).

Acknowledgments

The CASI data were collected by Geomatic Technologies Incorporated, St. John's, Nfld. School counts and area measurements were completed by Borstad Associates Ltd., Sidney, B.C. I am especially grateful to R. Linehan for assistance during the flights. M. Y. Hynes assisted in the preparation of the manuscript.

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Table 1. Summary of aerial surveys conducted from 1982 to 1994.

Year	Aircraft	Camera	Survey period	Altitude (m)	Flight time (hrs)
1982	Piper Aztec	RC 10	Jun 18-Jul 5	152-160	
1983	Aero-Commander	Wild RC 10	Jun 19-Jun 9	457	25.9
1984	Cessna 310	Wild RC 10	Jun 17-Jul 7	457	38.5
1985	Aero-Commander 500 B	Wild RC 10	Jun 18-Jul 3	290-610	28.6
1986	Aero-Commander 500 B	Wild RC 10	Jun 19-Jul 5	381-579	13.4
1987	Piper Aztec	Zeiss RMK	Jun 16-Jul 3	457	37.0
1988	Piper Navajo Piper Aztec	Zeiss RMK	Jun 15-Jul 5	305-488	33.0
1989	Piper Navajo	Zeiss RMK	Jun 16-27 Jun 30-Jul 4	434-732	26.0
1990	Piper Aztec	Zeiss RMK CASI	Jun 17-Jul 6	570-1260	27.0
1991	Piper Navajo	CASI	Jun 21-25 Jul 3-17	1220	27.3
1992	Cessna 185	CASI	Jun 21-Jul 14	275-1280	34.6
1993	De Havilland Beaver	CASI	Jun 30-Jul 16 Jul 19-22 Jul 26-28	364-1220	46.2
1994	De Havilland Beaver	CASI	Jul 2, 7-19 Jul 24-27 Aug 2-4	1220	43.8

Table 2a. Schooling data for the inside part of Trinity Bay from Masters Head to Hopeall.

Date		No. of schools	Total surface area (m^2)	School size (m^2) Mean	SD	Median	Survey time (hr)
1982	Jun 19	31	12724	411	712	149	0.7
	Jun 26	29	35607	1228	2755	299	0.8
	Jun 29	11	62397	5672	8378	592	0.6
	Jul 2	8	31365	3921	9281	705	0.6
	Jul 3	2	1920	960	17	960	0.4
1983	Jun 23	11	69583	6326	6299	4241	0.4
	Jun 24	26	39004	1500	1880	753	0.6
	Jun 25	30	174487	5816	12759	781	0.3
	Jun 29	35	152557	4359	11139	781	0.6
	Jun 30	46	199373	4334	6927	558	0.8
	Jul 1	25	189497	7580	19791	2288	0.5
1984	Jun 19	13	15624	1202	1770	335	0.6
	Jun 23	9	8314	924	888	502	0.3
	Jun 25	96	31526	328	505	117	0.9
	Jun 26	96	40510	422	679	223	1.1
	Jun 29	47	12053	256	314	167	0.5
	Jul 3	57	23827	418	814	167	0.9
	Jul 7	77	43245	562	1124	223	0.6
1985	Jun 21	13	7041	542	706	270	1.0
	Jun 25	35	22459	642	1144	211	1.0
	Jun 26	30	16540	551	721	214	1.1
	Jul 1	125	60245	482	963	181	0.7
	Jul 2	130	195659	1503	6046[a]	179	1.0
1986	Jun 28	59	95898	1625	4502	340	0.8
1987	Jun 17	45	167567	3724	17727	223	1.0
	Jun 19	91	399026	4385	31197	167	1.0
	Jun 27-28	37	59315	1603	5612	446	1.0
	Jul 3	5	1786	357	322	279	0.8
1988	Jun 16	27	18749	694	902	391	1.1
	Jun 19	50	104179	2084	4546	502	0.8
	Jun 22	67	112863	1685	5749	391	1.7
	Jun 25	20	87103	4338	15287[a]	474	0.4
	Jul 5	23	32252	1402	3199	223	0.8
1989	Jun 17	60	84349	1389	5040[a]	191	0.9
	Jul 3	0	0				0.6
1990	Jun 24	4	69498	17375	11184	21483	0.3
	Jun 27	30	58174	1831	3717	701	0.7
	Jun 29	38	141122	3714	5486	1503	1.4

Table 2a. Continued ...

	Date	No. of schools	Total surface area (m^2)	School size (m^2) Mean	SD	Median	Survey time (hr)
1991	Jun 23	0	0				1.6
	Jun 24	0	0				1.1
	Jul 5	139	170681	1228	1827	535	2.5
	Jul 14	54	64598	1196	1894	567	1.4
	Jul 16	33	93680	2839	5562	800	1.3
1992	Jun 25	29	40836	1408	1591	1078	1.4
	Jun 29	71	97424	1372	1510	679	1.4
	Jul 6	70	7565	1394	4273	267	2.3
	Jul 8	124	173219	1397	3862	370	2.7
	Jul 13	50	67889	1358	4008	263	1.7
1993	Jul 3	27	CASI data unavailable				1.5
	Jul 12	31	30502	1006	1747[a]	515	1.3
	Jul 14	14	58786	4199	2847	3976	1.1
	Jul 21	22	9760	451	611[a]	260	0.9
1994	Jul 2	0	0				0.3
	Jul 7	14	4311	308	408	220	1.1
	Jul 9	39	65179	1671	2081	846	1.6
	Jul 13	87	530460	6097	17469	577	1.8
	Jul 15	78	551755	7074	24456	753	1.6
	Jul 17	66	377255	5716	18303	1221	1.5
	Jul 19	57	296029	5193	19751	511	1.6
	Aug 2	9	16240	1804	1577	1115	1.0

a calculation excludes capelin in traps

Table 2b. Schooling data for the outside of Conception Bay from Bay de Verde to Harbour Grace Islands.

Date		No. of schools	Total surface area (m^2)	School size (m^2)			Survey time (hr)
				Mean	SD	Median	
1982	Jun 29	10	6577	658	366	642	0.7
	Jul 2	2	1357	679	554	679	0.4
1983	Jun 23	34	51838	1374	2266[a]	530	0.5
	Jun 24	16	10658	666	823	447	0.5
	Jun 25	4	4408	349	184	279	0.4
	Jul 1	5	5413	1083	1884	112	0.4
1984	Jun 18	1	391	391			0.4
	Jun 19	0	0				0.2
	Jun 25	49	63779	1294	2874	391	0.6
	Jun 26	67	65956	697	1091[a]	279	0.9
	Jun 30	21	22320	818	1509[a]	223	0.4
	Jul 3	4	1786	446	599	195	0.4
1985	Jun 20	0	0				0.4
	Jun 24	0	0				0.4
	Jun 27	30	8840	268	378[a]	120	0.6
	Jun 28	125	50837	368	800[a]	132	1.0
	Jun 29	22	19253	875	1169	291	0.7
	Jul 1	28	28036	991	1616[a]	264	0.5
	Jul 2	66	69166	914	2064[a]	223	0.4
1986	Jun 19	88	132455	1462	2853[a]	279	0.7
1987	Jun 16	139	184307	1322	2924[a]	391	1.4
	Jun 19	143	112660	766	1516[a]	279	1.2
	Jun 27	21	12164	539	559[a]	391	1.0
	Jun 30	37	29462	790	1481[a]	279	1.2
1988	Jun 16	0	0				0.5
	Jun 20	54	36993	679	1099[a]	223	2.0
	Jun 22	64	18916	230	324[a]	112	1.3
	Jun 25	116	87534	676	1331[a]	279	1.7
	Jul 4	51	39785	578	805[a]	279	0.9
1989	Jun 16	180	266878	1483	5512	335	1.9
	Jun 18	162	197372	1132	3607[a]	335	1.8
	Jul 1	8	6140	730	1359[a]	198	1.5
1990	Jun 24	89	85437	863	1483[a]	396	0.7
	Jun 26-27	42	88759	1937	3671[a]	670	1.0
	Jun 30	38	26013	686	771[a]	368	0.9

Table 2b. Continued ...

	Date	No. of schools	Total surface area (m²)	School size (m²) Mean	SD	Median	Survey time (hr)
1991	Jun 23	0	0				0.5
	Jun 24	0	0				1.1
	Jul 14	11	6374	579	2789	520	0.6
1992	Jun 30	5	27150	5430	4668	2629	0.5
	Jul 5	32	49308	1541	3383	558	1.5
	Jul 9	45	135723	3016	6069	883	1.9
	Jul 13	72	225838	3137	5026	1101	1.6
1993	Jul 2	6	CASI data unavailable				0.7
	Jul 4	13	CASI data unavailable				1.3
	Jul 11	30	30130	1560	4118[a]	239	0.9
	Jul 13	61	77202	1746	6014[a]	299	1.5
	Jul 15	54	32321	621	803[a]	239	1.5
	Jul 21	26	23598	908	1536[a]	1041	0.8
	Jul 27	20	8095	405	271	276	1.0
	Jul 28	21	27540	1311	1225	783	1.0
1994	Jul 2	2	CASI data unavailable				0.3
	Jul 8	17	27299	1606	2249	643	1.2
	Jul 10	16	11500	719	596	595	0.8
	Jul 12	19	25046	1318	2427	746	1.0
	Jul 16	16	28339	1771	1774	1223	0.9
	Jul 18	1	2449	2449	1	2449	0.4

a calculation excludes capelin in traps

Table 2c. Schooling data for the inside of Conception Bay from Harbour Grace Islands to Portugal Cove.

Date		No. of schools	Total surface area (m²)	School size (m²) Mean	SD	Median	Survey time (hr)
1982	Jun 26 (AM)	33	19408	571	907[a]	135	0.7
	Jun 26 (PM)	20	36513	1826	1914	2089	1.0
	Jun 27	48	151214	3134	6015[a]	527	0.8
	Jun 29	27	30275	1121	1707	418	0.7
	Jul 4	3	13042	4347	4951	1409	0.6
	Jul 5	7	5127	732	582	592	0.4
1983	Jun 23	53	97595	1787	2754[a]	558	0.6
	Jun 24	30	56860	1819	2965[a]	558	0.5
	Jun 25	29	79961	2677	3725[a]	781	0.4
	Jun 30	7	8091	1156	1181	558	0.3
	Jul 1	1	2009	2009			0.3
1984	Jun 18	0	0				0.2
	Jun 23	8	17689	2085	2556[a]	949	0.5
	Jun 25	70	63891	879	1789[a]	223	0.5
	Jun 26	33	23603	703	1708[a]	223	0.6
	Jun 30	29	16852	508	467[a]	335	0.7
	Jul 3	18	9040	329	254[a]	223	0.6
	Jul 5	0	0				0.3
1985	Jun 20	0	0				0.4
	Jun 24	2	1600	800	834	800	0.4
	Jun 26	17	10124	596	1145	314	0.4
	Jun 27	76	16552	214	426[a]	78	0.7
	Jun 28	120	33858	274	938[a]	67	0.5
	Jul 1	16	43228	2702	5140	308	0.3
	Jul 2	17	13436	676	1872[a]	191	0.5
1986	Jun 19	39	31574	786	1105[a]	357	0.6
	Jun 22	86	30930	343	616[a]	131	0.9
	Jul 2	10	5019	502	600	358	0.7
1987	Jun 17	196	53066	263	350[a]	167	1.5
	Jun 19	365	205846	556	1482[a]	167	1.6
	Jun 21	179	74128	393	699[a]	167	1.9
	Jun 27	138	94747	681	2389[a]	167	1.5
	Jun 28	63	68969	1036	2402[a]	167	1.2
	Jun 30	41	51336	1226	2892[a]	391	0.6
	Jul 3	47	34863	742	1400	279	0.7
1988	Jun 19	77	25780	335	599	223	1.6
	Jun 20	31	7742	240	256[a]	167	2.3
	Jun 24-25	289	201642	682	1091[a]	391	2.7
	Jul 4	24	32141	1295	4242a	251	0.9

Table 2c. Continued ...

Date		No. of schools	Total surface area (m^2)	School size (m^2) Mean	SD	Median	Survey time (hr)
1989	Jun 16	186	187311	991	2032[a]	319	1.4
	Jun 18	113	88283	686	1422[a]	279	1.3
	Jun 30	0	0				0.4
	Jul 1	22	13905	587	512[a]	396	1.2
	Jul 4	24	10707	446	651	279	1.4
1990	Jun 26	112	128743	1092	2960[a]	360	2.0
	Jun 29	32	88310	2591	4544[a]	742	0.8
	Jun 30	96	102615	1069	1993[a]	489	1.7
1991	Jul 8	Few schools observed - no CASI data					1.1
	Jul 11	56	15577	278	359	124	1.2
	Jul 17	8	8453	1057	531	875	1.1
1992	Jun 24	8	4772	597	328	468	0.9
	Jun 27	7	11726	1675	3478	133	0.4
	Jul 5	12	24263	2708	2880	2143	1.1
	Jul 6	23	10775	468	620	272	1.7
	Jul 9	30	45748	1525	1865	792	1.3
	Jul 13	63	148629	2359	3294	981	1.0
	Jul 14	143	350988	2454	6098	751	2.6
1993	Jul 2	16	CASI data unavailable				1.9
	Jul 4	45	CASI data unavailable				2.3
	Jul 11	60	102645	1867	4904[a]	440	2.0
	Jul 13	53	44184	910	1247[a]	455	1.7
	Jul 15	18	9670	551	681[a]	323	1.7
	Jul 20	73	69246	984	1357[a]	385	2.5
	Jul 21	72	98938	1390	3678	309	1.9
	Jul 27	69	198968	2884	5960	587	1.6
	Jul 28	35	41844	1196	1521	546	1.2
1994	Jul 2	5	CASI data unavailable				0.5
	Jul 7	9	11368	1263	1614	378	1.6
	Jul 9-10	16	79949	4997	10291	1609	1.8
	Jul 12-13	67	98926	1476	2607	333	1.7
	Jul 14	13	17110	1316	1624	416	1.3
	Jul 15	8	8678	1085	1089	868	0.7
	Jul 16	23	40575	1764	4753	576	1.0
	Jul 18	35	61500	1757	2294	1176	1.6
	Jul 26	0	0				0.9
	Aug 3	0	0				

a calculation excludes capelin in traps

Table 3. School surface area (m^2) index for Trinity Bay, Conception Bay, and the total of the two bays.

Year	Trinity Bay	Conception Bay	Total
1982	63,397	157,791	220,188
1983	199,373	149,433	348,806
1984	43,245	129,847	173,092
1985	195,659	112,394	308,053
1986	95,898	164,029	259,927
1987	399,026	318,506	717,532
1988	112,863	289,176	402,039
1989	84,349	454,189	538,538
1990	141,122	217,502	358,624
1991	(170,681)*	(21,951)*	(192,632)*
1992	173,219	374,467	547,686
1993	58,786	276,170	334,956
1994	551,755	123,972	675,727

* The survey in 1991 was completed before inshore spawning had begun.

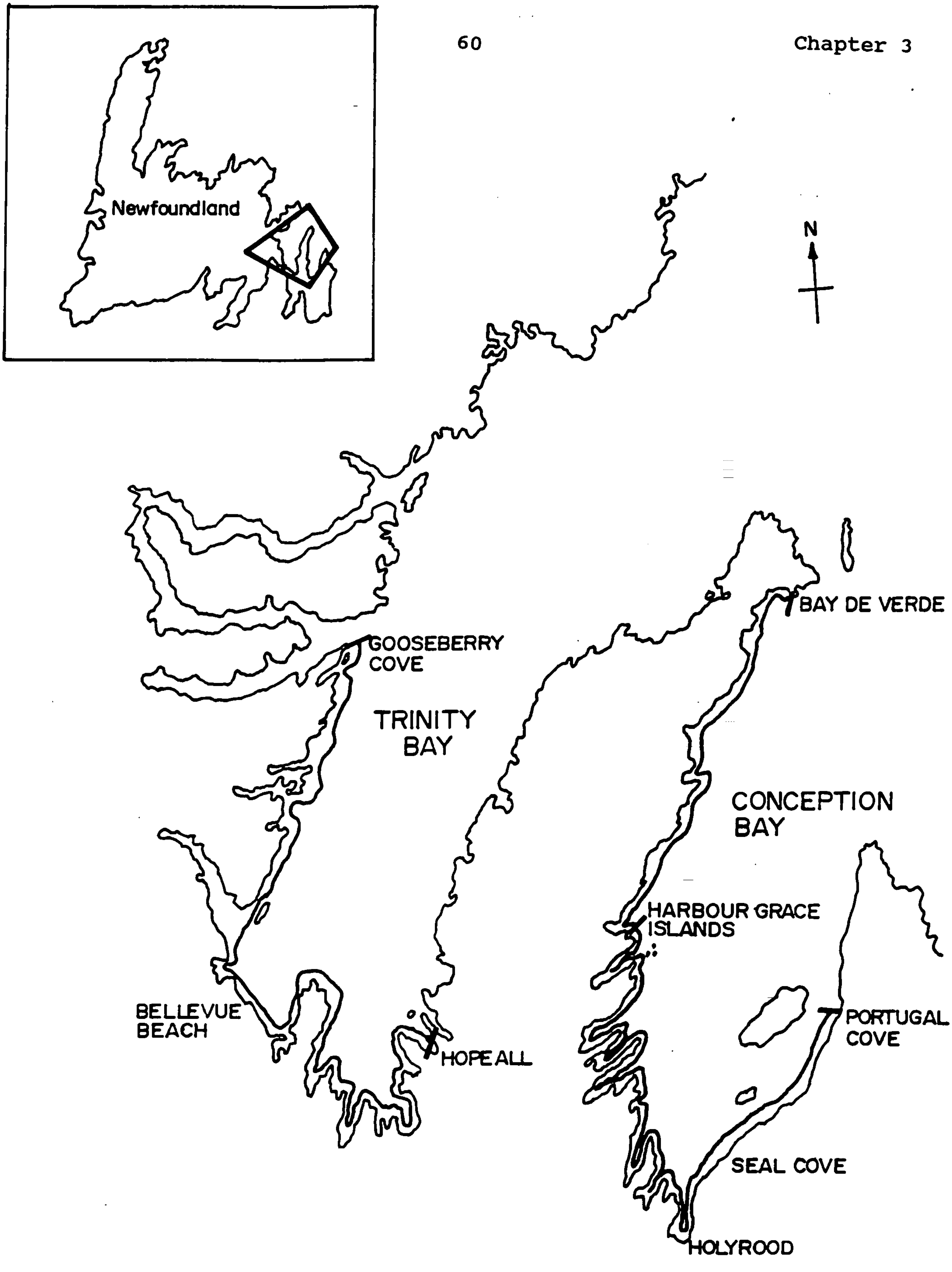

Fig. 1. Aerial survey transects in Conception Bay and Trinity Bay.

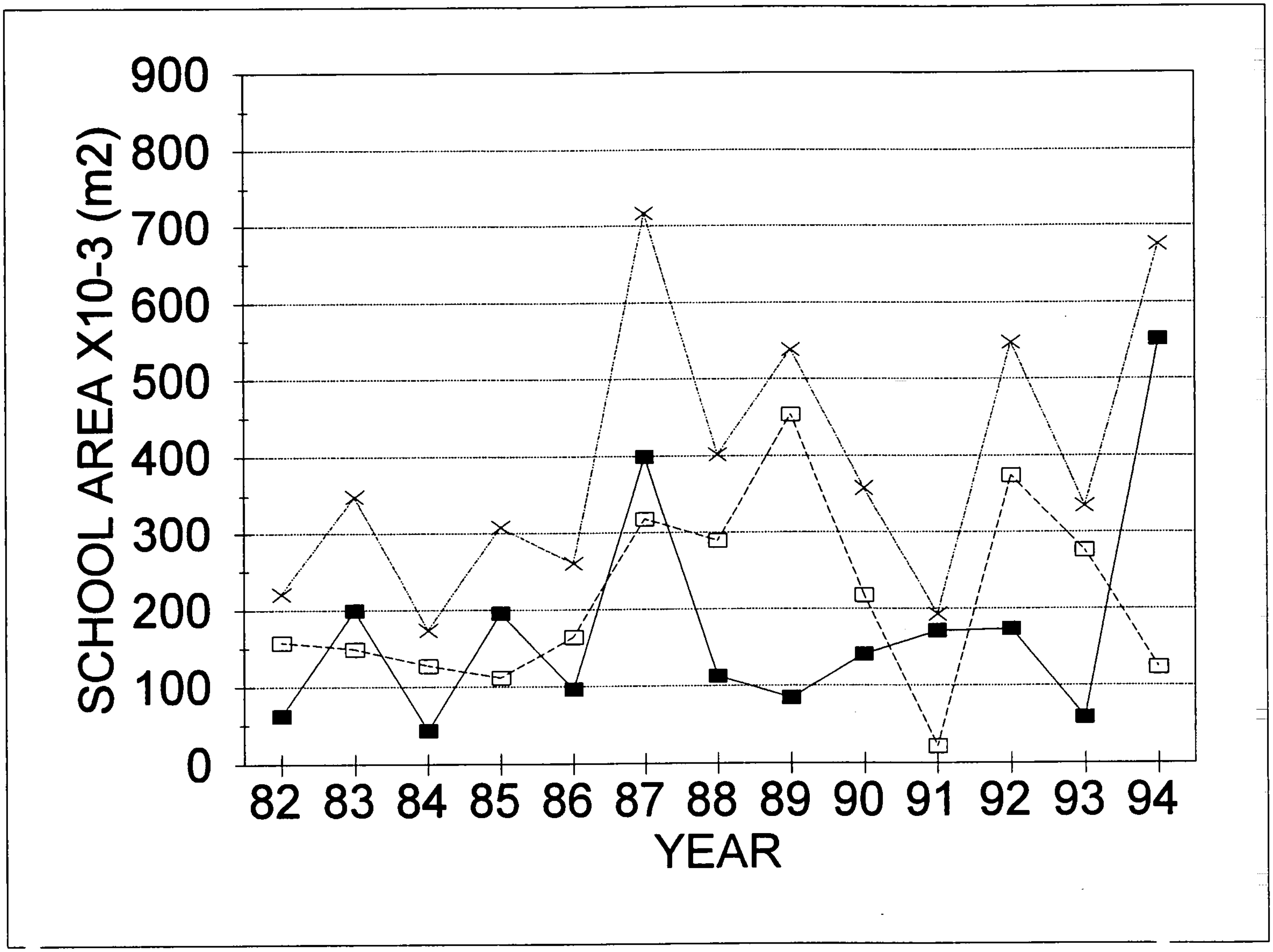

Fig. 2. Trends in the school surface area index for Conception Bay (open squares), Trinity Bay (closed squares), and combined (x).

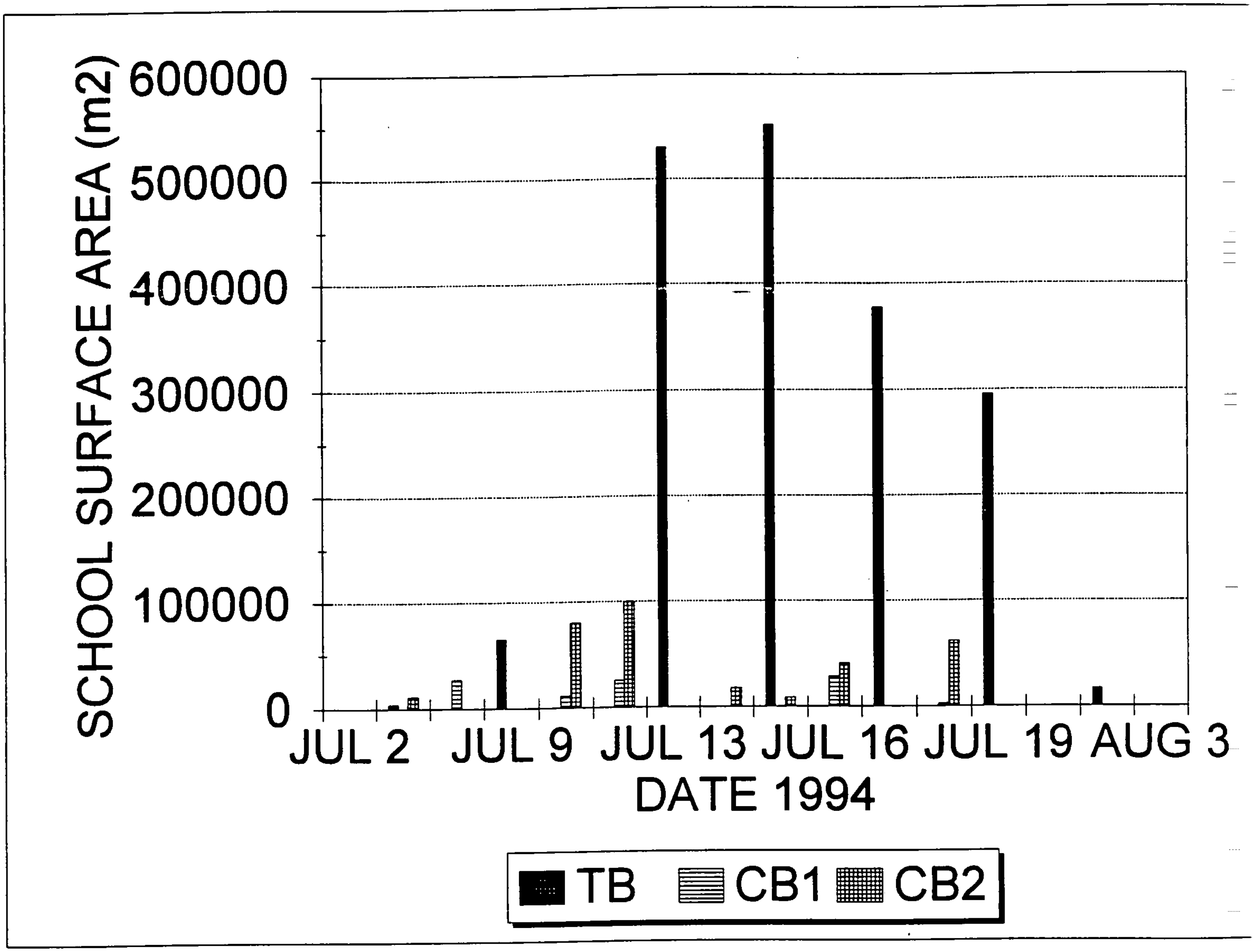

Fig. 3. Daily changes in 1994 of school surface areas by survey transect.

Results from an Acoustic Survey for Capelin (Mallotus villosus) in NAFO Divisions 2J3KL in the Autumn of 1994

by

D. S. Miller
Science Branch
Department of Fisheries and Oceans
P. O. Box 5667
St. John's, NF A1C 5X1

Introduction

From 1981 to 1992, east coast Newfoundland and Labrador capelin stocks have been surveyed acoustically by a spring (April-May) survey of Division 3L and an autumn (October-November) survey of Division 2J3K. In 1993, these surveys were combined into a combined 2J3KL survey covering the all the area covered by the separate surveys of the 1981-1992 period. Estimates of stock biomass from acoustic surveys declined dramatically in 1990 for the Division 2J3K survey and in 1991 for the Division 3L survey.

Methodology

The survey was conducted from the research vessel *Gadus Atlantica* during the period September 12 to October 29, 1994. The depth sounder and transducer used in 1994 changed in frequency to 38 kHz compared to the 49kHz frequency used on all previous surveys. The same value for target strength (-34 dB/kilogram) was used as for the past surveys as the change in sounder frequency is not expected to have any signifigant effect on target strength (George Rose, pers. comm.). A Biosonics ES2000 receiver was used with a Instruments Inc. S14 transmitter. A 38 kHz dual beam transducer was used in single beam mode and was mounted in a towed body that was deployed at a depth of about eight meters astern and abeam of the starboard side of the vessel. The acoustic system was calibrated at the beginning, during, and at the end of the survey. The geometric mean of the combined source level /receive sensitivity measurements from each calibration was used to integrate the data. Calibration parameters used were as follows:

Calibration date:	September 11	October 13	November 1
Combined source level/ receive sensitivity:	63.80dB	64.68dB	64.01dB
	Geometric mean=64.18dB		

Fixed receiver gain:	0.63625 dB
TVG gain:	20 log R
Attenuation coefficient:	0.012 dB/m
Pulse length:	0.8 millisecs
Bandwidth:	2.5 kHz
Average beam pattern:	-28.18 dB
Target strength:	-34 dB/kg

The survey design and area covered was identical to that in 1993 with the exception of the two southern most strata which had to be eliminated because of time lost due to equipment problems at the beginning of the survey.

Fishing sets were made on an opportunistic basis throughout the survey. It was attempted to have at least one set for each twelve hour watch and at least one set for each transect. For those midwater trawl sets that contained capelin, a random sample of 200 capelin was obtained for length, sex, and maturity observations and a stratified age sample was selected from each length/sex/maturity sample. Length composition and an age/length key was constructed for each stratum from the samples obtained in that stratum. As an acoustic estimate of biomass was made for stratum H but no biological sampling was carried out in that stratum, samples from the adjacent strata (G and I) were combined to estimate the length and age composition.

Results

Figure 1 Shows an outline of the strata that were surveyed along with acoustic transects and fishing set locations. Figure 2 shows contoured capelin densitiy from estimates of acoustic density for each 3.1 kilometer segment of survey track. When compared to a similar plot from the 1993 survey (Miller, Chapter 6 in Carscadden 1994), it is evident that the occurrence of capelin in Divisions 2J3K is reduced from that observed in 1993 and has increased in Division 3L, particularily in the south.

Table 1 provides the biomass estimate and acoustic estimation parameters for each stratum from the survey. Stratum K is equally divided by the boundary line between NAFO Divisions 3K and 3L so the biomass estimate for this stratum was split equally between 3K and 3L.

Table 2 provides the acoustic parameters and the biological sampling of capelin for each transect in the survey. Catches from midwater trawl sets in strata A-F indicated that capelin were not present in this area.

Tables 3 and 4 provide the acoustic estimate broken down by age groups into numbers and biomass respectively. For purposes of comparison with the surveys from the 1981-92 period when distinct surveys were carried out in Divisions 2J3K and 3L, the 1993 and 1994 estimates are shown for Division 2J-3K, Division 3L and Divisions 2J3KL in total. The 1994 age distribution is similar to that observed in 1993 with one year old capelin predominant in Division 3L and two year olds predominant in Divisions 2J3K. Overall abundance of 2+ capelin declined in 1994 compared to 1993.

Table 5 provides age composition and mean length at age by survey stratum. Larger (3+) capelin occurred almost exclusively in Divisions 2J-3K while one year old 1992 yearclass capelin were predominant in Division 3L.

References

Miller, D.S. 1994. Results from an acoustic survey for capelin (*Mallotus villosus*) in NAFO divisions 2J3KL in the autumn of 1993.

Table 1. Statistics for each strata and total survey

Strata	Transects sampled	Number of possible transects	Transect area	Transect area scattering coefficient Mean	S.E.	Strata total backscatter	Biomass per transect (tons) Mean	S.E.	Total biomass (tons)
A	3.	25.	237.0	0.	.0	0.	.0	.0	0.
B	2.	25.	319.7	0.	.0	0.	.0	.0	0.
C	2.	25.	343.0	0.	.0	0.	.0	.0	0.
D	2.	25.	309.7	0.	.0	0.	.0	.0	0.
E	4.	30.	189.7	0.	.0	0.	.0	.0	0.
F	4.	45.	432.5	0.	.0	0.	.0	.0	0.
G	5.	35.	555.6	1.	1.3	46.	3.3	3.3	117.
H	7.	60.	604.3	4.	1.4	227.	9.5	3.5	570.
I	4.	30.	642.4	15.	7.7	460.	38.5	19.4	1156.
J	4.	30.	372.1	86.	85.9	2578.	215.8	215.8	6475.
K	4.	30.	396.2	52.	10.1	1573.	131.7	25.4	3952.
L	4.	30.	409.2	81.	16.6	2431.	203.6	41.6	6107.
M	3.	30.	463.7	48.	15.1	1440.	120.6	38.0	3617.
N	5.	60.	735.7	366.	136.8	21931.	918.2	343.7	55089.
P	3.	30.	765.9	340.	75.9	10214.	855.3	190.7	25658.
Total	56.	510.		80.	2.2	40902. .209	201.5	5.6	102740. .209

Table 2. Backscatter, biomass, and biological sampling for each transect.

Strata	Transect Number	Transect length	Transect area	Area scattering	Total backscattering	Density	Transect biomass	# of sets	Lsms	Ages
A	1	128.0	237.0	.00	0.	.00	0.	1	0	0
	2	128.0	237.0	.00	0.	.00	0.	1	0	0
	3	128.0	237.0	.00	0.	.00	0.	0	0	0
B	1	172.6	319.7	.00	0.	.00	0.	1	0	0
	2	172.6	319.7	.00	0.	.00	0.	1	0	0
C	1	185.2	343.0	.00	0.	.00	0.	2	0	0
	2	185.2	343.0	.00	0.	.00	0.	1	0	0
D	1	167.2	309.7	.00	0.	.00	0.	1	0	0
	2	167.2	309.7	.00	0.	.00	0.	1	0	0
E	1	102.4	189.7	.00	0.	.00	0.	1	0	0
	2	102.4	189.7	.00	0.	.00	0.	1	0	0
	3	102.4	189.7	.00	0.	.00	0.	1	0	0
	4	102.4	189.7	.00	0.	.00	0.	1	0	0
F	1	233.5	432.5	.00	0.	.00	0.	1	0	0
	2	233.5	432.5	.00	0.	.00	0.	0	0	0
	3	233.5	432.5	.00	0.	.00	0.	1	0	0
	4	233.5	432.5	.00	0.	.00	0.	2	0	0
G	1	300.0	555.6	.00	0.	.00	0.	0	0	0
	2	300.0	555.6	.00	0.	.00	0.	1	0	0
	3	300.0	555.6	.00	0.	.00	0.	0	0	0
	4	300.0	555.6	.01	7.	.03	17.	1	200	32
	5	300.0	555.6	.00	0.	.00	0.	2	0	0
H	1	326.3	604.3	.00	0.	.00	0.	1	0	0
	2	326.3	604.3	.00	2.	.01	6.	2	0	0
	3	326.3	604.3	.00	2.	.01	6.	0	0	0
	4	326.3	604.3	.01	7.	.03	18.	2	0	0
	5	326.3	604.3	.00	0.	.00	0.	2	0	0
	6	326.3	604.3	.01	5.	.02	12.	3	0	0
	7	326.3	604.3	.02	10.	.04	24.	1	0	0
I	1	346.9	642.4	.00	0.	.00	0.	1	0	0
	2	346.9	642.4	.01	5.	.02	13.	1	0	0
	3	346.9	642.4	.05	33.	.13	84.	2	393	74
	4	346.9	642.4	.04	23.	.09	58.	1	0	0
J	1	200.9	372.1	.92	344.	2.32	863.	1	200	55
	2	200.9	372.1	.00	0.	.00	0.	1	0	0
	3	200.9	372.1	.00	0.	.00	0.	0	0	0
	4	200.9	372.1	.00	0.	.00	0.	0	0	0
K	1	213.9	396.2	.14	54.	.34	135.	1	200	45
	2	213.9	396.2	.12	47.	.30	119.	0	0	0
	3	213.9	396.2	.08	30.	.19	75.	1	200	44
	4	213.9	396.2	.20	79.	.50	198.	1	200	31
L	1	221.0	409.2	.14	57.	.35	143.	1	200	44
	2	221.0	409.2	.12	51.	.31	127.	1	0	0
	3	221.0	409.2	.23	96.	.59	241.	1	200	38
	4	221.0	409.2	.29	121.	.74	303.	2	400	72
M	1	250.4	463.7	.08	39.	.21	97.	1	200	20
	2	250.4	463.7	.17	78.	.42	195.	3	200	23
	3	250.4	463.7	.06	28.	.15	70.	0	0	0
N	1	397.2	735.7	1.21	890.	3.04	2237.	1	0	0
	2	397.2	735.7	.34	252.	.86	633.	4	400	48
	3	397.2	735.7	.35	261.	.89	655.	2	400	71
	4	397.2	735.7	.45	331.	1.13	831.	0	0	0
	5	397.2	735.7	.13	94.	.32	235.	1	200	28
P	1	413.6	765.9	.25	195.	.64	490.	1	200	27
	2	413.6	765.9	.59	451.	1.48	1134.	2	400	50
	3	413.6	765.9	.49	375.	1.23	942.	0	0	0

Table 3. Numbers (billions) at age of capelin from NAFO Division 2J3K hydroacoustic surveys.

Year	Cruise	Date/Age	1	2	3	4	5+	Total
1994	248	Sept 12-Oct 29						
		2J3KL combined	33.5	1.6	0.1	<0.1	0.0	35.2
		2J3K only	0.3	0.5	0.1	<0.1	0.0	0.8
		3L only	33.2	1.1	<0.1	<0.1	0.0	34.4
1993	234	Aug 29-Oct 19						
		2J3KL combined	10.9	1.1	0.3	<0.1	<0.1	12.4
		2J3K only	0.2	0.7	0.3	<0.1	<0.1	1.3
		3L only	10.7	0.4	<0.1	0.0	0.0	11.1
1992	223	Oct 2-25	0.1	1.9	0.2	<0.1	0.0	2.3
1991	207	Oct 4-28	4.7	2.5	0.4	0.1	<0.1	7.7
1990	189	Oct 6-28	1.4	2.6	1.6	0.6	<0.1	6.2
1989	173	Oct 13-29	1.9	59.0	35.3	2.5	0.5	99.2
1988	158	Oct 7-24	15.8	96.0	13.6	2.0	3.9	131.3
1987	144	Oct 10-25	0.7	4.4	0.5	0.6	0.1	6.3
1986	130	Oct 18-29	0.1	6.6	12.1	1.1	0.2	20.1
1985	115	Sept 26-Oct 19	1.5	54.0	13.5	1.5	0.6	71.1
1984	100	Sept 29-Oct 22	6.2	34.7	7.1	4.1	0.4	52.5
1983	85	Oct 2-24	2.6	2.5	1.3	0.2	0.0	6.6
1981	56	Oct 1-19	67.8	59.3	7.4	2.8	0.7	138.0

Table 4. Biomass (thousands of tons) at age of capelin from NAFO Division 2J3K hydroacoustic surveys.

Year	Cruise	Date/Age	1	2	3	4	5+	Total
1994	248	Sept 12-Oct 29						
		2J3KL combined	84.0	16.1	2.1	0.5	0.0	102.7
		2J3K only	1.9	6.5	1.5	0.4	0.0	10.3
		3L only	82.1	9.6	0.6	0.1	0.0	92.4
1993	234	Aug 29-Oct 19						
		2J3KL combined	25.8	12.4	6.6	0.7	<0.1	45.5
		2J3K only	1.6	9.5	6.1	0.7	<0.1	17.9
		3L only	24.2	2.9	0.5	0.0	0.0	27.6
1992	223	Oct 2-25	0.5	28.6	4.3	0.6	0.0	34.0
1991	207	Oct-4-28	10.7	32.6	8.8	2.1	0.4	54.6
1990	189	Oct 6-28	1.8	43.8	36.2	14.1	0.5	96.4
1989	173	Oct 13-29	15.4	850.1	791.2	68.9	18.5	1744.1
1988	158	Oct 7-24	76.2	1208.7	336.9	55.1	127.0	1803.9
1987	144	Oct 10-25	3.9	77.8	12.0	15.1	3.0	111.8
1986	130	Oct 18-29	0.7	109.9	284.1	30.2	6.0	430.9
1985	115	Sept 26-Oct19	8.4	686.6	286.3	36.7	17.8	1035.4
1984	100	Sep 29-Oct 22	25.5	497.9	181.9	109.8	11.3	826.4
1983	85	Oct 2-24	17.6	41.1	31.2	4.3	0.0	94.2
1981	56	Oct 1-19	337.8	891.2	172.4	71.9	20.8	1494.1

Table 5. Age composition and mean length at age ,total number in billions, total mean length, and number of samples by survey stratum.

Stratum	Age	1	2	3	4	5+	Total N/L	Number of samples
G	%	0.0	90.0	10.0	0.0	0.0	<0.1	1
	L	-	146	151	-	-	146	
H	%	0.5	65.0	24.7	9.8	0.0	<0.1	3
		96	147	155	160	-	150	
I	%	0.8	51.0	32.1	16.6	0.0	<0.1	2
	L	96	148	156	160	-	152	
J	%	14.2	74.5	10.2	1.0	0.0	0.5	1
	L	122	146	164	173	-	144	
K	%	70.5	28.4	0.9	0.2	0.0	0.5	3
	L	118	132	145	168	-	122	
L	%	66.6	31.2	1.9	0.3	0.0	0.9	4
	L	110	131	155	164	-	118	
M	%	99.8	0.2	0.0	0.0	0.0	2.0	2
	L	86	113	-	-	-	86	
N	%	96.8	3.1	0.1	0.0	0.0	31.7	5
	L	85	120	148	-	-	85	
P	%	99.5	0.5	0.0	0.0	0.0	11.0	3
	L	91	126	-	-	-	93	
Total	%	95.5	4.1	0.3	0.1	0.0	46.7	
	L	87	128	156	163	-	89	

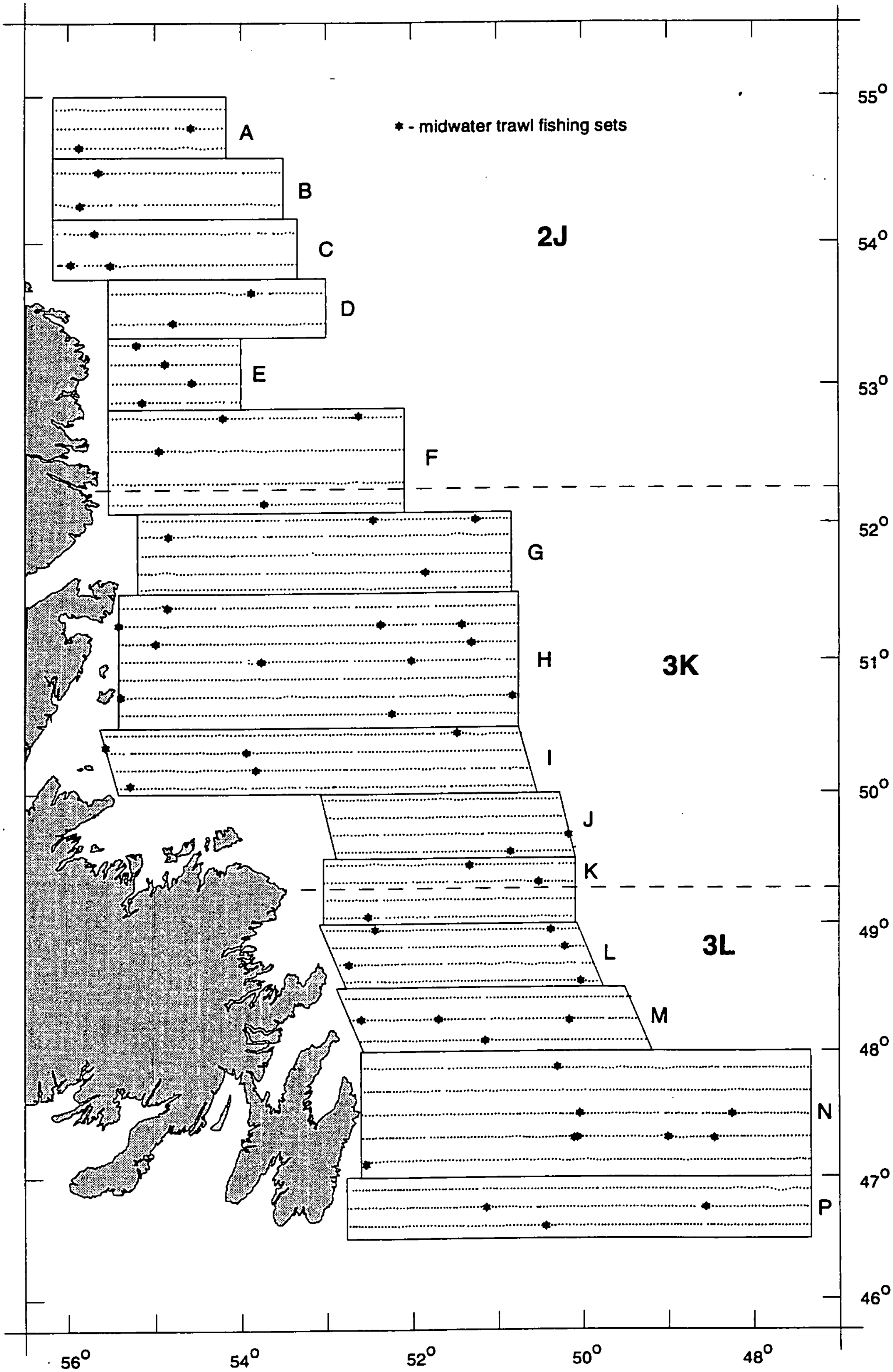

Figure 1. Cruise track, survey area and fishing set locations

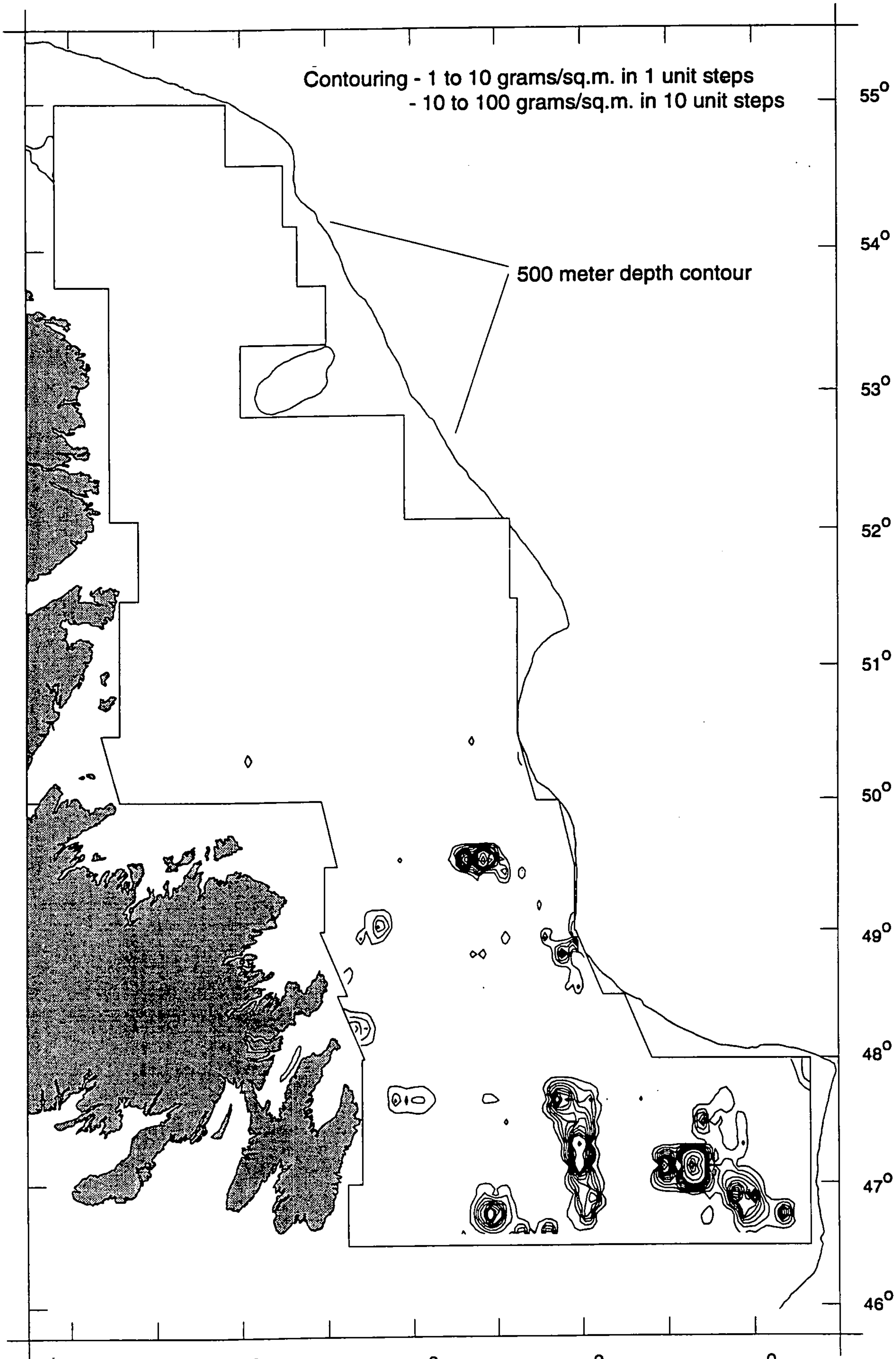

Figure 2. Contoured capelin distribution - autumn 1994 survey

Results from Monitoring Six Spawning Beaches on the Northeast Coast of Newfoundland

by

B. S. Nakashima and G. H. Winters
Science Branch
Department of Fisheries and Oceans
P. O. Box 5667
St. John's, NF A1C 5X1

Introduction

In 1990 we monitored spawning times, egg deposition and development, larval emergence and various environmental variables (eg. sunlight hours, wind direction and speed, air temperature, water temperature, precipitation, beach sediment temperatures, beach disturbance) on two capelin spawning beaches located at Arnold's Cove in Div. 3Ps and at Bellevue Beach in Div. 3L (Fig. 1). The number of sites was expanded in 1991 to include five more beaches in Div. 3KL at Chapels Cove, Eastport, Cape Freels, Twillingate, and Hampden (Fig. 1). In this report we present information on age compositions, fish lengths, spawning times, egg deposition estimates, and estimates of emerging larvae from the six beaches located in Div. 3KL.

Materials and Methods

Adult Samples

Random samples of 25 males and 25 females were collected at each beach whenever significant spawning had taken place. Fish were measured for length and weight and otoliths removed for age determination. In 1990 only females were collected from Bellevue Beach.

Egg Samples

During low tide conditions egg samples in beach sediments were collected every time substantial spawning had taken place and once every 48 hours until eggs were no longer on the beach (<500 eggs per sample). Nine samples subdivided into three samples per tidal zone (low tide, mid tide, high tide) were collected each time. A steel sediment corer (6.5 cm internal diameter) was used to collect each sample as described in Nakashima and Slaney (1993). Samples were preserved in 4% formalin and seawater solution buffered with sodium borate. To separate eggs from sediments, samples were immersed in 2% KOH solution for 24-36 hr. To estimate egg abundance, eggs were counted by subsampling with a whirling vessel (Pitt 1965) or by using a volume displacement technique.

At each sampling at least 50 eggs were placed in Stockard's Solution (Bonnet 1939) to fix and clear the eggs. Stages I-II which include eggs from fertilization to the formation of the blastula accounts for egg development up to the first 1.5 days according to Fridgeirsson (1976).

Egg Density

The ratio of Stage I-II eggs to all eggs in the Stockard's sample was used to estimate the number of Stage I-II eggs occurring in each beach core sample assuming that these eggs had been deposited recently on the beach. The daily average density of Stage I-II stage eggs in all cores per tidal zone on a given beach was then estimated. An average beach density as assumed to be the mean of the three tidal zones. Total egg density per beach was the sum of the daily average beach density estimates of stage I-II eggs.

Larval Emergence

Newly emerging larvae were collected in the intertidal zone at high tide water conditions generally twice a day. A 165 μm plankton net was towed parallel to the beach, rinsed, and the contents preserved in 4% formalin and seawater solution buffered with sodium borate. Two tows were conducted each time. Larvae were enumerated by subsampling when sample size was large using splitting techniques. Larvae were categorized into 'good' and 'bad' condition larvae based on visual inspection. Larval density was expressed as larvae per m^3. Total production of larvae per beach was the sum of all high tide estimates in a given year.

Results and Discussion

Age Composition

Age compositions from samples of spawning fish from 1990 to 1994 indicate that age 3 fish dominated in 1990, 1993 and 1994 and age 4 in 1991 and 1992 (Table 1). Samples collected over the entire spawning season in 1994 may be more representative of the spawning population than commercial samples which were primarily from one area.

Egg Density

Egg density was based on four complete (1991-94) and one incomplete (1990) survey and was high in 1991 and 1993 and low in 1992 (Table 2). Egg density on the monitored beaches was very low in 1994 with no spawn being deposited on the beach in Cape Freels. Unfortunately, there are no estimates from these beaches in the 1980's when spawning times were earlier. Consequently, there are insufficient years to adequately assess trends in the estimates.

Larval Emergence

For the four years available with full coverage 1992-93 appears to have higher production of larvae than 1991 or 1994 (Table 2). Although only Bellevue Beach was monitored in 1990 larval production relative to later years at Bellevue Beach was relatively high (Fig. 2).

Spawning Time

The spawning period was noticeably short at Chapel Cove, Twillingate, and Eastport in 1994 compared to other years, whereas Hampden had an extended spawning season (Table 2). Spawning tended to be earlier and shorter at beaches where water temperatures were warm and drawn out where water temperatures were cooler.

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Pitt, T. K. 1965. Modification of the whirling vessel for fecundity studies. J. Fish. Res. Board Can. 22: 247-251.

Table 1. Age composition by numbers for mature capelin in Div. 3KL combined. In 1990 only females from Div. 3L were sampled.

		Age				
Sex	Year	2	3	4	5	6
F	1990	4.8	49.8	42.2	3.2	0
	1991	4.8	37.5	41.0	15.9	0.8
	1992	8.9	34.9	47.3	8.8	0.1
	1993	9.2	69.3	18.0	3.0	0.5
	1994	16.9	49.6	25.3	7.9	0.3
M	1991	4.0	34.6	52.4	8.8	0.2
	1992	2.8	25.5	60.4	11.1	0.2
	1993	1.5	64.7	30.6	3.2	0
	1994	7.8	55.0	32.4	4.5	0.2
Combined	1991	4.4	35.8	47.6	11.8	0.4
	1992	5.7	30.0	54.1	10.0	0.2
	1993	5.4	67.0	24.2	3.1	0.2
	1994	12.2	52.3	28.9	6.4	0.2

Table 2. Egg density, larval emergence, and spawning dates for each of the monitored beaches.

Year	Chapel Cove (3L)	Bellevue Beach (3L)	Eastport (3L)	Cape Freels (3K)	Twillingate (3K)	Hampden (3K)	Total
Total Egg Density ('000 eggs/core)							
1990	-	62.4	-	-	-	-	(62.4)
1991	45.8	223.8	146.1	148.5	132.2	95.2	791.6
1992	91.1	155.5	199.1	41.2	22.2	59.9	569.0
1993	36.6	222.3	167.9	247.9	66.9	160.3	901.9
1994	48.0	130.7	3.6	0	1.0	53.4	236.7
Total Emerging Larvae ('000 larvae/m^3)							
1990	-	206.4	-	-	-	-	(206.4)
1991	27.6	59.5	48.8	52.3	28.8	4.9	221.9
1992	10.3	190.1	135.1	38.2	61.2	35.0	469.9
1993	18.8	102.7	24.7	46.9	45.1	97.4	335.6
1994	25.9	107.0	1.5	0	3.8	14.7	152.9
Total 'Good Condition' Larvae ('000 larvae/m^3)							
1990	-	116.8	-	-	-	-	(116.8)
1991	20.9	43.1	44.0	38.3	27.7	4.3	178.3
1992	10.2	181.4	109.9	33.8	46.2	34.2	415.7
1993	17.1	100.4	18.4	38.4	44.0	93.4	311.7
1994	24.6	83.2	1.4	0	3.6	14.6	127.4
Spawning dates (Julian Day)							Range
1990	-	175-207	-	-	-	-	175-207
1991	192-219	185-234	178-214	209-230	210-226	188-232	178-234
1992	205-230	185-232	187-204	205-230	190-210	192-224	185-232
1993	190-218	182-242	197-220	198-229	190-233	188-249	182-249
1994	186-195	180-217	199-210	-	207-209	173-235	173-235

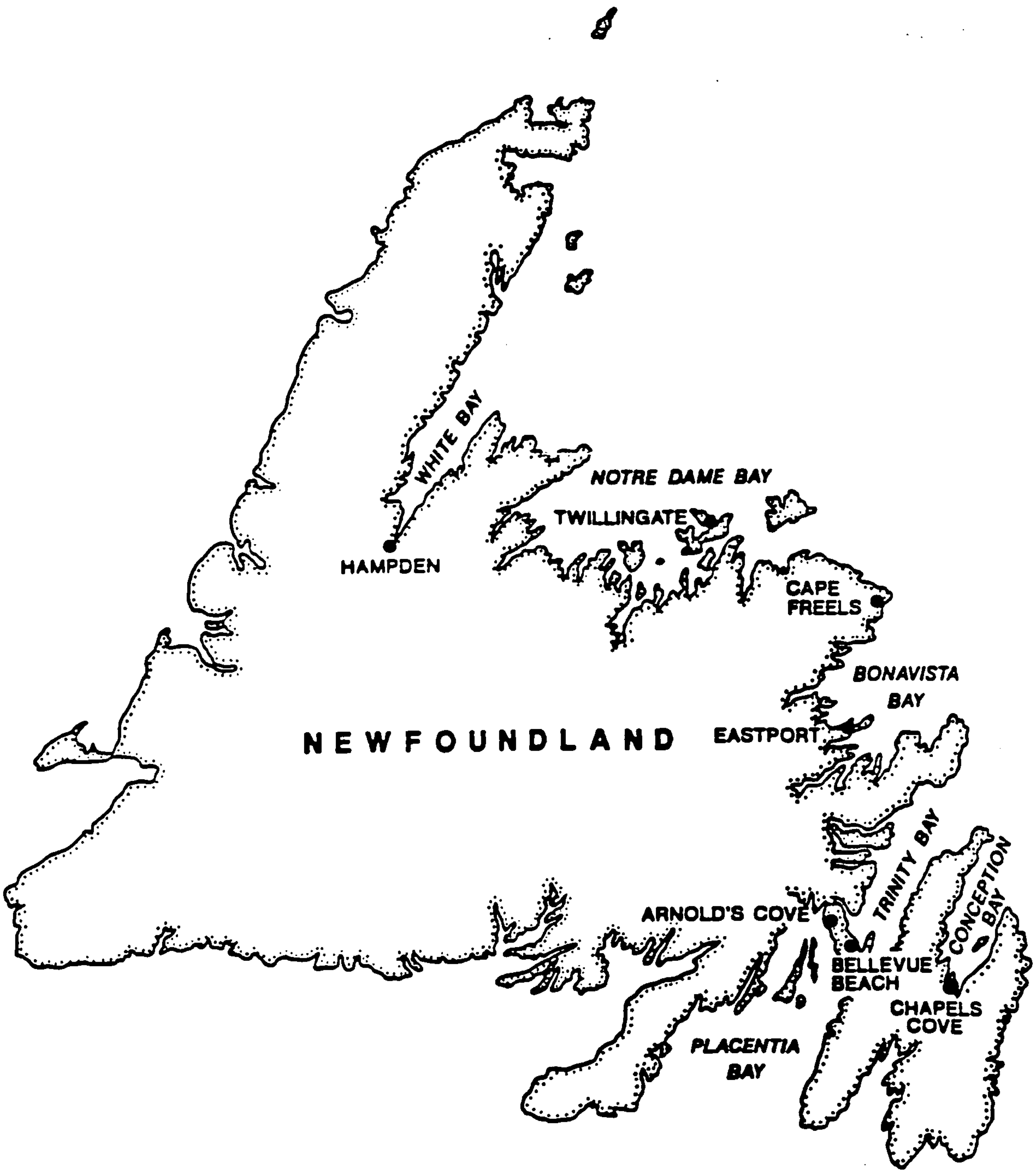


Fig. 1. Sampling sites.

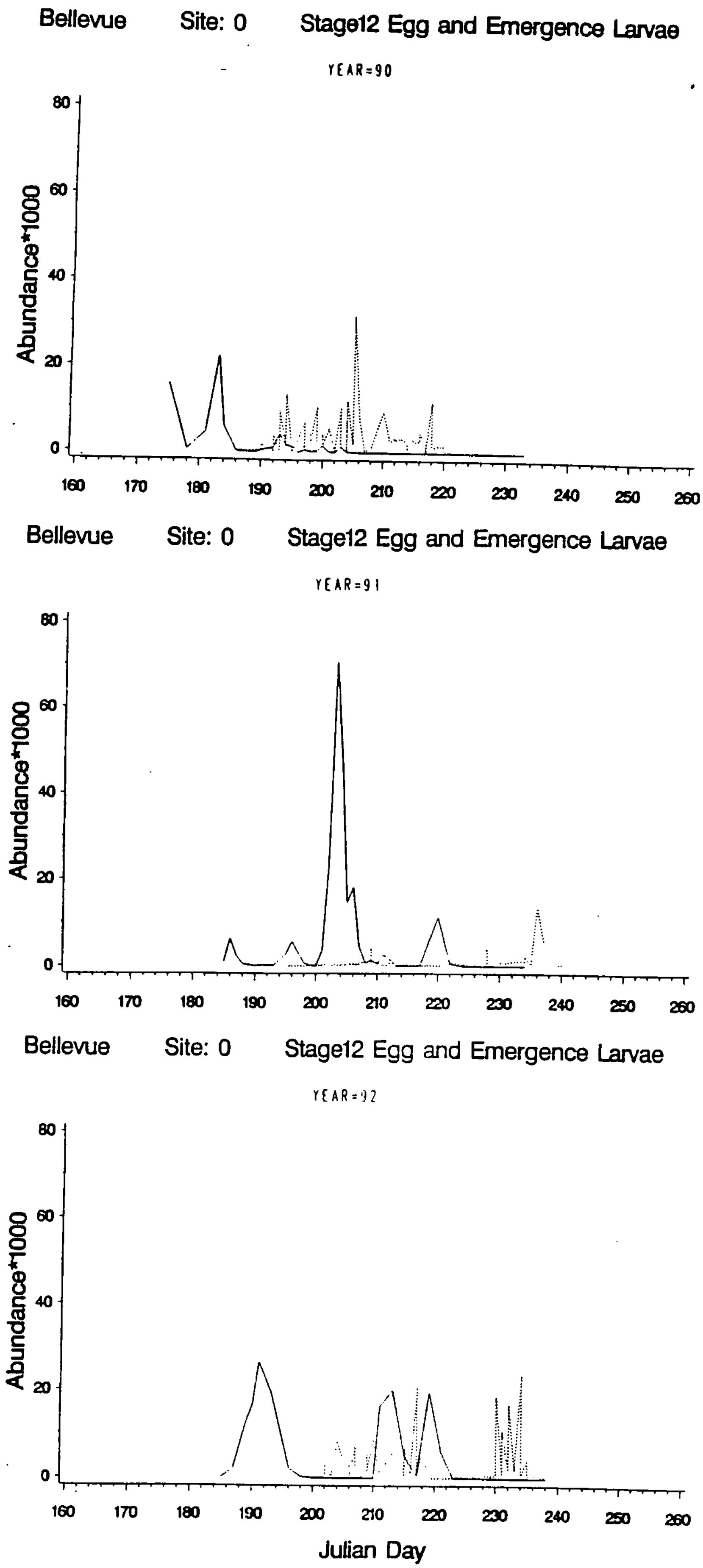
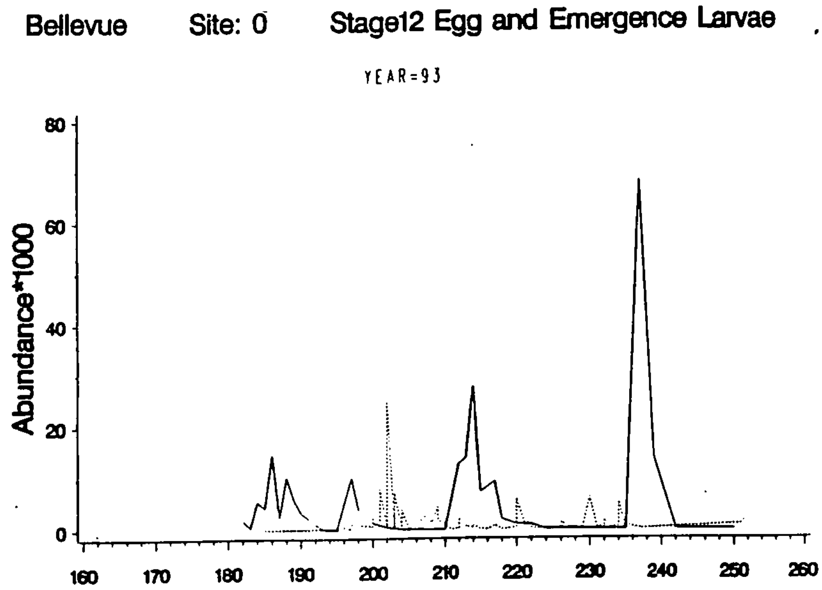


Fig. 2. Stages I-II eggs (solid line) per core and larval emergence (broken line) per m^3 patterns for Bellevue Beach.



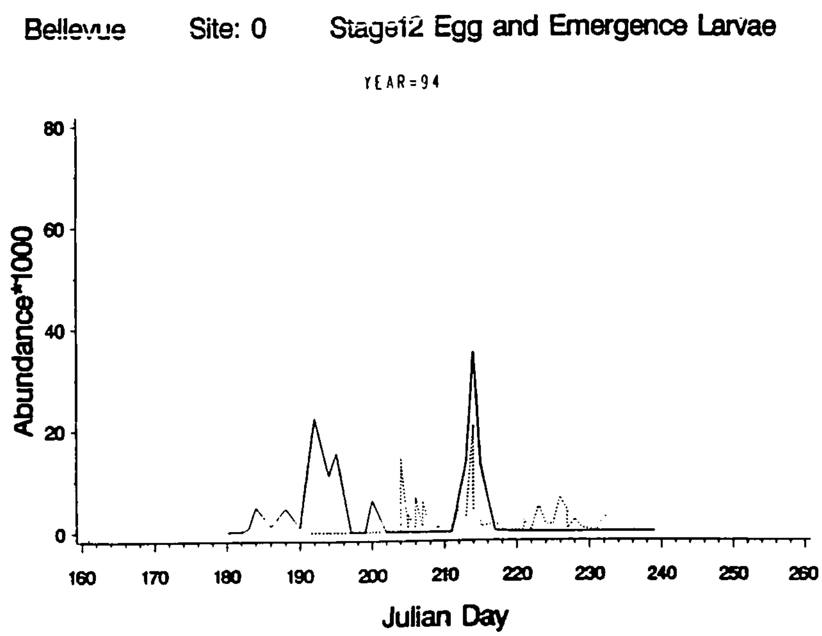


Fig. 2. Continued ...

Changes in Distribution of Capelin in Divisions 2J3KL During Autumn, as Inferred from Cod Stomach Contents

by

G. R. Lilly
Science Branch
Department of Fisheries and Oceans
P. O. Box 5667
St. John's, NF A1C 5X1

Introduction

The occurrence of capelin in the stomachs of cod caught in the offshore environment of Divisions 2J3KL during the autumn (Lilly 1987, 1991, 1994b) provides a source of information on capelin distribution and relative abundance which is independant of the information obtained from capelin acoustic surveys and the offshore capelin fishery. During the period 1980-1988, the average quantity of capelin in cod stomachs, expressed as a stomach fullness index, was moderate to high in two broad regions: (1) northern and western Divisions 2J3K (Hamilton Bank, western Belle Isle Bank, and the inner shelf off northeastern Newfoundland) and (2) northern Division 3L (northern and northeastern slopes of Grand Bank) (Fig. 1). In many years, such as 1984 and 1985 (Fig. 2), the capelin in Divisions 2J3K were primarily on Hamilton Bank and along the coastal shelf off southern Labrador and northeastern Newfoundland, whereas in some other years, notably 1986 and 1987 (Fig. 3), they were more aggregated on the central Northeast Newfoundland Shelf. The capelin in Divisions 2J3K experienced a pronounced shift from the northwest to the southeast during the early 1990s. The apparent distinction between a Division 2J3K group and a Division 3L group was less clear in 1990 and absent in 1991 and 1992 (Fig. 4).

These changes in capelin distribution, as inferred from examination of cod stomach contents, are similar to those revealed from other sources, including the by-catches of capelin during the autumn bottom-trawl surveys (Lilly and Davis 1993). The latter have been examined during the annual capelin assessment meetings since 1989 to determine if there is evidence of substantial quantities of capelin outside the area covered by the Canadian acoustic surveys (Carscadden et al. 1989; Carscadden et al. 1990; Miller and Lilly 1991; Lilly 1992, 1994a). The information from cod stomach contents has not been presented routinely to the annual capelin assessment meetings because the meetings have generally been held early in the year, before the cod stomach content data have become available. Nevertheless, such information may be of value in assessing historical patterns in the distribution and relative abundance of capelin.

This chapter provides information on the occurrence of capelin in cod stomachs in Divisions 2J3KL during the autumn of 1993.

Materials and Methods

Cod stomachs were collected during the autumn bottom trawl survey in 1993 (see Lilly 1994a for details of the survey), and examined as described in Lilly (1994b).

To study the geographical distribution of capelin, it was assumed that the average quantity of capelin in the stomachs of cod collected at a specific locality reflected the relative abundance of capelin at that locality (Fahrig et al. 1993). The average quantity of capelin in the stomachs of the cod in a specified sample was expressed as a mean partial fullness index:

$$PFI_c=\frac{1}{n}\sum_{j=1}^{n}\frac{W_{cj}}{L_j^3}*10^4$$

where W_{cj} is the weight (g) of capelin in fish j, L_j is the length (cm) of fish j, and n is the number of fish in the sample. This index is based on the assumption that stomach capacity is a power function of length, and is analogous to Fulton's condition factor (body weight/length^3). For simplicity, the present analysis was restricted to cod within the 36-71 cm length range, and all cod within this range were pooled. Cod smaller than about 30-35 cm cannot feed on the largest capelin and cod larger than about 70 cm tend to feed to an increasing extent on groundfish and crabs (Lilly 1991).

The geographic distributions of cod catches and capelin in cod stomachs (PFI_c) are presented in expanding symbol plots in order to provide visual information on annual changes in the spatial distribution of fishing stations, the among-station variability in cod catch and PFI_c, and the relationship between fish distribution and bathymetry. This presentation also permits station-by-station comparison of the cod catch and the quantity of capelin in cod stomachs.

Results and Discussion

Distribution

Catches of cod during autumn 1993 were very small, with the exception of a few moderate catches near the shelf break just south of the 3K/3L boundary (Fig. 5). This greatly limited the value of cod as a sampling tool for capelin.

Capelin were found in greatest quantities in the stomachs of those cod caught in southeastern Division 3K and in northern Division 3L (Fig. 5). The northern limit of the occurrence of capelin in cod stomachs in large quantities was approximately the middle of Funk Island Bank, which is further south than in any previous year. The lack of a distinction between a Division 2J3K group and a Division 3L group has continued.

The distribution of capelin, as inferred here from cod stomachs, is similar to that revealed by the by-catches of capelin during the survey (Lilly 1994a). However, for Division 3K, the stomach content data revealed capelin primarily in the southeastern quadrant, whereas the by-catches were largest in the northern and central areas (especially the western flank of St. Anthony Basin, the flanks of the southern half of Funk Island Deep, and the saddle between Belle Isle Bank and Funk Island Bank).

Potential indices of capelin abundance

The intensity of feeding by cod on capelin may be positively correlated with capelin abundance (Lilly 1991; Fahrig et al. 1993). Potential indices of capelin abundance are (1) percentage occurrence (the percentage of stations in which capelin were found in cod stomachs) and (2) average PFI_c (the average quantity of capelin in cod stomachs, expressed as the mean of station PFI_c values). In Division 2J3K, the percentage occurrence (48%) was just below the median of 52% and the average PFI_c (1.03) was above the median of 0.91 but far below the maximum of 1.95 (Table 1). In Division 3L, both the percentage occurrence (64%) and the average PFI_c (1.29) were the maximum values in their respective time-series.

The value of these simple statistics as potential indices of capelin abundance was diminished by a change in survey design, which occurred in 1991, and the reduction in cod distribution, which has become increasingly dramatic since 1989. An adjustment for the change in survey design could be applied, using the procedure adopted for the capelin by-catch data (Lilly, this meeting). However, an appropriate adjustment for inadequate spatial coverage (that is, the absence of cod from many strata) is not readily apparent. There is also a concern about the potential influence of the high proportion of small cod catches. It has been demonstrated that there is a tendency for large PFI_c values to be found only in cod obtained from small catches, whereas individual cod taken from large catches tend to have small PFI_c values (Lilly 1994b). Therefore, average PFI_c values may be inflated in recent years. It is therefore recommended that the cod stomach content data not be used to provide a potential index of capelin abundance. If these data are to be explored as potential indices, there should also be consideration of that portion of the stomach contents which was recorded as unidentified fish (Lilly 1991). The ratio of identified fish to unidentified fish varied among years.

The possibility of using the stomach contents of Greenland halibut to identify changes in capelin distribution and to provide an index of capelin abundance should be investigated. Medium-sized

Greenland halibut in Division 2J3K feed almost exclusively on capelin in the autumn (Bowering and Lilly 1992) and have not experienced the severe reduction in distribution which has been observed in cod.

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Table 1. Occurrence of capelin in stomachs of cod (36-71 cm only) caught during phase 1 of surveys in Divisions 2J3KL in the autumns of 1977-1993. (Updated from Lilly and Davis 1993)

Year	Div.	No. of stations where stomachs collected	Stations with capelin in stomachs No.	%	Mean[ab] PFI_c
1977	2J3K	40	3	8	0.01
1978	2J3K	70	1	1	+
1979	2J3K	-			
1980	2J3K	122	27	22	0.11
1981	2J3K	137	71	52	0.77
	3L	76	26	34	0.16
1982	2J3K	239	91	38	0.26
	3L	85	25	29	0.15
1983	2J3K	195	117	60	0.38
	3L	104	47	45	0.21
1984	2J3K	207	114	55	0.63
1985	2J3K	229	133	58	0.91
	3L	163	78	48	0.64
1986	2J3K	176	80	45	1.19
	3L	113	57	50	0.60
1987	2J3K	234	150	64	1.00
	3L	134	78	58	0.56
1988	2J3K	184	121	66	1.69
	3L	148	58	39	0.56
1989	2J3K	185	129	70	1.79
	3L	121	56	46	0.70
1990	2J3K	132	93	70	1.95
	3L	124	69	56	1.12
1991	2J3K	217	60	28	0.72
	3L	150	86	57	1.15
1992	2J3K	193	94	49	1.50
	3L	133	78	59	1.26
1993	2J3K	107	51	48	1.03
	3L	85	54	64	1.29

[a]Mean of station means. [b]+ indicates presence but $PFI_c < 0.005$.

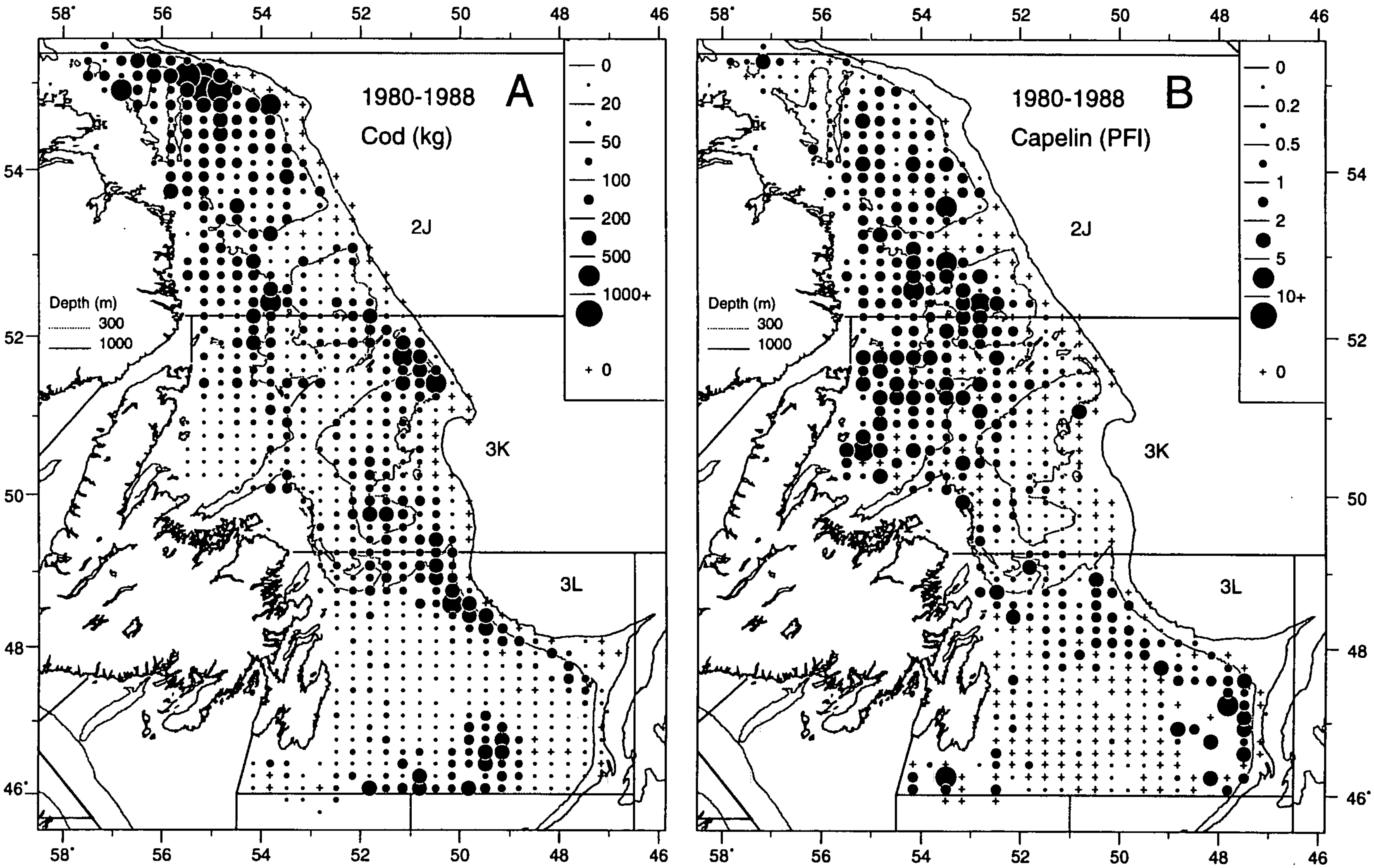

Fig. 1. (A) Mean catch of cod (kg/30 min tow) and (B) mean partial fullness index for capelin in cod stomachs, in 1980-1988. The data from all tows in areas of 10′ latitude and 20′ longitude were combined. From Lilly (1994).

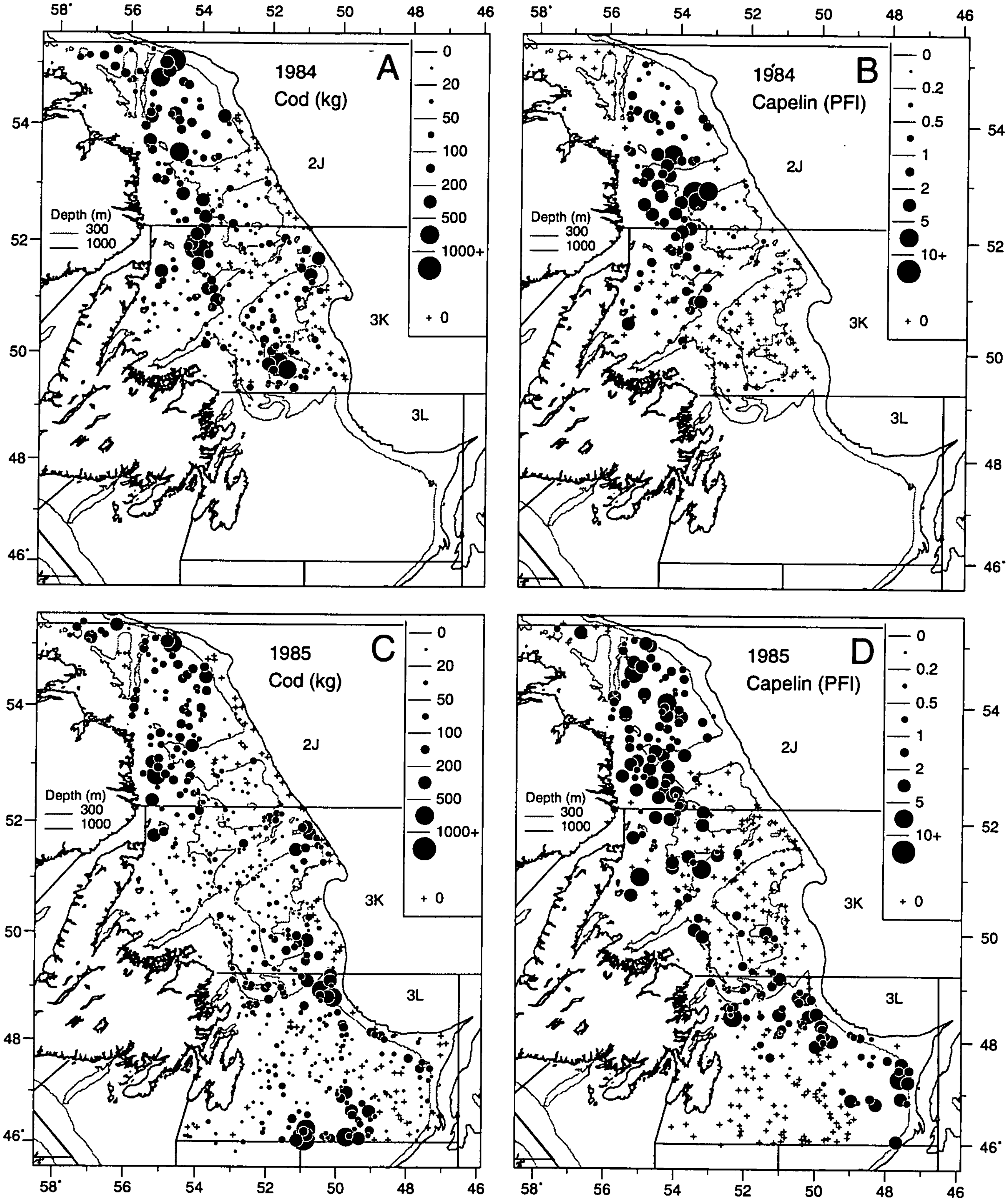

Fig. 2. Cod catch (kg/30 min tow) and average partial stomach fullness index for capelin (PFI_c), for each fishing station in 1984 and 1985. There was no survey in Division 3L in autumn 1984. From Lilly (1994).

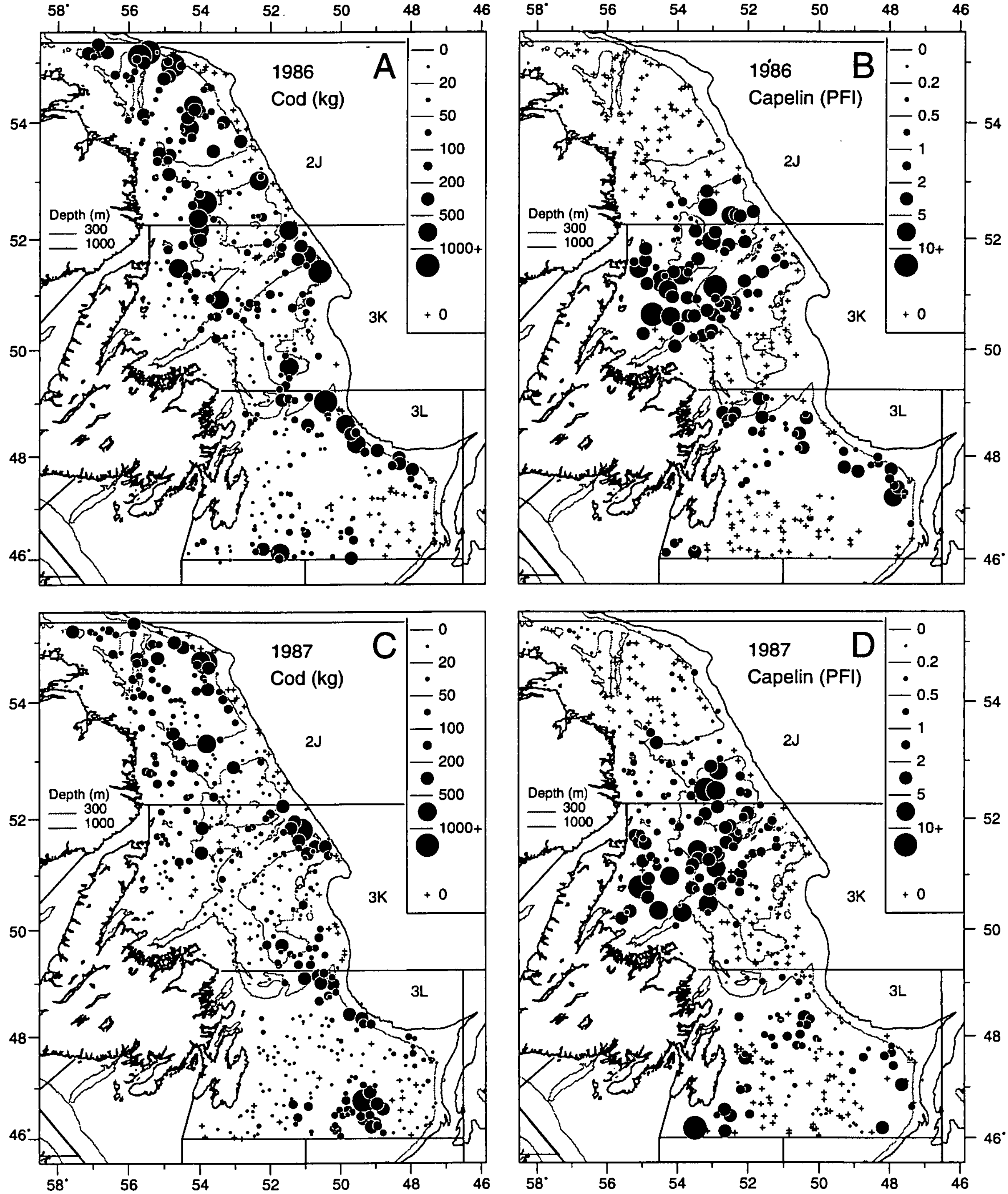

Fig. 3. Cod catch (kg/30 min tow) and average partial stomach fullness index for capelin (PFI_c), for each fishing station in 1986 and 1987. Panels for 1986 are from Lilly (1994).

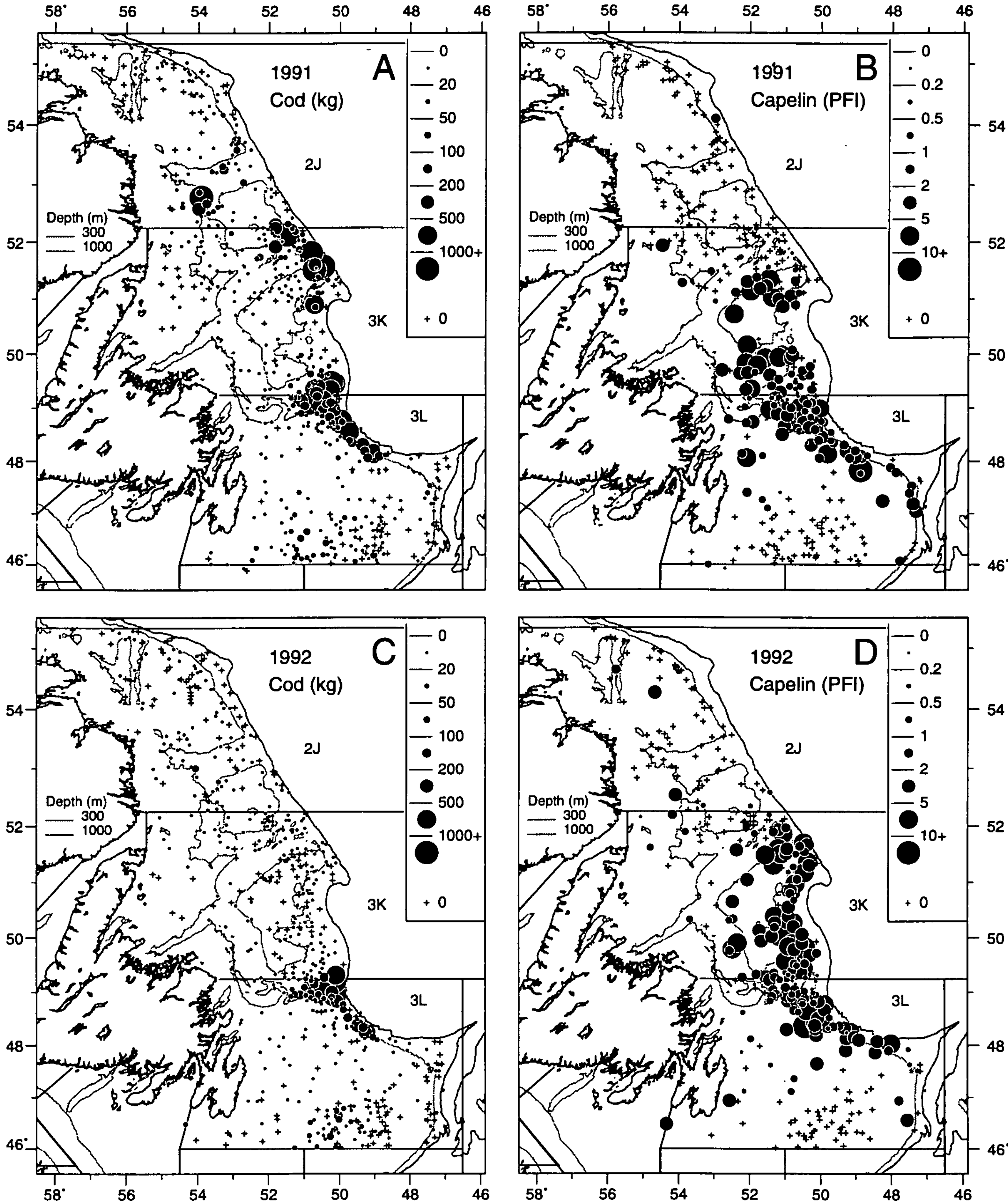

Fig. 4. Cod catch (kg/30 min tow) and average partial stomach fullness index for capelin (PFI_c), for each fishing station in 1991 and 1992. From Lilly (1994).

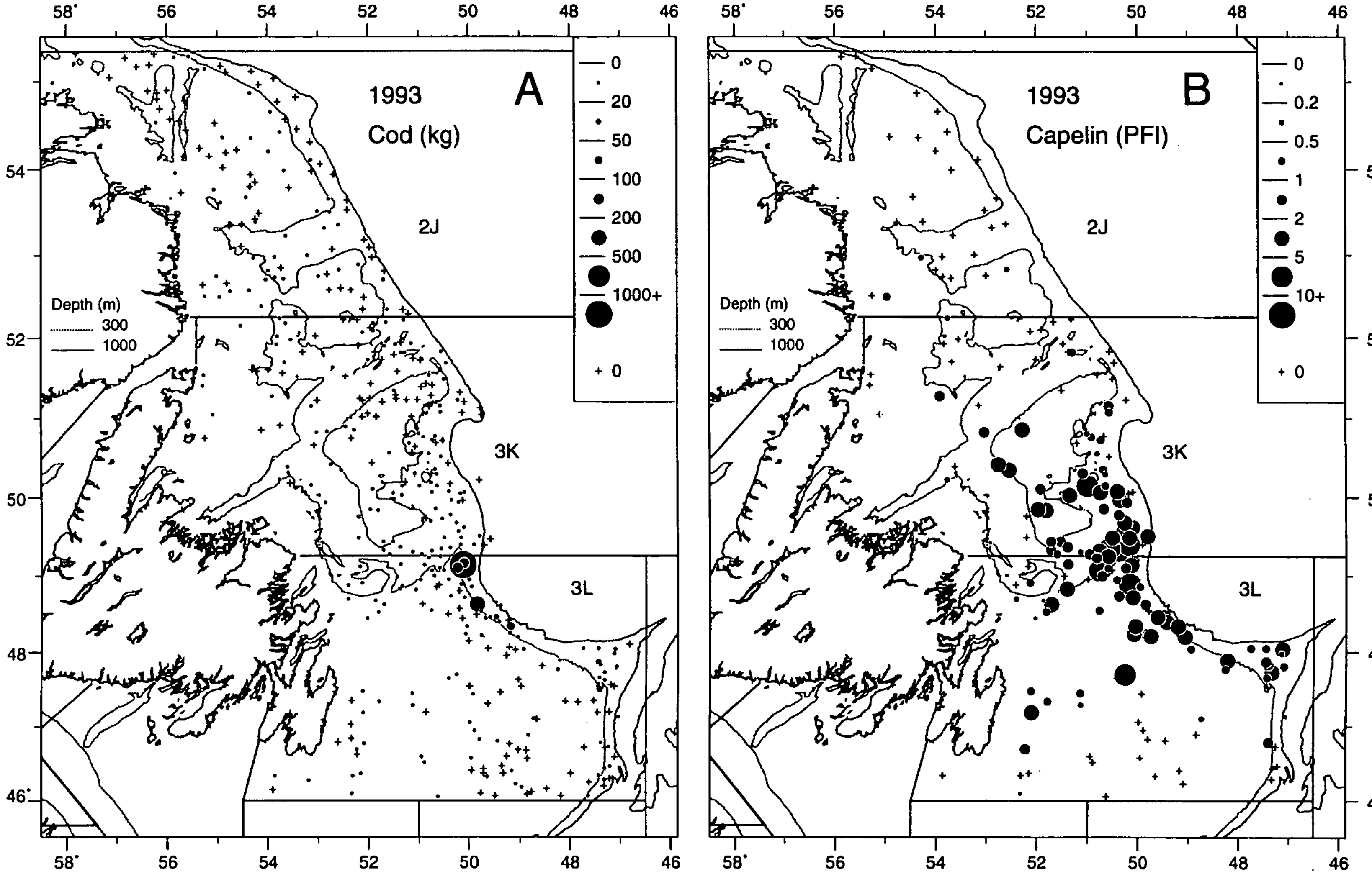

Fig. 5. Cod catch (kg/30 min tow) and average partial stomach fullness index for capelin (PFI_c), for each fishing station in 1993.

By-catches of Capelin During Autumn Bottom Trawl Surveys in Divisions 2J3KLNO, with Emphasis on 1994

by

G. R. Lilly
Science Branch
Department of Fisheries and Oceans
P. O. Box 5667
St. John's, NF A1C 5X1

Introduction

Capelin are frequently caught during bottom trawl surveys directed toward demersal fish off southern Labrador and eastern Newfoundland. The distribution and magnitude of capelin catches from the surveys in Divisions 2J and 3K during the autumns of 1978-93 have been compared with geographic coverage by acoustic surveys for capelin to help determine whether coverage by the acoustic surveys has been adequate (Carscadden et al. 1989; Carscadden et al. 1990; Miller and Lilly 1991; Lilly 1992, 1994a) and to provide supporting data on changes in capelin distribution (Lilly and Davis 1993). This chapter continues this series of comparisons with data from the bottom trawl survey in autumn 1994. In addition, the broader-scale distribution of capelin in autumn 1994 is examined with catch data from bottom trawl surveys on Grand Bank (Div. 3LNO). These surveys provide information on capelin distribution south of the area covered by the acoustic survey, which was restricted to Divisions 2J and 3K in 1981-1992 and extended to Division 3L in 1993 and 1994.

There has also been interest in exploring the extent to which the frequency of occurrence of capelin in bottom trawl catches might provide an index of capelin abundance. This chapter provides information on the frequency of occurrence of capelin in Division 2J3K (1978-1994) and Division 3L (1981-1994, excluding 1984), where the frequency of occurrence is adjusted to take into account the high proportion of sets allocated to certain strata in each year beginning in 1991. Estimates of biomass from areal expansion of mean catch per tow are also provided.

Materials and Methods

Surveys

Capelin were caught during random-stratified bottom trawl surveys designed to assess the biomass of demersal fish during October-December 1978-1993 (Table 1) and 1994 (Table 2). All surveys in Divisions 2J and 3K were conducted with the 74 m stern trawler R.V. 'Gadus Atlantica'. Surveys in Division 3L were conducted with the 51 m side trawler R.V. 'A. T. Cameron' and the sister 50 m stern trawlers R.V. 'Wilfred Templeman' and R.V. 'Alfred Needler'. There were no autumn surveys in Division 3L in 1978-1980 and 1984. The 'Gadus Atlantica', 'Wilfred Templeman' and 'Alfred Needler' deployed an Engel-145 trawl, whereas the 'A. T. Cameron' deployed a Yankee 41-5 trawl. In all instances, a 29 mm meshliner was inserted in the codend. Tows were made at 3.5 knots for 30 min at each fishing station, and catches from the few tows of duration other than 30 min were appropriately adjusted. No adjustments were made for possible between-vessel differences in catching efficiency. Additional details regarding areas and locations of strata and changes in survey pattern are provided by Bishop et al. (1994), Lilly and Davis (1993) and Bishop (1994). The most notable change in survey coverage was the addition of depths between 100 and 200 m in northwestern Division 3K (St. Anthony Shelf and Grey Islands Shelf) in 1984 and subsequent years. Fishing in all Divisions and years was conducted on a 24-h basis.

Distributions

The distribution of capelin is presented in expanding symbol plots, as opposed to contour plots generated from modelling of the catches, in order to provide visual information on the spatial distribution of fishing stations, among-station variability in catch of capelin, and the relationship between capelin catches and bathymetry.

Estimation of frequency of occurrence of capelin

The frequency of occurrence of capelin in the bottom trawl catches is simply the number of occurrences expressed as a percentage of the number of sets. The number of sets assigned to each stratum was approximately equal to stratum area in 1978-1990, but in subsequent years a proportionally higher number was assigned to sets in which the variance of the cod catch had been high for some years previous. An adjusted percentage occurrence was calculated as

$$O_{ad}=\frac{\sum_{i=1}^{m}\left(\frac{nc_h}{N_h}\times 100\right)A_h}{\sum_{h=1}^{m}A_h}$$

where nc_h is the number of sets in which capelin were caught in stratum h, N_h is the number of sets in stratum h, A_h is the area of stratum h, and m is the number of strata fished.

Estimation of capelin biomass and numbers

The biomass of capelin in each stratum was estimated as

$$W_h = \frac{A_h \sum_{i=1}^{n_h} W_{hi}}{a n_h}$$

where W_{hi} is the weight (kg) of capelin in set i (i = 1, 2, ..., n_h) in stratum h, and a is the area sampled by a standard tow (estimated to be 4.58 x 10^4 m^2). The biomass in each Division was obtained by summing over strata. Population abundance was estimated in the same way.

Results

Surveys in 1994

Divisions 2J3K

Capelin were recorded at 46% of the 237 fishing stations conducted at depths of 750 m or less (Table 3). This is the third highest frequency of occurrence in the period 1978-1994. Catches were moderate compared to previous years (95th percentile = 10 kg; maximum = 30 kg) (Table 3).

Very few capelin were caught on Hamilton and Belle Isle Banks and near the coast off southern Labrador and northeast Newfoundland (Division 2J and western Division 3K) (Fig. 1). Largest catches were in Funk Island Deep, on western Funk Island Bank, and southeast of Funk Island Bank. In general, the distribution in 1994 was similar to that observed in 1991-1993 (Lilly 1992, 1994a; Lilly and Davis 1993).

All of the large catches in Divisions 2J and 3K occurred within the area covered by the acoustic survey, although several near the southern corner of Division 3K were very close to the boundary of the survey (Fig. 1).

Division 3L

Capelin were recorded at 42% of the 200 stations (Table 2). This is the third highest frequency of occurrence in the period 1985-1994 (Table 4). Catches were small compared to earlier years (95th percentile = 1 kg; maximum = 2 kg) (Table 4).

Capelin were caught in northern and northeastern Division 3L and in the Avalon Channel in western Division 3L (Fig. 1,2). There were no catches on the plateau of Grand Bank. There were also no catches in the extreme northeast of Division 3L, where catches had been taken in 1992 and 1993.

Division 3NO

Capelin were recorded in just 3% of the 148 stations (Table 2). Small catches occurred primarily on Whale Bank and the southwestern slope of Grand Bank (Fig. 2).

Frequency of occurrence of capelin in bottom trawl surveys

The adjustment of the frequency of occurrence, to take into account the allocation of a relatively large number of sets to certain strata in 1991-1994, did not substantially change the estimate of the frequency of occurrence, except in Division 3L in 1992 (Table 5, Fig. 3). Increased sampling intensity in strata with a high frequency of occurrence of capelin was usually offset by increased sampling intensity in strata with a low frequency of occurrence.

In Division 2J3K, the adjusted frequency of occurrence increased, with irregular fluctuations, from 20-35% in the early 1980s to 40-50% in the 1990s. Since 1985, the frequency of occurrence in Division 3L has fluctuated more widely than in Division 2J3K. Low values of about 20% in 1990-1991 were followed by high values of about 50% in 1992-1993 and a decline to an intermediate level of about 40% in 1994.

Estimates of abundance and biomass

The minimum trawlable abundance and biomass were relatively high in 1979-1981 (Fig. 4), due almost entirely to a few very large catches on the plateau of Hamilton Bank (Carscadden et al. 1989). The values have fluctuated without trend since 1981.

Discussion

Capelin distribution

Bottom trawl surveys during the autumn of 1994 covered the area from southern Labrador (Division 2J) to the Tail of the Bank (Division 3NO). Largest catches of capelin were taken in central and southeastern Division 3K. Small catches occurred in western Division 3K and northern Division 3L. Only a few very small catches were recorded in Division 2J and Divisions 3NO. As in 1991-1993 (Lilly and Davis 1993; Lilly 1994a), there was no clear distinction between capelin catches in southeastern Division 3K and northern Division 3L. There is no evidence from these surveys that large quantities of capelin occurred outside the boundary of the acoustic survey in Divisions 2J, 3K and 3L, but several large catches were very close to the boundary in southeastern Division 3K.

Comparisons between capelin distribution as observed during the acoustic survey and capelin distribution as inferred from the bottom trawl survey must be treated with caution because the bottom trawl survey did not start until the acoustic survey had finished and required about 6 weeks to complete. Thus, for any point in space, the duration between coverage by the two surveys could be as great as two months.

Capelin abundance

Neither the frequency of occurrence of capelin nor the estimates of capelin abundance and biomass have shown declines in the 1990s, compared with levels in the period 1982-1989. However, the extent to which either of these metrics may serve as indices of capelin abundance or biomass is not known. There has been no directed study of the relationship between catches in a bottom trawl and the density and behaviour of capelin in the immediate vicinity as measured and observed with hydroacoustics. It is possible that a large catch of capelin indicates a high density of capelin near the bottom, especially since large catches are frequently taken close together, often in sequential sets. However, the existence of such large catches does not necessarily indicate a high stock abundance. For example, the large catches of capelin on Hamilton Bank in 1979-1981 (Carscadden et al. 1989) contributed to high estimates of biomass at a time when estimates from both Russian and Canadian acoustic surveys indicated that the abundance of the 2+3K capelin stock was relatively low (Lilly 1994b). (It may be noted, though, that the estimate from the Canadian acoustic survey in 1981 was the third highest in the time-series).

A major difficulty with employing bottom trawl catches as indices of capelin abundance is inadequate understanding of the manner in which changes in capelin behaviour may change the vulnerability of capelin to a bottom trawl. For example, if capelin tend to stay near the bottom in both night and day, instead of migrating upward at night as has often been observed, then they may be captured more frequently and in greater numbers. Shackell et al. (1994) reported that the capelin found during the acoustic survey of Division 3L in spring 1992 were relatively deep and did not surface at night as in previous years. Such behaviour might result in inflated estimates of frequency of occurrence and biomass from a bottom trawl survey.

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Table 1. Selected data for bottom-trawl surveys in Divisions 2J3KL in the autumns of 1977-1992. AN = ALFRED NEEDLER, ATC = A. T. CAMERON, GA = GADUS ATLANTICA, WT = WILFRED TEMPLEMAN.

				Number of stations occupied		Phase 1 stations with cod		Phase 1 stations with capelin	
Year	Div.	Ship/Trip	Sampling dates (d/mo.-d/mo.)	Phase 1	Phase 2	No.	%	No.	%
1977	2J3K	GA 3	11/11-02/12	127		96	76	7	6
1978	2J3K	GA 15	04/11-27/11	125		122	98	2	2
1979	2J3K	GA 29	15/11-04/12	124		121	98	42	34
1980	2J3K	GA 44	22/11-08/12	134		129	96	25	19
1981	2J3K	GA 58,59	14/11-13/12	224		182	81	53	24
	3L	ATC 323,325	03/10-18/11	97		87	90	13	13
1982	2J3K	GA 71,72	30/10-08/12	303		251	83	97	32
	3L	ATC 333,334	30/10-06/12	121		113	93	43	36
1983	2J3K	GA 86-88	28/10-07/12	255		220	86	57	22
	3L	WT 7-9	13/10-14/11	126		122	97	44	35
1984	2J3K	GA 101-103	27/10-05/12	262		219	84	67	26
1985	2J3K	GA 116-118	23/10-02/12	311		251	81	127	41
	3L	WT 37-39	09/10-18/11	232		189	82	80	34
1986	2J3K	GA 131-133	03/11-11/12	215		185	86	52	24
	3L	AN 72	13/11-30/11	142		119	84	38	27
1987	2J3K	GA 145-147	29/10-08/12	288		252	88	94	33
	3L	WT 65	15/10-01/11	165		149	90	38	23
1988	2J3K	GA 159-161	04/11-13/12	239		209	87	84	35
	3L	WT 78	26/10-13/11	189		167	88	85	45
1989	2J3K	GA 174-176	02/11-19/12	276	48	228	83	134	49
	3L	WT 87	12/10-31/10	174	21	134	77	72	41
1990	2J3K	GA 190-192	03/11-19/12	243	68	178	73	83	34
	3L	WT 101	18/10-18/11	161	27	140	87	31	19

Table 1. (Cont'd.)

Year	Div.	Ship/Trip	Sampling dates (d/mo.-d/mo.)	Number of stations occupied		Phase 1 stations with cod		Phase 1 stations with capelin	
				Phase 1	Phase 2	No.	%	No.	%
1991	2J3K	GA 208-210	06/11-17/12	313		229	73	117	37
	3L	WT 114,115	08/11-02/12	219		168	77	45	21
1992	2J3K	GA 224-226	29/10-09/12	319		209	66	153	48
	3L	WT 129,130	05/11-29/11	215		146	68	80	37
1993	2J3K	GA 236-238	30/10-06/12	263		137	52	98	37
	3L	WT 145,146	12/11-04/12	153		94	61	76	50

Table 2. By-catches of capelin and other selected data for bottom-trawl surveys in Divisions 2J3KLNO in autumn 1994. GA="Gadus Atlantica"; WT="Wilfred Templeman".

Division	Ship/Trip	Sampling dates (d/mo. - d./mo.)	No. of stations	Stations with capelin No.	%
2J3K	GA 250-252	09/11 - 19/12	255	108	42
3L	WT 161-162	08/11 - 07/12	200	83	42
3NO	WT 160-161	25/10 - 13/11	148	5	3
TOTAL		25/10 - 19/12	603	196	33

Table 3. Statistics for by-catches of capelin during bottom-trawl surveys in NAFO Divisions 2J3K during the autumns of 1978 to 1994.

Year	GADUS ATLANTICA trip number	Number[a] of stations	Stations with capelin No.	Stations with capelin %	Percentiles of capelin[b] catches (kg) 50	75	95	Max.
1978	15	125	2	2	0.03			<<1
1979	29	124	42	34	0.09	0.3	9	185
1980	44	134	25	19	0.50	1.8	149	172
1981	58,59	214	53	25	0.30	1.0	234	345
1982	71,72	291	97	33	0.20	0.5	3	18
1983	86-88	248	58	23	0.10	0.3	2	24
1984	101-103	251	67	27	0.15	0.4	2	3
1985	116-118	297	127	43	0.12	0.4	3	10
1986	131-133	209	50	24	0.18	0.8	12	24
1987	145-147	276	94	34	0.20	1.0	18	117
1988	159-161	233	84	36	0.15	0.8	3	39
1989	174-176	273[c]	134	49	0.12	0.3	2	32
1990	190-192	232[c]	82	35	0.09	0.3	1	11
1991[d]	208-210	302	117	39	0.14	0.5	4	68
1992[d]	224-226	308	151	49	0.10	0.3	3	15
1993[d]	236-238	245	98	40	0.14	0.5	6	9
1994[d]	250-252	237	108	46	0.50	1.9	10	30

[a] Stations in depths >750 m are not included. Stations in strata 618 and 619 on the coastal shelf off northern Newfoundland are included. These strata were not fished prior to 1984.

[b] Percentiles are calculated for those stations in which capelin were recorded in the catch.

[c] Only stations from first-stage sampling are included.

[d] Not directly comparable to 1978-90, because the number of fishing stations assigned to each stratum was not roughly proportional to stratum area, as was the case in the earlier years.

Table 4. Statistics for by-catches of capelin during bottom-trawl surveys in NAFO Division 3L during the autumns of 1985 to 1994.

Year	Ship[a] and trip number	Number of stations	Stations with capelin		Percentiles of capelin[b] catches (kg)			
			No.	%	50	75	95	Max.
1985	WT 37-39	232	80	35	0.33	0.8	6	16
1986	AN 72	142	38	27	0.11	0.4	2	6
1987	WT 65	165	38	23	0.10	0.5	2	4
1988	WT 78	189	85	45	0.20	0.8	7	21
1989	WT 87	174[c]	72	41	0.20	0.4	7	30
1990	WT 101	161[c]	31	19	0.10	0.5	11	17
1991[d]	WT 114,115	219	45	21	0.11	0.5	7	10
1992[d]	WT 129,130	215	80	37	0.12	0.4	2	6
1993[d]	WT 145,146	153	76	50	0.13	0.4	3	16
1994[d]	WT 161,162	200	83	42	0.10	0.3	1	2

a WT = WILFRED TEMPLEMAN, AN = ALFRED NEEDLER

b Percentiles are calculated for those stations in which capelin were recorded in the catch.

c Only stations from first-stage sampling are included.

d Not directly comparable to 1985-90, because the number of fishing stations assigned to each stratum was not roughly proportional to stratum area, as was the case in the earlier years.

Table 5. The frequency of occurrence of capelin in catches during the autumn bottom trawl surveys in Divisions 2J3K and Division 3L in 1978-1994. Division 3L was not surveyed in 1978-1980 and 1984. Only sets in 750 m or less are included. The method of adjustment is described in the text. For 1989 and 1990, the unadjusted value includes only sets from phase 1, whereas the adjusted value includes sets from phases 1 and 2. The tows in Division 3L in 1981-1983 were conducted with a Yankee 41-5 bottom trawl. All other tows were conducted with an Engel 145 bottom trawl.

Year	2J3K unadj.	2J3K adj.	3L unadj.	3L adj.
1978	1.6	1.3		
1979	33.9	35.0		
1980	18.7	18.4		
1981	24.8	26.4	13.4	14.1
1982	33.3	33.6	35.5	28.8
1983	23.4	24.8	34.9	30.6
1984	26.7	26.4		
1985	42.8	43.7	34.5	34.3
1986	23.9	26.1	26.8	27.0
1987	34.1	35.3	23.0	26.6
1988	36.1	36.9	45.0	45.5
1989	49.1	48.8	41.4	39.8
1990	35.3	35.2	19.3	21.0
1991	38.7	43.3	20.5	22.9
1992	49.0	53.0	37.2	52.1
1993	40.0	47.4	49.7	52.8
1994	45.6	46.7	41.5	38.7

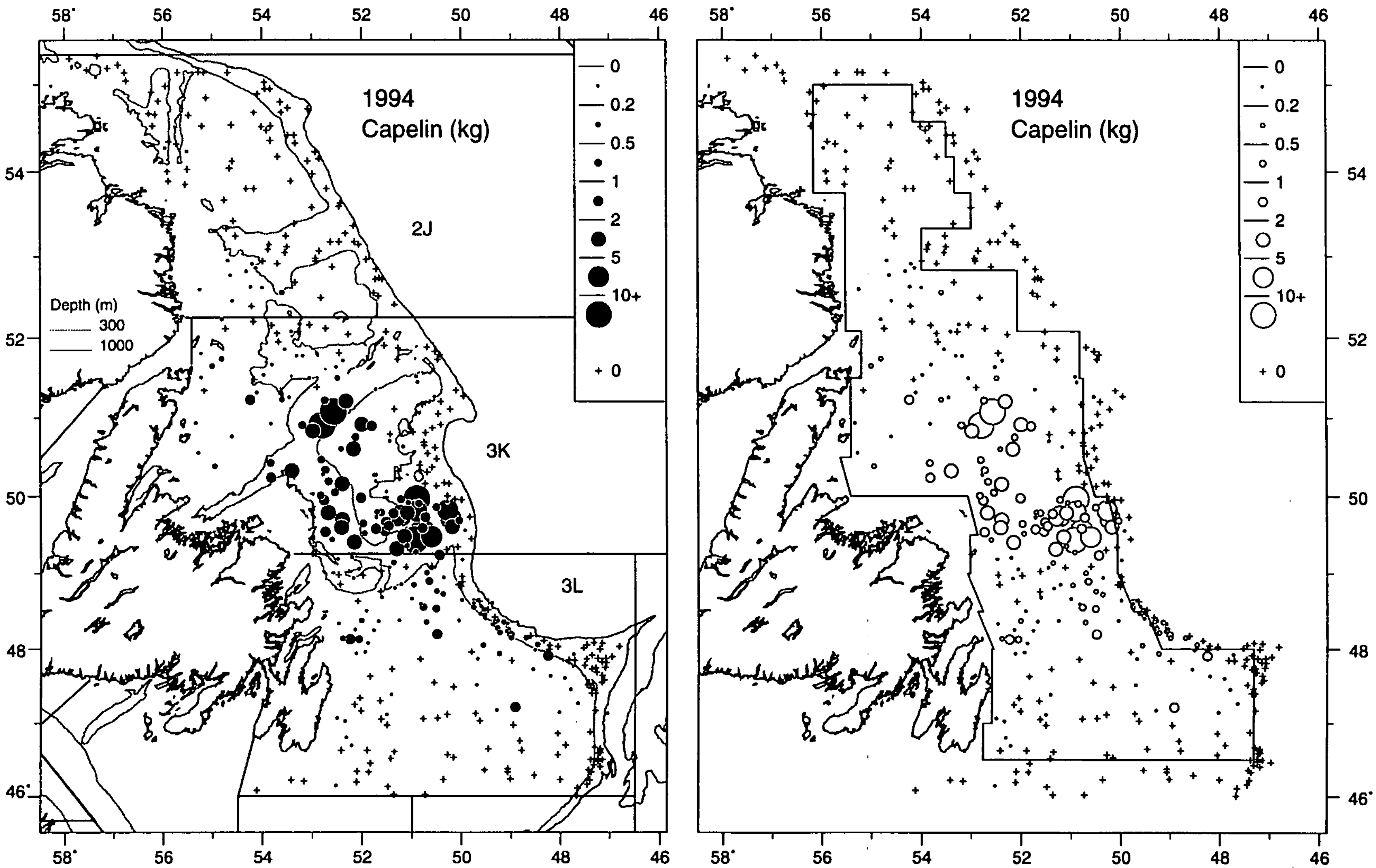

Fig. 1. Capelin catches (kg/30 min tow) during random-stratified bottom trawl surveys in Divisions 2J3KL during autumn 1994. The left panel shows the 300 and 1000m isobaths. The right panel shows the boundary of the acoustic survey.

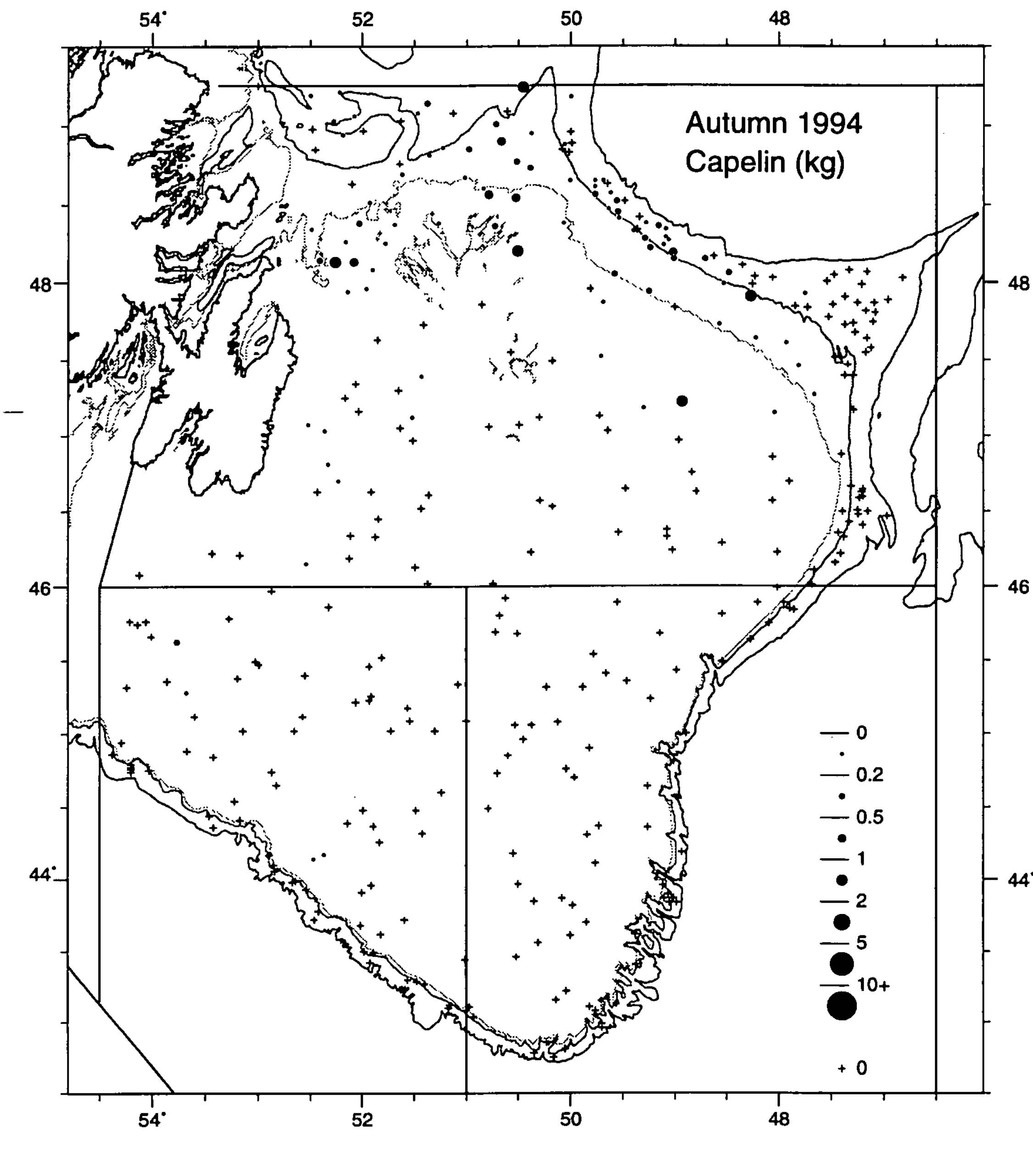

Fig. 2. Capelin catches (kg/30 min tow) during random-stratified bottom trawl surveys in Divisions 3LNO during autumn 1994.

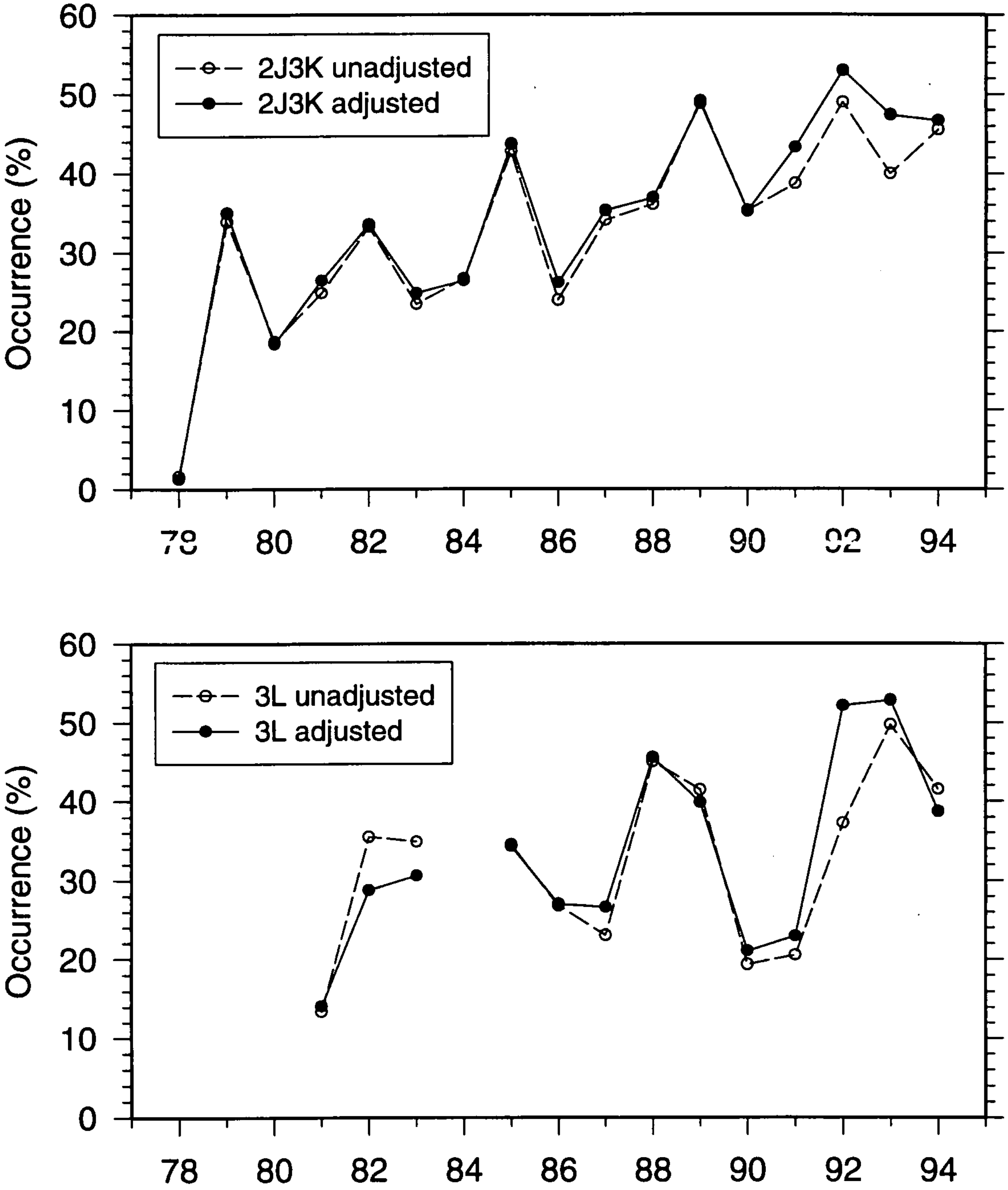

Fig. 3. The frequency of occurrence of capelin in catches during the autumn bottom trawl surveys in Divisions 2J3K (upper panel) and Division 3L (lower panel) in 1978-1994. Division 3L was not surveyed in 1978-1980 and 1984.

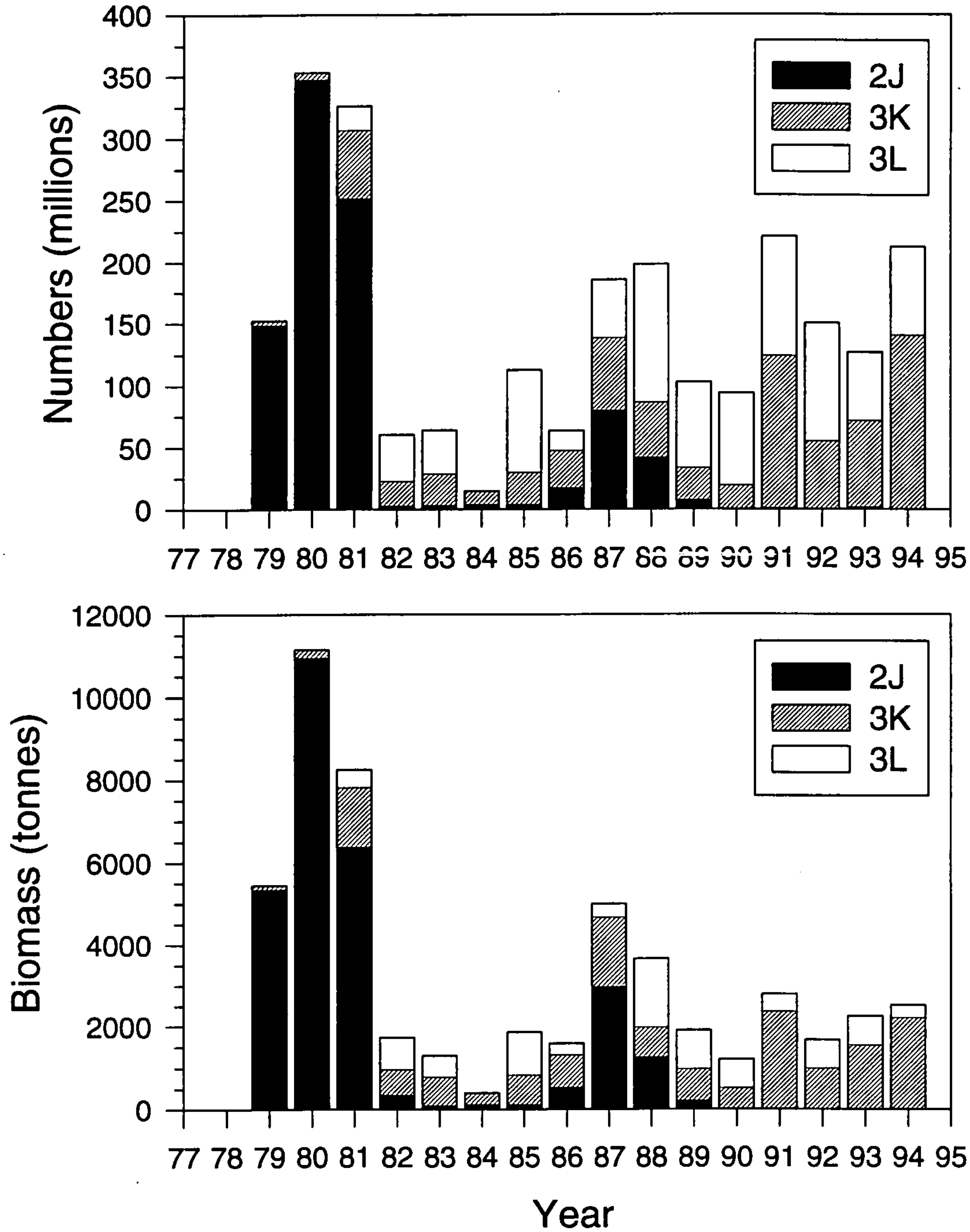

Fig. 4. Abundance and biomass of capelin by year and Division, estimated from areal expansion of stratified mean catch per tow. Division 3L was not surveyed in 1978-1980 and 1984.

By-catches of Capelin During Spring Bottom-trawl Surveys in Divisions 3LNO

by

G. R. Lilly
Science Branch
Department of Fisheries and Oceans
P. O. Box 5667
St. John's, NF A1C 5X1

Introduction

Bottom-trawl surveys, designed to assess trends in the abundance and biomass of demersal fish, have been conducted in the spring in Divisions 3LNO since the early 1970s. By-catches of capelin during these surveys have been examined to illustrate that capelin occur outside the 200 mile limit in some years (Lilly and Carscadden 1986), but the surveys have not been used to provide information on changes in capelin abundance and biomass. This chapter provides plots of the geographic distribution of capelin by-catches in Divisions 3LNO during the years 1971-1994, and provides, for Division 3L only, estimates of the frequency of occurrence of capelin in the trawl catches and estimates of the biomass of capelin as determined from areal expansion of the stratified mean catch per tow.

Materials and Methods

Surveys

Capelin were caught during random-stratified bottom trawl surveys of Divisions 3LNO during April-June 1971-1994, excluding 1983 (Table 1). Surveys were conducted with the 51 m side trawler R.V. 'A. T. Cameron' and the sister 50 m stern trawlers R.V. 'Wilfred Templeman' and R.V. 'Alfred Needler'. The 'A. T. Cameron' deployed a Yankee 41-5 trawl, whereas the 'Wilfred Templeman' and 'Alfred Needler' deployed an Engel-145 trawl. In all instances, a 29 mm meshliner was inserted in the codend. Tows were made at 3.5 knots for 30 min at each fishing station, and catches from the few tows of duration other than 30 min were appropriately adjusted. No adjustments were made for possible between-vessel differences in catching efficiency. Additional details regarding areas and locations of strata are provided by Doubleday (1981). Fishing in all Divisions and years was conducted on a 24-h basis.

Most surveys in Division 3L were conducted in May (Fig. 1). The 1971 survey was conducted entirely in June, and the 1981 survey was conducted primarily in April. The 1985 survey was part of special seasonal surveying, and was conducted by three consecutive trips of the 'Wilfred Templeman' over a period of 40 d. The median dates of fishing in 1993 and 1994 (June 1 and June 2 respectively) were the latest since 1971.

Distributions

The distribution of capelin is presented in expanding symbol plots, as opposed to contour plots generated from modelling of the catches, in order to provide visual information on the spatial distribution of fishing stations, among-station variability in catch of capelin, and the relationship between capelin catches and bathymetry.

Estimation of frequency of occurrence of capelin

The frequency of occurrence of capelin in the bottom trawl catches is simply the number of occurrences expressed as a percentage of the number of sets. The number of sets assigned to each stratum was approximately equal to stratum area, with the provision that at least two sets be allocated to each stratum. To adjust for variation in the number of sets per unit area, an adjusted percentage occurrence was calculated as

$$O_{ad}=\frac{\sum_{i=1}^{m}\left(\frac{nc_h}{N_h}\times 100\right)A_h}{\sum_{h=1}^{m}A_h}$$

where nc_h is the number of sets in which capelin were caught in stratum h, N_h is the number of sets in stratum h, A_h is the area of stratum h, and m is the number of strata fished.

Estimation of capelin biomass

The biomass of capelin in each stratum in Division 3L was estimated as

$$W_h=\frac{A_h\sum_{i=1}^{n_h}W_{hi}}{an_h}$$

where W_{hi} is the weight (kg) of capelin in set i (i = 1, 2, ..., n_h) in stratum h, and a is the area sampled by a standard tow (estimated to be 4.58×10^4 m^2). The biomass in the Division was obtained by summing over strata. The abundance of capelin was not estimated because numbers were not always recorded, especially in some years in the 1970s.

Results

Catches

The frequency of occurrence of capelin during the surveys in Division 3L ranged from 8% in 1978 to 80% in 1986 (Table 1). During the period 1991-1994, the frequency of occurrence was steady at an intermediate level (48-52%).

The size of the catches varied greatly (Table 2). The 95th percentile was 2 kg or less in 3 years and 100 kg or more in 5 years. The largest single catch was 544 kg in 1975. During the period 1991-1994, the 95th percentile was no greater than 5 kg in any year, and the maximum catch was 26 kg.

Distributions

Capelin were caught on the eastern, northern and northwestern slopes of Grand Bank, and toward the shelf break along the southwestern and southeastern parts of the bank (Fig. 2). Largest catches tended to occur in the eastern and southern Avalon Channel and on the adjacent northwestern slope of Grand Bank. Catches tended to be small in the deeper water of the Northeast Newfoundland Shelf north of Grand Bank. Only in a few years were moderate to large catches obtained on the plateau of Grand Bank.

The timing of the surveys may influence the pattern observed in the capelin catches. In 1981, when the survey was early, the largest catches in Division 3L tended to be in the northern Avalon Channel. In 1971, when the survey was late, large catches occurred on the plateau of Grand Bank in southern Division 3L. In many years, especially 1986 and 1990, there was a strong contrast between large catches in southwestern Division 3L and very small catches across the boundary in Division 3O. This is most likely caused by the pattern of surveying, wherein surveys usually started in northwestern Division 3O, moved to Division 3N, and finished in Division 3L. There was often a period of several weeks between fishing on either side of the 3L/3O boundary, during which period capelin may have moved into the area from northern Division 3L.

Frequency of occurrence

Analysis of frequency of occurrence was restricted to the years 1977-1982 and 1985-1994 because there was no survey in 1983 and coverage was inadequate in 1971-1976 and 1984.

The adjustment to the frequency of occurrence did not substantially change the estimates (Table 3; Fig. 3).

The adjusted frequency of occurrence of capelin in sets made in 750 m or less varied from a low of 6% in 1978 to a high of 80% in 1986 (Table 3; Fig. 3). The frequency of occurrence in 1991-1994 was at an intermediate level of about 50%.

Biomass estimated from areal expansion

The minimum trawlable biomass varied from a low of 25 t in 1978 to a high of 34,000 t in 1986 (Table 3; Fig. 4). The biomass has been very low for the most recent 4 years. The estimate for 1994 was 432 t, the third lowest level in the 16 y time-series.

Comparison between bycatches and acoustic surveys

To determine if bycatches of capelin during bottom-trawl surveys in Division 3L provide information on the quantity of capelin in the area, both the adjusted frequency of occurrence in the bottom-trawl survey and the biomass estimated from the by-catches were compared with the biomass estimated from the acoustic survey (Table 3; Fig. 5,6). In both cases the association was positive but not significant. However, many of the catches in the bottom-trawl surveys were outside the area covered by the acoustic survey. This included in particular catches east of 50^0 W and south of the Avalon Peninsula. The frequency of occurrence and biomass were recalculated for a smaller area corresponding approximately to the area covered by the acoustic survey. This smaller area included those strata west of 50^0 W but excluded the one stratum south of the Avalon Peninsula. Recalculation of the frequency of occurrence and the trawlable biomass increased their correlations with the biomass estimated during the acoustic surveys, but the correlations were still not significant (Fig. 5,6).

Discussion

Distribution

The distribution of capelin in Division 3L during April-June, as inferred from by-catches during bottom trawl surveys, corresponds in a general way with distributions inferred from other sources. The tendency for large catches to be obtained in southwestern Division 3L is in agreement with the migration of maturing capelin from northern Division 3L to southwestern Division 3L and northwestern Division 3O, as described by Kovalyov and Kudrin (1973). A visual comparison between plots of by-catches, presented in this chapter, and plots of capelin biomass, as recorded during acoustic surveys (Miller 1991), reveals many similarities, but also many differences. A detailed comparison between the two sources of information has not been conducted. Such a study would be confounded by differences in timing between the bottom trawl surveys and the acoustic surveys (Fahrig et al. 1993), but may nevertheless yield important insight into the manner in which catches during the bottom trawl survey may be influenced by factors such as water depth and capelin behaviour (including their density, average depth in the water column, and extent of their diel vertical migration).

The moderate and large catches obtained on northeastern Grand Bank in some years, notably 1982 and 1985-1990, occurred outside the area covered by the acoustic surveys in those years. Additional study is required to determine if those capelin to the east of the acoustic survey were primarily immature or mature. Acoustic surveys were extended to the east in 1991 and 1992 (Miller and Carscadden 1991; Miller 1992), but failed to detect sizable concentrations of capelin. Catches of capelin on eastern Grand Bank were generally small in those two years.

The stock affinity of the capelin found toward the southern tip of Grand Bank in some years is not known. They could belong to either the 2+3KL stock or the 3NO stock.

The distribution of capelin, as inferred from the bottom trawl catches, varied among years. Additional study is required to determine the extent to which these differences may be related to changes in stock size, age and maturity composition of the stock, water temperature (compare Shackell et al. 1994), and the timing of the surveys.

Capelin biomass

The extent to which the by-catches of capelin in the spring bottom trawl surveys may be used to infer the status of the capelin stock is not known. The two potential indices presented in this chapter (frequency of occurrence and trawlable biomass) may be influenced not only by the size of the capelin stock but also by the behaviour of the capelin (including aspects such as degree of aggregation, average depth in the water column, and extent of diel vertical migration). Another concern is the change in survey gear from the Yankee 41-5 trawl deployed from the 'A. T. Cameron' (1971-1982) to the Engel-145 trawl deployed from the 'Wilfred Templeman' and the 'Alfred Needler' (1984-1994). There is evidence that the Engel-145 trawl may be more efficient at catching capelin, at least in Division 3L in the spring. During the 1979 survey, the 74 m stern trawler R.V. 'Gadus Atlantica' fished beside the 'A. T. Cameron', and obtained more frequent and larger catches of capelin than did the 'A. T. Cameron' (unpubl. data). During that comparative fishing exercise the 'Gadus Atlantica' deployed an Engel-145 trawl very similar to the trawls deployed by the 'Wilfred Templeman' and the 'Alfred Needler'.

The frequency of occurrence and the trawlable biomass were both positively (but not significantly) related to the biomass estimated from the acoustic survey. However, it is known that biomass estimates from the acoustic surveys may not closely track the biomass of the capelin stock. For example, the estimates are influenced by water temperature (Shackell et al. 1994), and the sudden decline from high biomass levels in 1989 and 1990 to very low levels in 1991 and 1992 (Miller 1992) has not been adequately explained. In the absence of an accepted index of capelin biomass, it is difficult to determine how well the frequency of occurrence and the trawlable biomass track the true capelin biomass. It is notable, however, that both metrics were very low in 1978, when the capelin stock was at its nadir, and relatively high in the mid- to late 1980s, when capelin biomass was relatively high.

The decline in trawlable biomass from a relatively high level in 1990 to low levels in 1991 and 1992 coincided with the decline in the acoustic estimates. The continuing low trawlable biomass in 1993 and 1994 may be a cause for concern.

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Table 1. Selected data for bottom-trawl surveys in Divisions 3LNØ in the springs of 1971-1993.

Year	Div.	Ship/Trip	Sampling Dates (d/mo.-d/mo.)	Number of Stations Occupied	Stations with cod No.	Stations with cod %	Stations with capelin No.	Stations with capelin %
1971	3L	ATC 187	03/06-18/06	60	55	92	25	42
	3NØ	ATC 187	09/06-13/06	25	23	92	7	28
1972	3L	ATC 199	12/05-18/05	38	38	100	16	42
	3NØ	ATC 199	04/05-12/05	45	44	98	6	13
1973	3L	ATC 208, 209	07/04-06/05	33	27	82	3	9
	3NØ	ATC 207-209	22/03-04/05	96	80	83	17	18
1974	3L	ATC 222	07/05-21/05	70	57	81	17	24
	3NØ	ATC 222	08/05-13/05	37	30	81	3	8
1975	3L	ATC 233	09/05-25/05	55	47	86	39	71
	3NØ	ATC 233	15/05-24/05	58	45	78	24	41
1976	3L	ATC 246	23/04-03/05	64	60	94	30	47
	3NØ	ATC 245	02/04-13/04	78	58	74	4	5
1977	3L	ATC 262	04/05-18/05	102	92	90	36	35
	3NØ	ATC 263	26/05-07/06	88	77	88	12	14
1978	3L	ATC 276	06/05-17/05	95	86	91	8	8
	3NØ	ATC 276, 277	14/05-07/06	92	78	85	5	5
1979	3L	ATC 290	17/05-04/06	141	134	95	42	30
	3NØ	ATC 289, 291	02/04-25/06	172	133	77	21	12

Table 1. (Cont'd)

Year	Div.	Ship/Trip	Sampling Dates (d/mo.-d/mo.)	Number of Stations Occupied	Stations with cod No.	Stations with cod %	Stations with capelin No.	Stations with capelin %
1980	3L	ATC 304, 305	10/05-02/06	115	113	98	20	17
	3NØ	ATC 303, 304	11/04-11/05	140	109	78	4	3
1981	3L	ATC 317, 318	06/04-07/05	81	67	83	28	35
	3NØ	ATC 318, 319	04/05-22/05	77	67	87	10	13
1982	3L	ATC 329	06/05-17/05	103	93	90	44	43
	3NØ	ATC 327, 328	27/03-26/04	138	119	86	20	15
1984	3L	AN 28	17/05-21/05	37	37	100	18	49
	3NØ	AN 27	28/04-08/05	117	86	74	15	13
1985	3L	WT 28-30	17/04-26/05	221	198	90	94	43
	3NØ	WT 29 AN 43	11/04-05/05	178	134	75	33	19
1986	3L	WT 48	07/05-25/05	211	203	96	169	80
	3NØ	WT 47	18/04-04/05	203	160	79	21	10
1987	3L	WT 59, 60	14/05-01/06	181	169	93	53	29
	3NØ	WT 58, 59	23/04-14/05	190	168	88	56	29
1988	3L	WT 70, 71	05/05-24/05	154	142	92	108	70
	3NØ	WT 70	21/04-05/05	161	132	82	28	17
1989	3L	WT 82,83	06/05-28/05	205	189	92	157	77
	3NØ	WT 82	20/04-06/05	195	155	80	47	24

Year	Div.	Ship/Trip	Sampling Dates (d/mo.-d/mo.)	Number of Stations Occupied	Stations with cod No.	Stations with cod %	Stations with capelin No.	Stations with capelin %
1990	3L	WT 96	18/05-04/06	156	137	88	108	69
	3NØ	WT 94-96	22/04-01/06	178	146	82	59	33
1991	3L	WT 106, 107	11/05-29/05	143	89	62	69	48
	3NØ	WT 105, 106	19/04-11/05	209	128	61	44	21
1992	3L	WT 120-122	13/05-07/06	178	51	29	92	52
	3NØ	WT 119, 120	22/04-13/05	185	90	49	54	29
1993	3L	WT 137, 138	18/05-10/06	181	55	30	93	51
	3NØ	WT 136, 137	27/04-18/05	166	77	46	67	40
1994	3L	WT 153,154	22/05-10/06	159	18	11	74	47
	3NO	WT 152,153	30/04-22/05	157	44	28	48	31

Table 2. Statistics for by-catches of capelin during bottom-trawl surveys in NAFO Div. 3L during the autumns of 1985 to 1994.

Year	Ship[a] and trip number	Number[b] of stations	Stations with capelin No.	Stations with capelin %	Percentiles of capelin[c] catches (kg) 50	75	95	Max.
1971	ATC 187	60	25	42	4.54	14.3	135	181
1972	ATC 199	38	16	42	1.24	4.5	9	9
1973	ATC 208,209	33	3	9	0.14	21.8	22	22
1974	ATC 222	70	17	24	1.13	9.3	58	58
1975	ATC 233	55	39	71	0.91	6.2	145	544
1976	ATC 246	64	30	47	1.86	6.0	17	18
1977	ATC 262	102	36	35	0.89	4.5	119	255
1978	ATC 276	95	8	8	0.07	0.3	<1	<1
1979	ATC 290	141	42	30	0.80	8.4	137	227
1980	ATC 304,305	115	20	17	0.48	1.6	12	13
1981	ATC 317,318	81	28	35	1.00	2.4	18	20
1982	ATC 329	103	44	43	0.50	2.9	27	48
1983								
1984	AN 28	37	18	49	3.25	11.5	190	190
1985	WT 28-30	221	94	43	0.30	1.4	8	24
1986	WT 48	211	169	80	2.00	6.0	72	483
1987	WT 59,60	181	53	29	4.50	17.0	69	167
1988	WT 70,71	154	108	70	0.30	1.7	12	33
1989	WT 82,83	205	157	77	0.80	2.1	18	32
1990	WT 96	156	108	69	0.98	3.2	52	175
1991	WT 106,107	143	69	48	0.14	0.5	5	24
1992	WT 120-122	178	92	52	0.04	0.1	1	4
1993	WT 137,138	181	93	51	0.09	0.4	5	26
1994	WT 153,154	151	73	48	0.11	0.3	2	4

[a] ATC = A. T. Cameron, AN = Alfred Needler, WT = Wilfred Templeman

[b] Stations in depths >750 m are not included.

[c] Percentiles are calculated for those stations in which capelin were recorded in the catch.

Table 3. The frequency of occurrence and trawlable biomass of capelin in Division 3L in the springs of 1977-1994, as estimated from bottom trawl surveys, and the biomass in 1982-1992, as estimated from acoustic surveys. The frequency of occurrence of capelin in bottom trawl catches is calculated for the entire survey area and for a reduced area in western Division 3L, corresponding approximately to the area covered by the acoustic surveys prior to 1991. Both unadjusted and adjusted values are presented. The method of adjustment is described in the text. The trawlable biomass of capelin was estimated from the capelin catches during the bottom trawl surveys, and is provided for both the entire survey area and the reduced area.

	Frequency of occurrence (%)				Biomass ('000 tons)		
	Div. 3L		Western Div. 3L		Bottom trawl survey		
Year	Unadj.	Adj.	Unadj.	Adj.	Div. 3L	Western Div. 3L	Acoustic survey[a]
1977	35.3	38.2	42.1	44.1	18.246	17.878	
1978	8.4	5.9	11.8	8.6	0.025	0.024	
1979	29.8	31.7	43.2	42.3	15.441	8.372	
1980	17.4	15.6	24.0	23.4	0.492	0.490	
1981	34.6	28.5	44.4	35.8	2.045	1.897	
1982	42.7	47.9	32.8	34.0	6.005	0.843	466
1983							84
1984							353
1985	42.5	41.0	44.7	41.0	1.874	1.286	3426
1986	80.1	79.7	78.8	78.7	33.864	17.571	3697
1987	29.3	32.1	38.7	40.9	12.919	8.223	2576
1988	70.1	69.8	70.5	69.4	4.007	2.351	4551
1989	76.6	78.0	80.0	80.2	6.250	3.819	3829
1990	69.2	71.5	84.3	84.5	15.546	8.624	6958
1991	48.3	52.1	63.8	65.1	1.398	0.603	116
1992	51.7	54.1	56.4	56.8	0.259	0.055	206
1993	51.4	53.1	56.2	57.5	1.436	0.944	
1994	48.3	48.6	54.7	54.7	0.432	0.143	

[a] From Miller (1992)

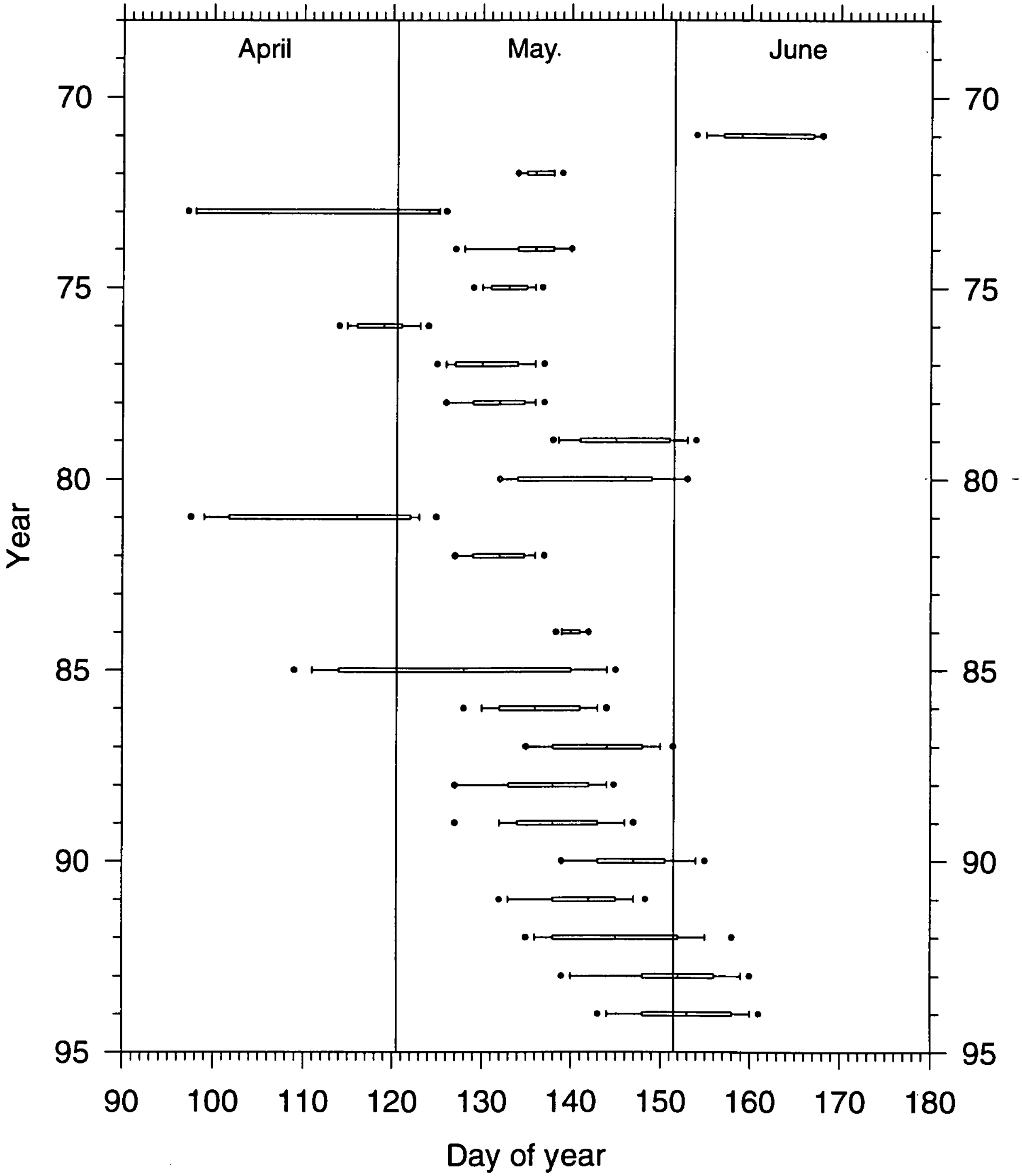


Fig. 1. Dates of fishing during stratified-random bottom trawl surveys in Division 3L in 1971-1994. The box plot for each year illustrates the 5th, 25th, 50th, 75th and 95th percentiles, and outliers.

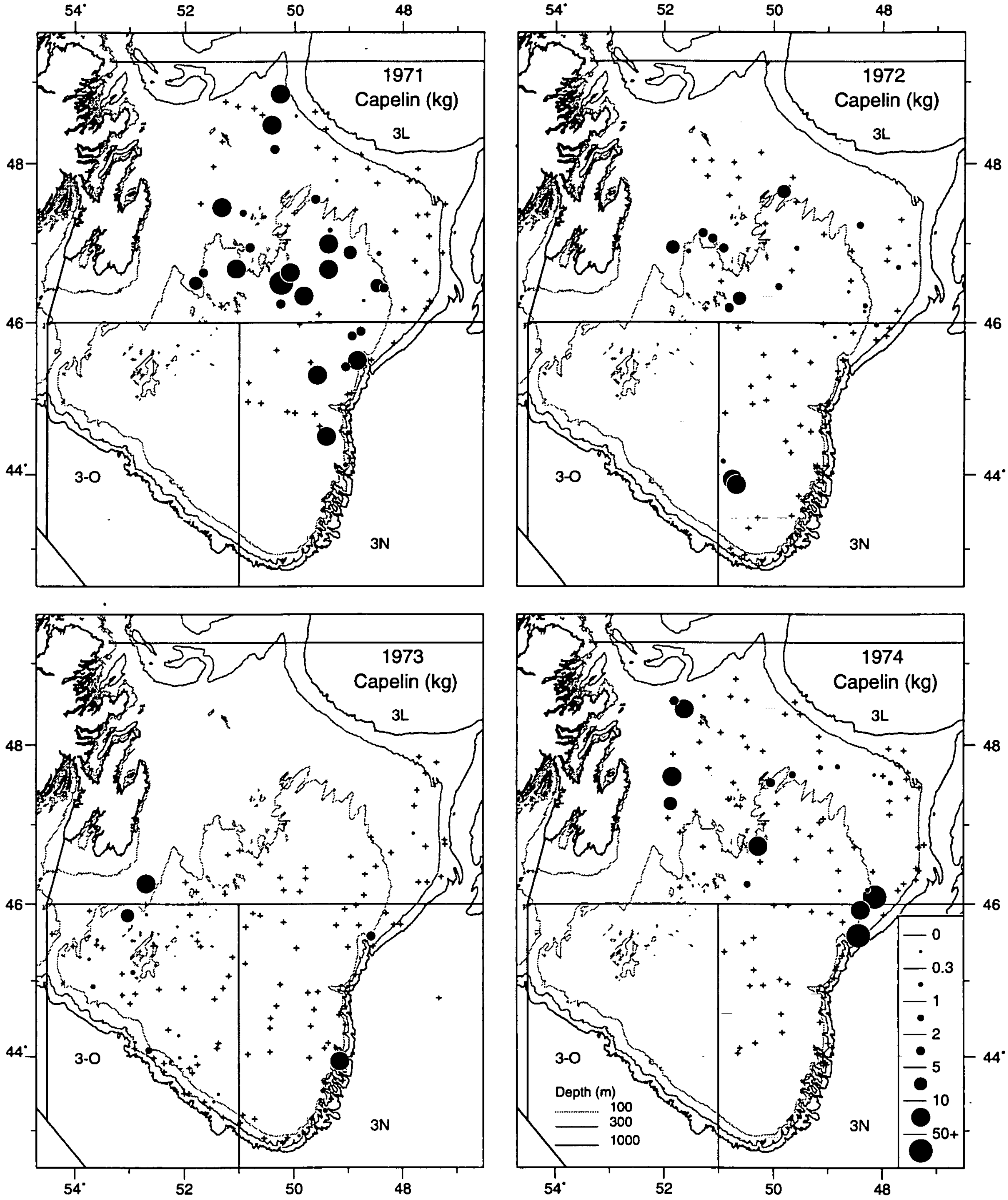


Fig. 2. Capelin catches (kg/30 min tow) during stratified-random bottom trawl surveys in Divisions 3LNO in the springs of 1971-1994. There was no survey in 1983. "+" = nil catch.

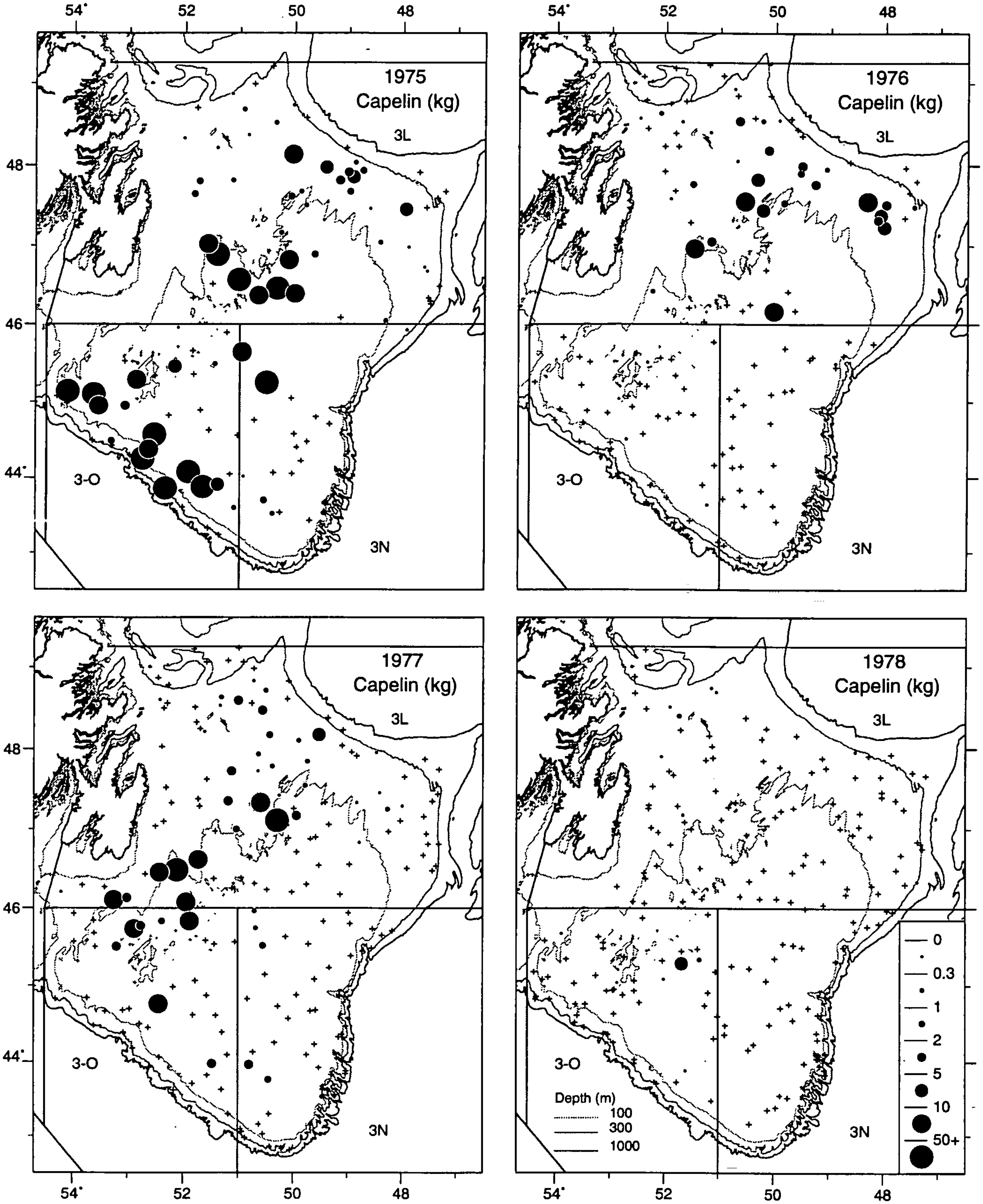

1975
Capelin (kg)
1976
Capelin (kg)
1977
Capelin (kg)
1978
Capelin (kg)
3L
3-O
3N
54°
52
50
48
46
44°
Depth (m)
100
300
1000
0
0.3
1
2
5
10
50+

Fig. 2. (cont'd)

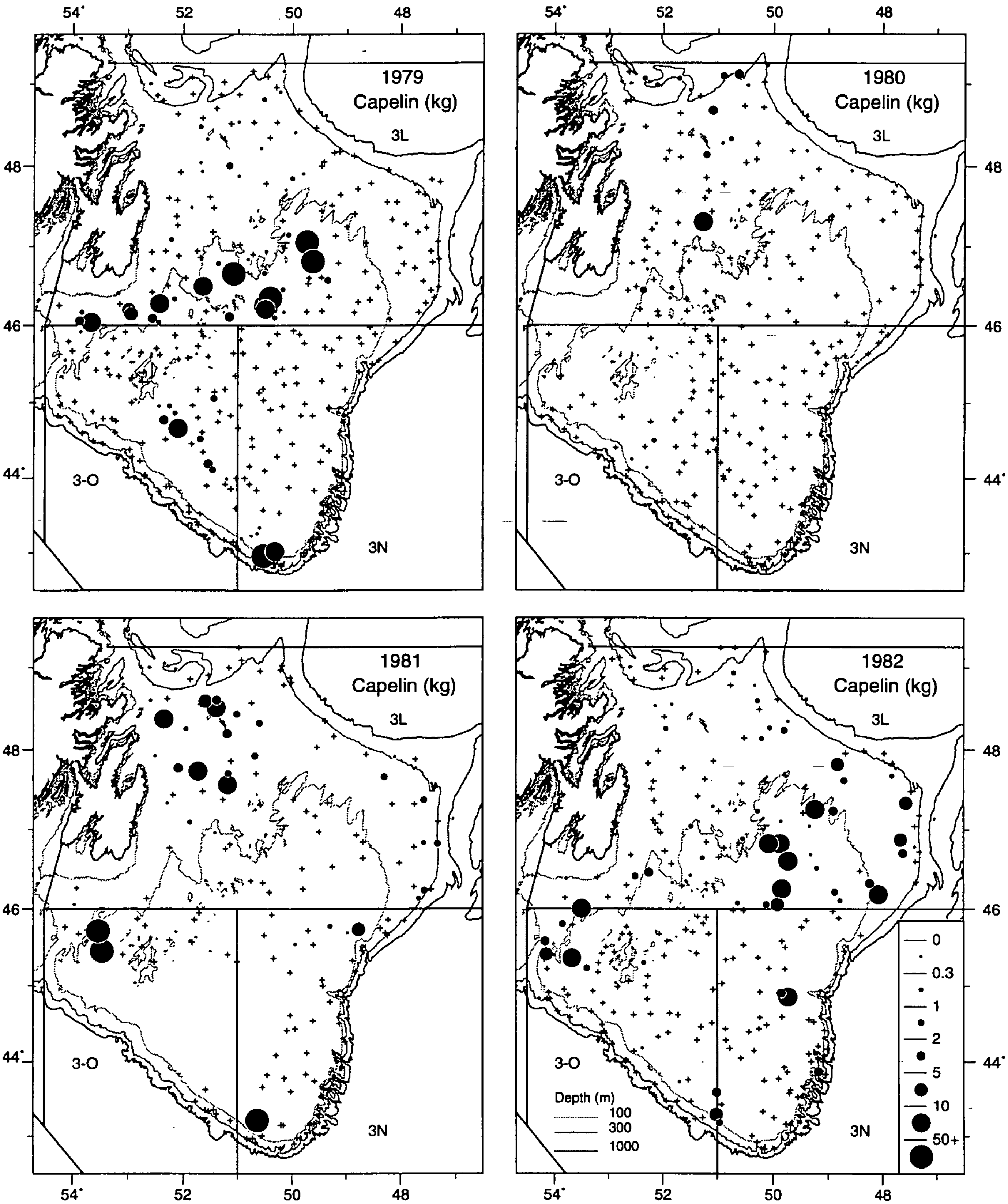
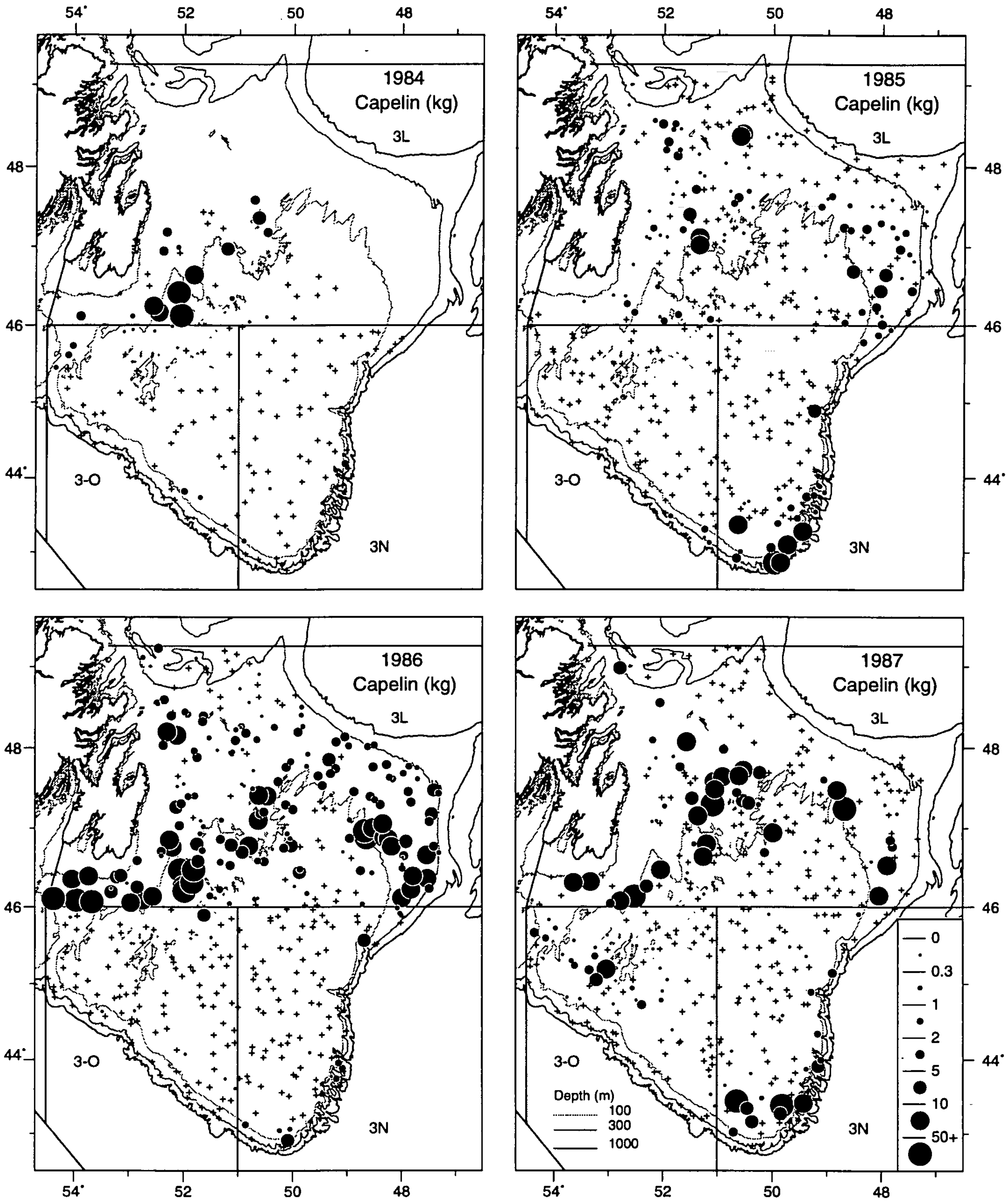

54°
52
50
48
1979
Capelin (kg)
3L
3-O
3N
1980
Capelin (kg)
1981
Capelin (kg)
1982
Capelin (kg)
46
44°
0
0.3
1
2
5
10
50+
Depth (m)
100
300
1000

Fig. 2. (cont'd)


54°
52
50
48
1984
Capelin (kg)
3L
48
46
44°
3-O
3N
1985
Capelin (kg)
1986
Capelin (kg)
1987
Capelin (kg)
Depth (m)
100
300
1000
0
0.3
1
2
5
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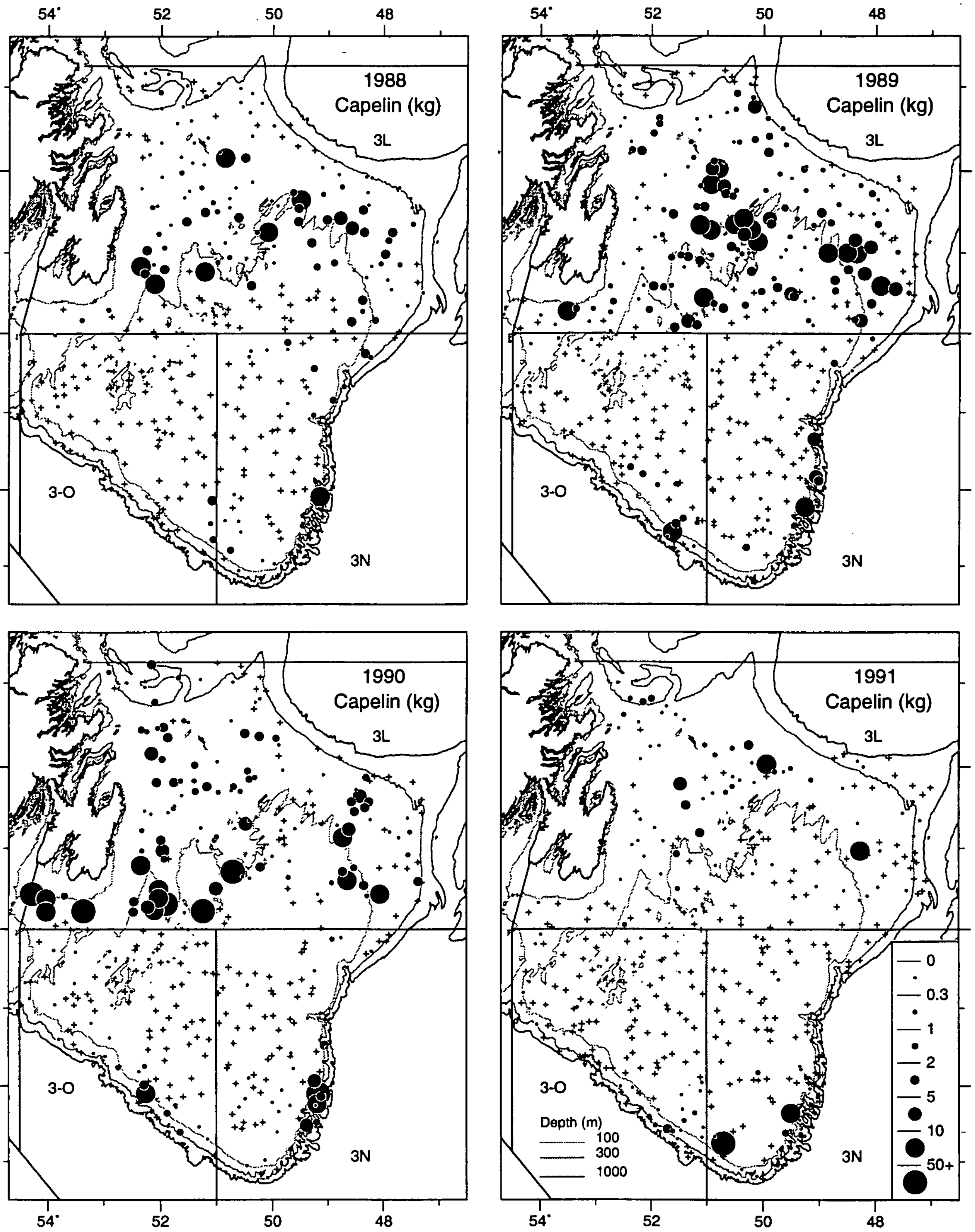
50+

Fig. 2. (cont'd)


1988
Capelin (kg)
1989
Capelin (kg)
1990
Capelin (kg)
1991
Capelin (kg)
3L
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54°
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Depth (m)
100
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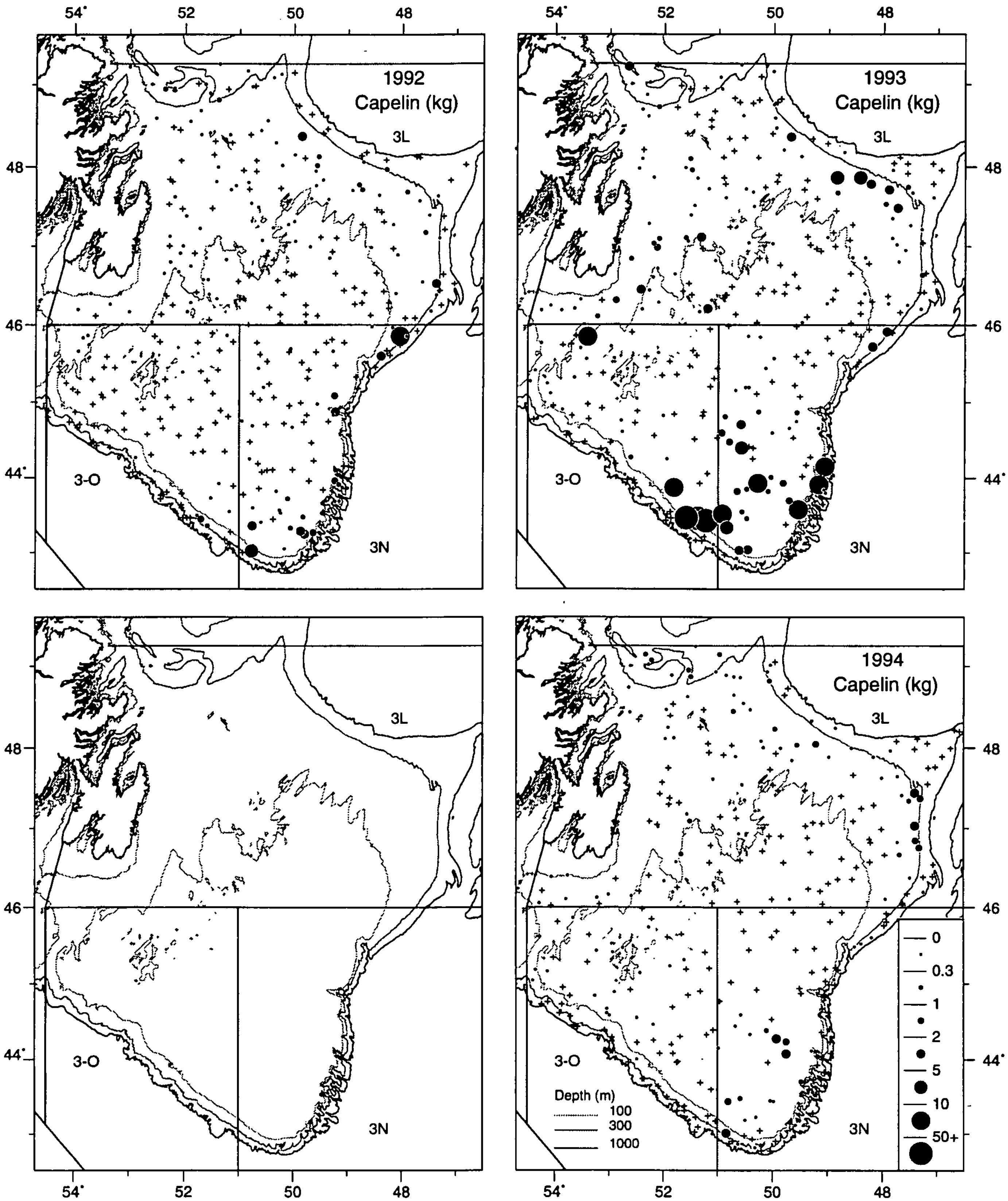
Fig. 2. (cont'd)


1992
Capelin (kg)
1993
Capelin (kg)
1994
Capelin (kg)
3L
3-O
3N
54°
52
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48
46
44°
Depth (m)
100
300
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0
0.3
1
2
5
10
50+

Fig. 2. (cont'd)

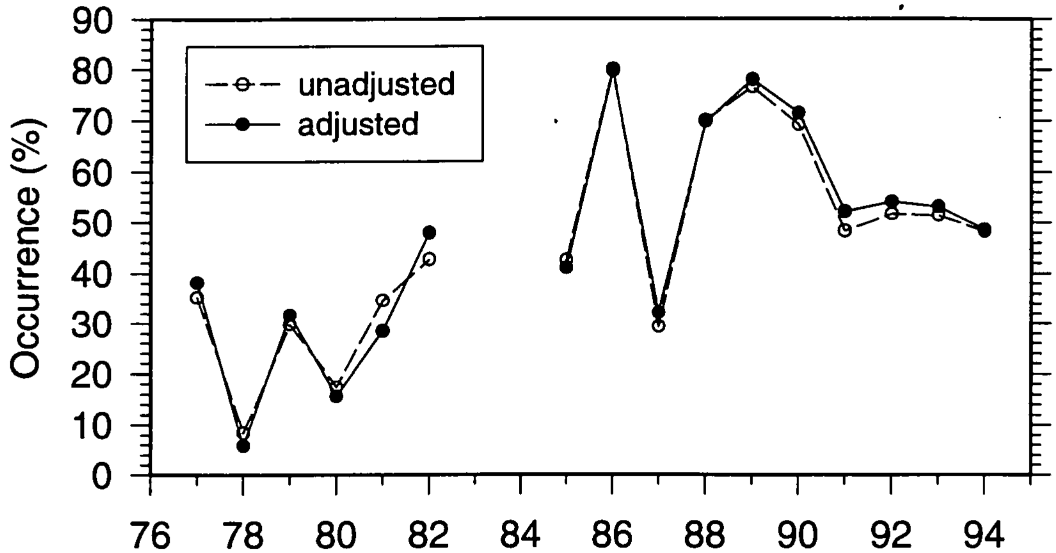

Fig. 3. The frequency of occurrence of capelin in catches during the spring bottom trawl surveys in Division 3L. There was no survey in 1983 and coverage was inadequate in 1971-1976 and 1984.

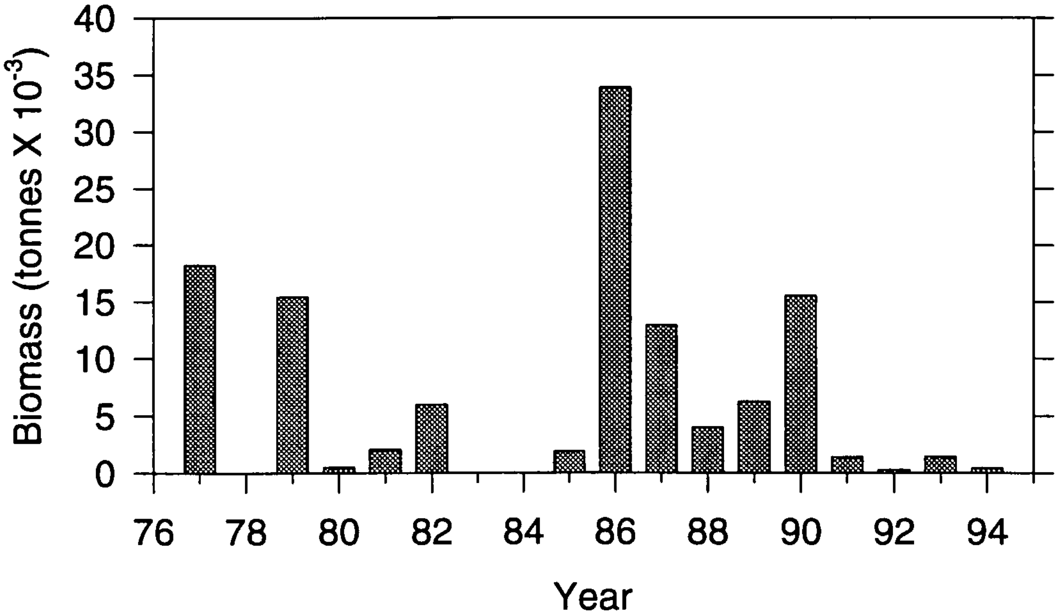

Fig. 4. Biomass of capelin, estimated from areal expansion of stratified mean catch per tow during stratified-random bottom trawl surveys in Division 3L. There was no survey in 1983 and coverage was inadequate in 1971-1976 and 1984.

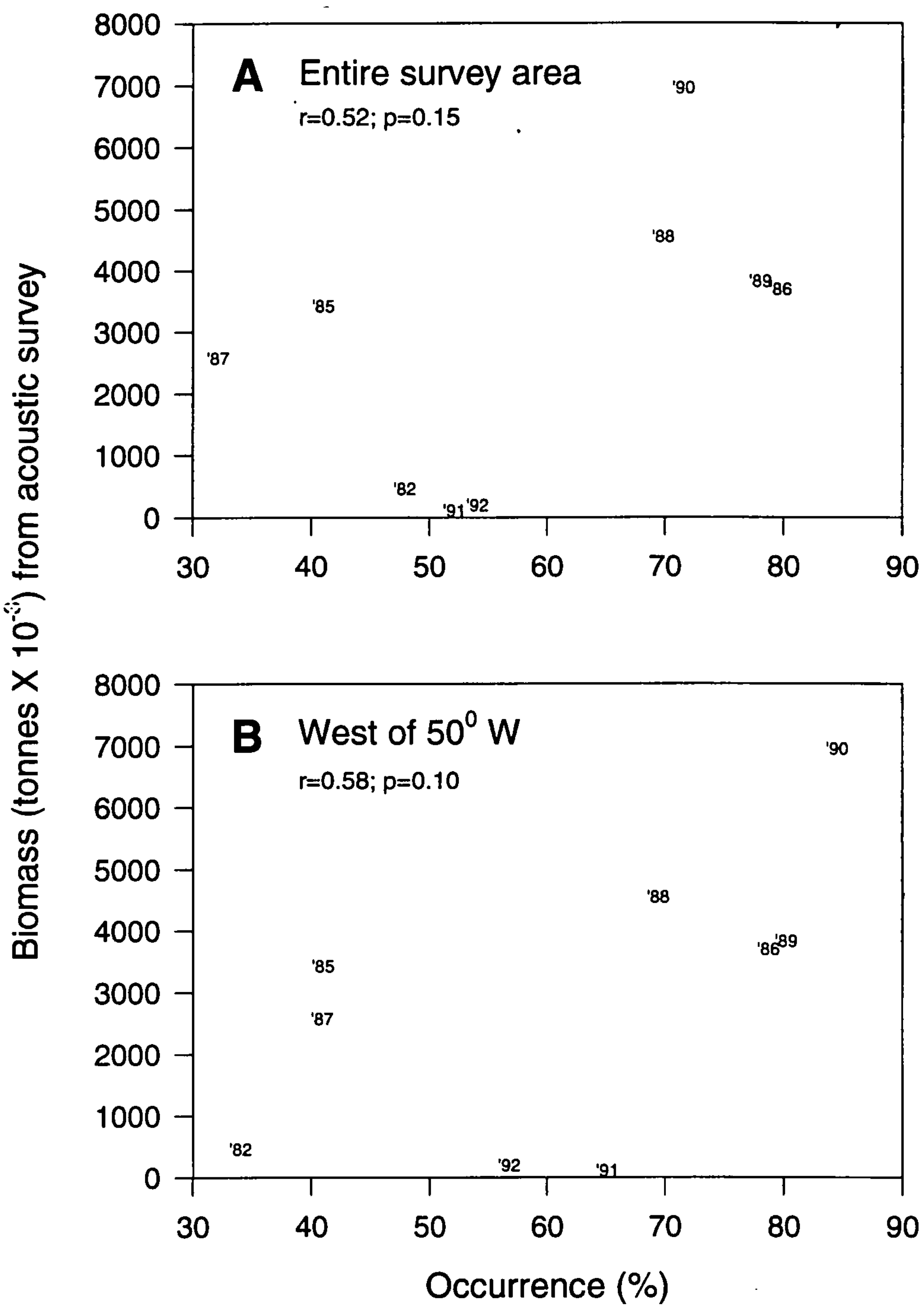

Fig. 5. Comparison between the biomass of capelin estimated during acoustic surveys (Miller 1992) and the adjusted frequency of occurrence of capelin in the bottom trawl survey, where the frequency of occurrence is calculated for (A) all strata fished and (B) strata west of 50^0 W, but excluding the stratum south of the Avalon Peninsula (ie. strata included are 341-350 and 363-366; see Fig. 6 in Doubleday 1981).

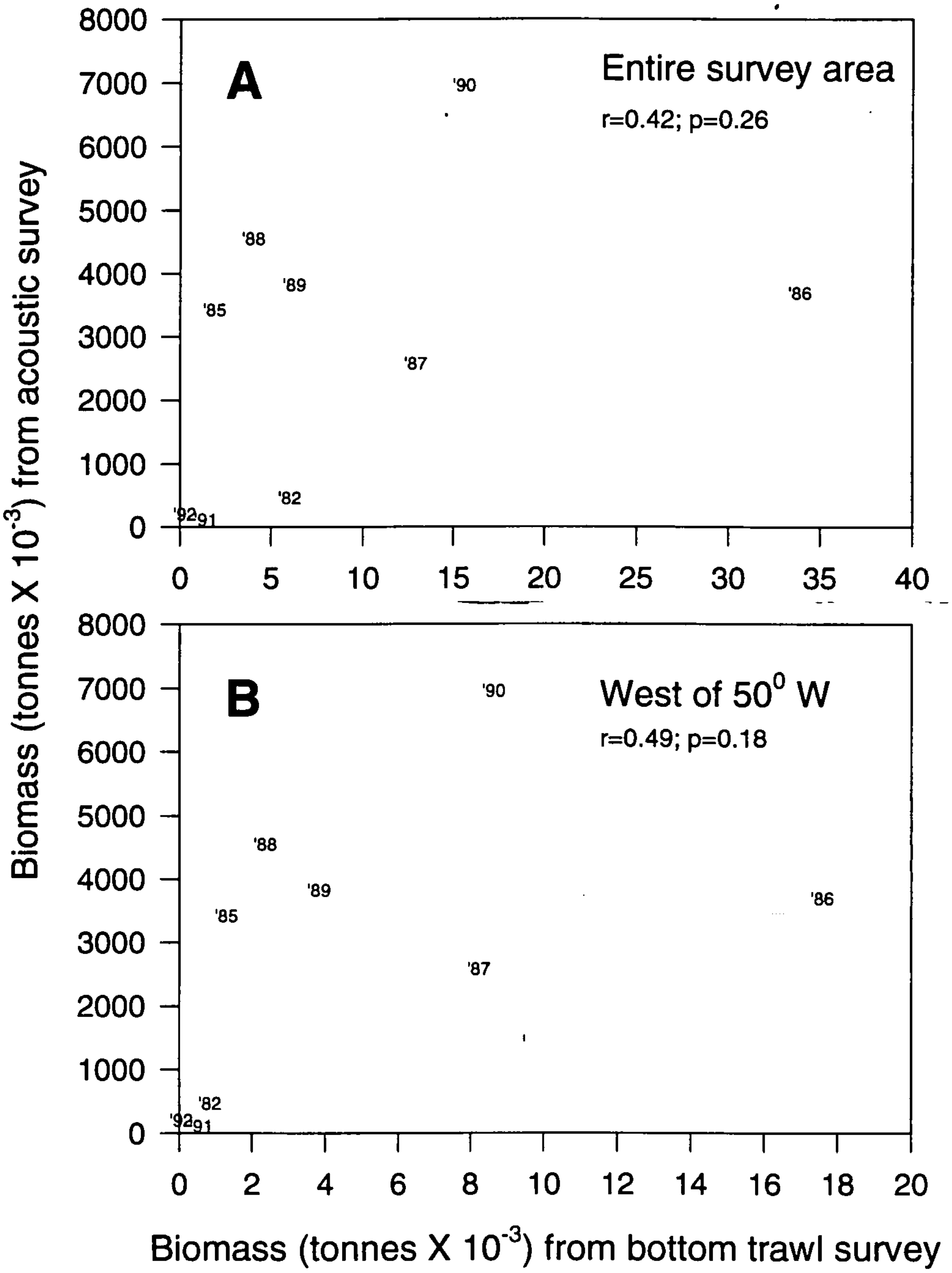

Fig. 6. Comparison between the biomass of capelin estimated during acoustic surveys (Miller 1992) and the biomass of capelin estimated from areal expansion of stratified mean catch per tow in the bottom trawl survey, where the biomass is calculated for (A) all strata fished and (B) strata west of 50^0 W, but excluding the stratum south of the Avalon Peninsula (ie. strata included are 341-350 and 363-366; see Fig. 6 in Doubleday 1981).

Preliminary Catch Rates of Capelin (Mallotus villosus) in Inshore and Offshore Areas of NAFO Div. 3KL During Recent Demersal Juvenile Cod Surveys

by

E. L. Dalley, J. T. Anderson, and D. S. Miller
Science Branch
Department of Fisheries and Oceans
P. O. Box 5667
St. John's, NF A1C 5X1

Introduction

Several types of assessment related research are considered for capelin each year during the regional assessment process. In the offshore, annual acoustic surveys are carried out to estimate abundance of recruiting year classes to be used in projections. In the inshore, catch rate indices, estimates of capelin school areas, and egg deposition estimates are all considered. In addition bycatch of capelin from other sources such as groundfish surveys and indices of cod feeding on capelin have been used. In recent years there has been a divergence of indices with the offshore acoustic survey finding low abundances which have not been reflected in the inshore the next year. The acoustic surveys have not included any of the large inshore bays along the Northeast coast.

During early winter of the past three years surveys have been carried out under the Northern Cod Science Program to examine the distribution of juvenile cod in inshore and offshore areas of NAFO Div. 3KL. During these surveys capelin were taken as bycatch. To examine an independent index of capelin abundance in recent years and to address the question of relative abundance in inshore and offshore areas during early winter these catches of capelin are reported here. Also, for the most recent survey a biomass estimate is derived for a portion of the survey area to compare with the acoustic estimate from the same area.

Methods

Three surveys were carried out using the research vessel Wilfred Templeman in: 1) December 1992, 2) December 1993-January 1994, and 3) December 1994-January 1995 and will be referred to a the 1992, 1993, and 1994 surveys respectively. Line transects were utilized to sample from bays and headlands across the shelf (Fig. 1). Additional sampling was carried out in each of the major inshore bays. Attempts were made to sample available depth strata. Sampling was carried out using a Campelen 1800 shrimp trawl. Catch in numbers and weight of capelin was standardized using a 30 minute tow once the trawl had settled to the bottom, as determined by Scanmar. Depth and temperature along the tow path were monitored using a trawl mounted CTD. Additional information on the trawl and survey design are found in Dalley and Anderson (1995).

Samples were frozen and returned for standard processing by Pelagic Section of Science Branch. Since capelin are assigned an arbitrary birthdate of January 1 ages in this analysis were assigned to correspond to the sampling year noted above (eg. fish caught in January 1994 were given ages as if they had been caught in December 1993).

A biomass estimate was derived for 3K using mean catch rate from 22 stations within an area (72,633 sq. km.) approximating strata G, H, I, J, and 1/2 of K from the acoustic survey (Miller 1995). The Campelen trawl wing spread of 16.8 m.(W) and an average tow distance of 2780 m.(L) was used to estimate a swath area (L x W) of 0.0467 sq. m. for each tow. Mean arithmetic and geometric catch rates within this swath area were used to estimate the biomass of capelin within the total area to compare to the estimate of biomass derived acoustically for the same area.

Results

Mean catch rate for the three surveys (Table 1) varied by a factor of ~ 8x in terms of numbers and 6x in terms of weight. Mean catch rates (numbers) decreased by a factor of ~ 4.5x from 1992 to 1993 but increased by a factor of 8x from 1993 to 1994. Catch weights were somewhat less variable with an approximate 3x decrease followed by a 5.6x increase over the same period.

Results of correlation analysis indicate no correlation between the catch rate (in numbers or weight) and tow (bottom) depth or mean temperature along the tow path (Table 2).

A comparison of catch rates (log10) expressed in number of fish and in weight of fish, is shown in Figures 2 and 3 respectively for the three surveys, using expanding symbols for each set. The expanding symbols are scaled the same for all surveys and are therefore comparable from year to year. The results indicate that capelin were widely distributed throughout the survey area, both inshore and offshore, in all three years. In 1992 highest catch rates were concentrated around Funk Island Bank and near the shelf edge at ~47.5°N. Capelin occurred in all bays but catch rates in Notre Dame Bay were relatively low. In 1993, when mean catch rate was the lowest of the three years, relatively few capelin were taken near the shelf edge. There were 11 zero catches compared to 7 in 1992 and 5 in 1994. In 1994 high catch rates were again taken on Funk Island Bank, the northern portion of the survey area, and near the nose of the Grand Bank. Overall distribution patterns appeared similar in 1992 to 1994.

In terms of numbers overall mean catch was higher in 3L than 3K in 1992 but higher in 3K than 3L in 1993 and 1994 (Table 3). The mean catch weight was higher in 3L all three years indicating a high proportion of small fish in 3L in 1992. Using the ratio of weight/numbers, fish caught in 3K were larger than those in 3L all three years.

A comparison of catch rates of stations within the bays compared to those on the offshore transects indicate that in general the percentage of the overall mean catch rate taken inshore was higher for 3L than 3K. In all cases mean catch rates (weight) were higher in the offshore in both 3K and 3L during all three years. In 3K the proportion of total catch rate inshore ranged from 4.5% in 1992 to 32.8% in 1993. In terms of numbers the same is true except in 1993 mean catch rate was slightly higher inshore in 3L. The proportion of catch rate (numbers) ranged from 13.9% to 37.9% inshore in 3K and from 21.5 to 54.2% inshore in 3L over the three surveys.

Samples processed for each survey indicate an age structure that is predominated by young fish (Table 4). Age 1 fish averaged ~ 55% each year. Age 2 fish ranged from 30.8% in 1993 to 43.7% in 1992. The age structure from the samples was weighted by the overall mean catch rate for each survey to obtain a catch rate at age index (Table 5).

The arithmetic mean catch rate of the 22 stations sampled in 3K was 14,367.3g. or 0.308g./sq. m. representing a total biomass of 22,371 metric tons. Using the geometric mean catch rate of 2,009.1g. or 0.043g./sq. m. the biomass estimate for the total area is 3,123 tons.

Discussion

The results clearly indicate that capelin were widely distributed throughout the area surveyed in early winter, both inshore and offshore, during all surveys. There was not, however, any statistically significant association between catch rate of capelin and either a) water depth or b) water temperature.

In two of the three surveys the mean catch rate of capelin was higher in statistical area 3K than 3L. Mean catch rate in weight of capelin consistently ranked higher in 3L than 3K. The proportion of catch rates within the inshore bays is substantial when compared to that of the offshore. In 3L the catch rate in weight inshore was approximately equivalent to that offshore in 1992 and also in number of fish in 1993. The proportion of overall catch rate, in the inshore compared to offshore, is consistently higher in the more southern bays (3L) than the bays in 3K for all three years. These relatively high catch rates inshore indicate that the annual acoustic capelin estimate may be negatively biased by the exclusion of inshore areas. Catch rates of capelin inshore may occur at a level similar to that of the offshore.

The age structure of the population estimated from these demersal trawl surveys, whereby a large proportion consists of younger fish, is similar to that derived from samples collected during the acoustic survey. The fact that the numbers at age 2, 3, and 4 in 1994 were higher than the same age classes at age 1, 2, and 3 in 1993 appears anomalous and may simply be a result of sampling variability among years. Alternatively it may be a result of differences in catchability resulting from distribution differences between years. For instance in 1993 when catch rates were low capelin may have been distributed differently in the water column, decreasing their catchability in a bottom trawl.

The estimate of biomass in 3K in 1994 derived here, (22,370 metric tons) using the arithmetic mean catch rate, is over twice the 10,000 tons estimated from the acoustic survey in September-October (Miller 1995) and substantially higher than the ~ 2,000 tons derived from the random stratified groundfish survey in November-December (Lilly 1995). It is not surprising that the estimate is higher here than the groundfish survey since the large meshed Engels survey trawl would not be as efficient at catching small fish as the shrimp trawl used here. However, the results may indicate that the acoustic survey underestimates biomass. This is not the case if the geometric mean catch rate is used for the demersal surveys which results in a biomass estimate is only 3,123 tons. Consideration should be given to which of the mean values is more appropriate.

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Table 1. Mean overall catch rates of capelin during demersal trawl surveys in 1992, 1993 and 1994 (n = number of sets, cv = coefficient of variation in mean catch rate).

NUMBERS

Year	N	Mean	Max Catch	CV
1992	64	373	7205	273
1993	63	83	1028	198
1994	66	652	10008	238

WEIGHTS

Year	N	Mean	Max Catch	CV
1992	64	3491	37000	216
1993	63	1148	9800	165
1994	66	6407	123560	275

Table 2. Results of Pearson's correlation analysis of depth and temperature vs catch rate (log^{10}) of capelin for demersal juvenile cod surveys carried out in 1992, 1993 and 1994 (top number = correlation coefficient, bottom number = probability).

	Number	Weight
1992		
Depth	0.088	0.239
	0.489	0.057
Temperature	-0.077	0.009
	0.548	0.941
1993		
Depth	0.109	0.222
	0.397	0.080
Temperature	-0.194	-0.105
	0.127	0.411
1994		
Depth	-0.001	0.084
	0.993	0.503
Temperature	0.003	0.045
	0.978	0.718

Table 3a. Comparison of capelin catch rates in a) kg/30 min tow, and b) numbers/30 min tow, in inshore and offshore areas of 3K and 3L from Campelen trawl surveys from 1992-1994.

	3K				3L			
Year	Overall	In	Off	% In	Overall	In	Off	% In
1992	5.56	0.32	6.87	4.5	2.09	2.02	2.17	48.2
1993	1.74	0.93	1.91	32.8	1.14	0.73	1.49	32.9
1994	10.37	2.58	12.46	17.2	2.99	1.35	4.76	22.1

Table 3b.

	3K				3L			
Year	Overall	In	Off	% In	Overall	In	Off	% In
1992	372	72	447	13.9	471	207	755	21.5
1993	107	70	115	37.8	95	104	88	54.2
1994	967	332	1138	22.6	411	227	610	27.1

Table 4. Percent at age of capelin from selected samples in 3KL trawl surveys during 1992, 1993 and 1994.

Year		AGE 1	2	3	4	5
1992						
	Percent	53.8	43.7	1.8	0.1	0.0
1993						
	Percent	55.3	30.8	12.6	1.3	0.0
1994						
	Percent	55.3	36.1	6.2	2.3	<0.1

Table 5. Catch rate (numbers) at age for capelin in NAFO Div. 3KL from Campelen Trawl surveys carried out in 1992, 1993 and 1994.

	AGE				
Year	1	2	3	4	5
1992	269.4	218.9	8.9	0.7	0.0
1993	38.7	21.5	8.8	0.9	0.0
1994	331.2	216.3	37.1	14.0	0.2

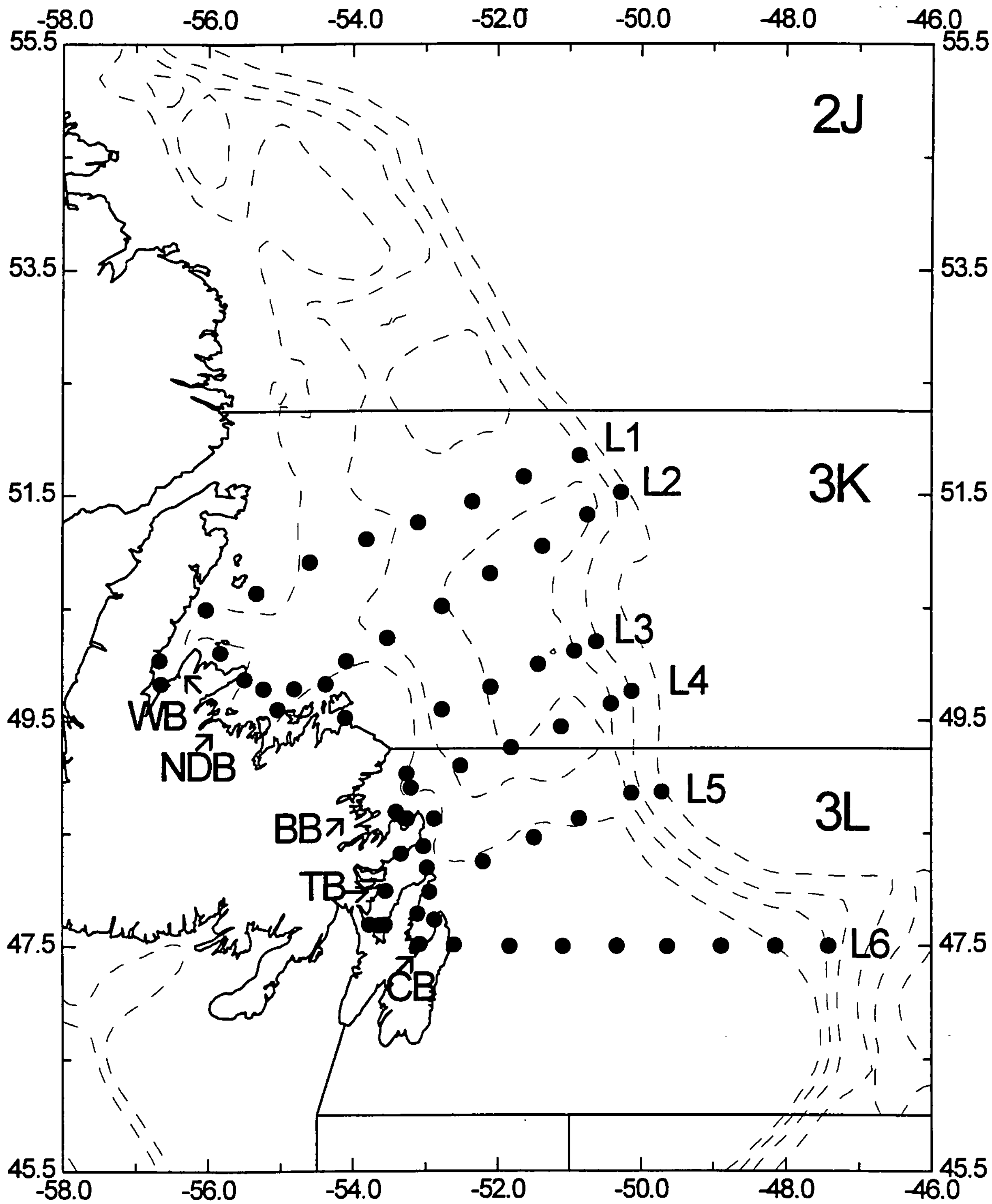

Fig. 1. Map of northeast Newfoundland shelf showing positions of stations sampled during demersal juvenile cod surveys on R.V. Wilfred Templeman, 1992-1994. (WB, NDB, BB, TB, CB = White, Notre Dame, Bonavista, Trinity and Conception Bays respectively, L1-L6 = transect line 1-6).

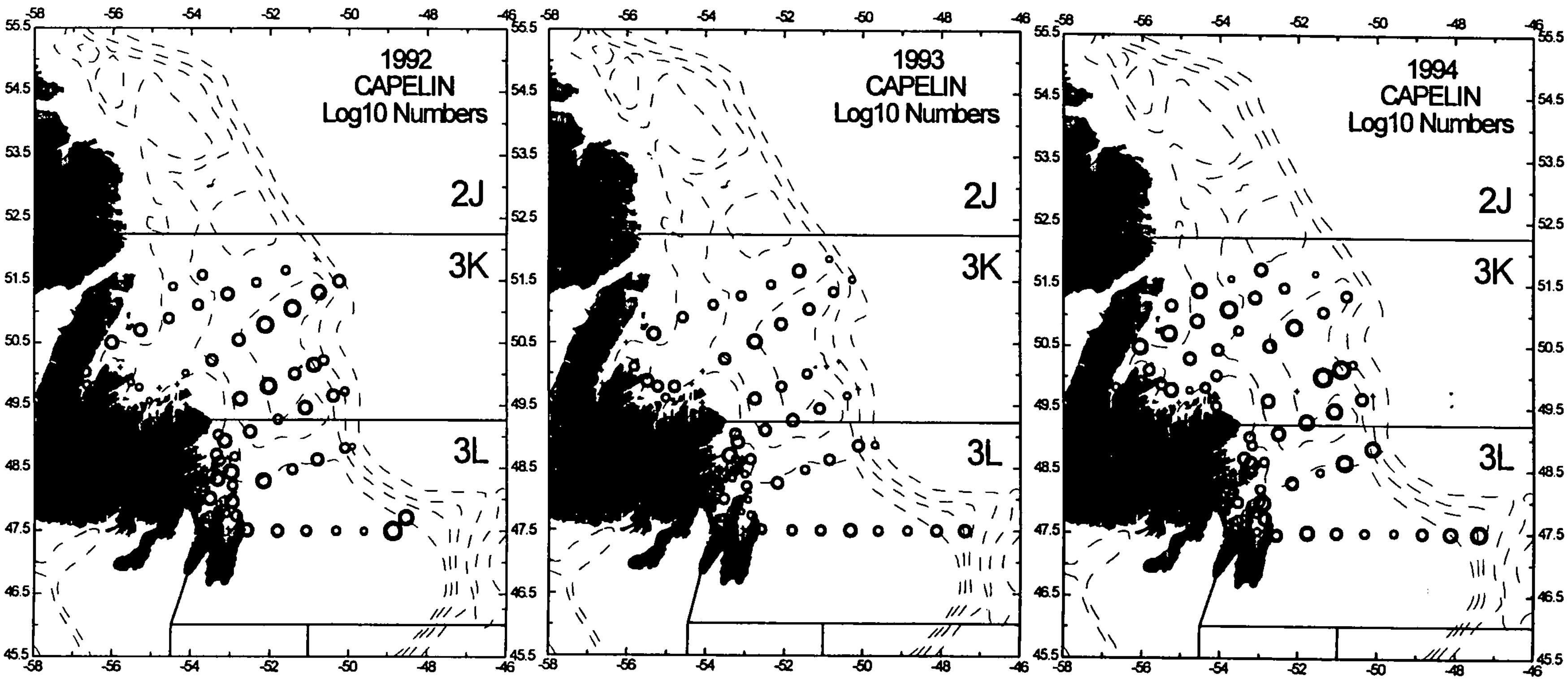

Fig. 2. Catch rates of capelin (numbers) sampled during Campelen 1800 bottom trawl surveys carried out 1992 - 1994. The expanding symbols represent a linear scale based on log10 (catch number) per 30 minute tow. Largest expanding symbol = 10,008 fish. Crosses represent zero catches.

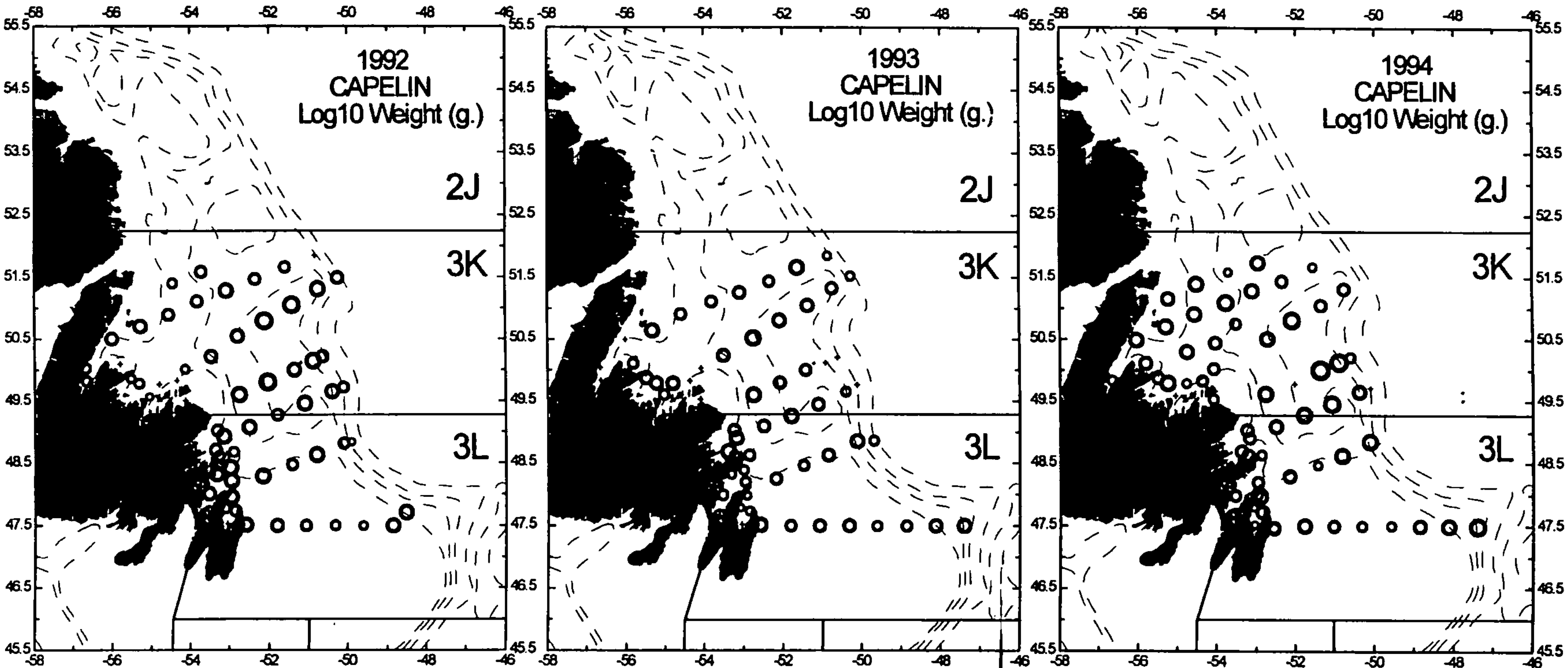

Fig. 3. Catch rates of capelin (weight in g.) sampled during Campelen 1800 bottom trawl surveys carried out 1992 - 1994. The expanding symbols represent a linear scale based on log10 (catch weight) per 30 minute tow. Largest expanding symbol = 123,560g. fish. Crosses represent zero catches.

Distributions and Abundances of Pre-Recruit Capelin (*Mallotus villosus*) in the Newfoundland Region, 1991-1994

by

John T. Anderson and Edgar L. Dalley
Science Branch
Department of Fisheries and Oceans
P. O. Box 5667
St. John's, NF A1C 5X1

Introduction

Previously it has been demonstrated that year-class strength of capelin in the Newfoundland region is established during the first year of life (Leggett et al. 1984). This result was based on the statistical association of two factors. The first factor was the successful release of capelin larvae from beach sediments and the second was warm water temperatures integrated from July-December (op. cit.).

The purpose of this study was to measure the year-class strength of capelin in the early fall, following the period of release from beach sediments. Year-class strength was assessed as a combination of abundance, the size range of capelin present as this related to periods of release, and the geographical distribution of capelin on the shelf.

Methods

The sampling program was designed as series of synoptic inshore/offshore surveys. During the first three years of the program, 1991-93, sampling was carried out using one ship targeting the inshore areas along the northeast coast of Newfoundland and the offshore area which covered the southern Northeast Newfoundland Shelf and northern part of the Grand Bank (Fig. 1). These surveys were carried out from late September to the middle of October (Table 1). In 1994 the survey was expanded to cover the entire area from southern Labrador to the southern tip of the Grand Bank using two ships simultaneously (NAFO Divisions 2J3KLNO, Fig. 1). The survey time occurred approximately six weeks earlier in 1994 due to sampling considerations regarding measurements of pelagic juvenile cod (Anderson and Dalley 1995).

A survey grid at 54 km (30 nautical mile) station spacing was used. This design is equivalent to a systematic stratified sampling design, where the first station is selected randomly from within a 54x54 km stratum with subsequent stations spaced systematically at 54 km (Snedcor and Cochrane 1967). Within the inshore bays stations were positioned to lie approximately 54 km apart along a line running through the centre of each bay to maintain a comparable sampling effort over space within the inshore areas to that offshore. When a line of stations within a bay was not possible, such as Notre Dame Bay and Bonavista Bay, then an approximate 54 km spacing was chosen, spread throughout each bay.

Multiple samplers were used during these surveys. Small larval capelin were sampled using 0.61 m bongos (0.505 and 0.333 mm mesh) towed obliquely 0-100 m depth at 1.25-1.5 m s^{-1} with payout and retrieval rates of approximately 0.8 m min^{-1} and 0.3 m min^{-1}, respectively (Smith and Richardson 1977). The bongo sampler was instrumented with a CTD which was used to monitor net performance in real time to ensure that each depth was sampled representatively. Volume filtered was estimated from mechanical flowmeters (General Oceanics) 1991-93 and electronic flowmeters (TSK) in 1994. Larger larval capelin were sampled using either a 4.5 m^2 Tucker trawl (Harding et al. 1987) or the International Young Gadoids Pelagic Trawl (IYGPT) (Koeller and Carrothers 1981, Koeller et al. 1986). In 1991 the entire survey was carried out using the Tucker trawl. In 1992 both Tucker and IYGPT trawls were used but both trawls were not used at all stations. In 1993 and 1994 only the IYGPT trawl was used. The Tucker trawl was towed obliquely 0-100 m depth using the same sampling criteria as the bongos. The mesh size was 3.2 mm in the main portion of the net, while the cod end was 0.505 mm Nitex netting. The Tucker trawl was instrumented to monitor trawl performance in real time, including electronic flowmeters (TSK), net angle and a CTD. The IYGPT trawl is a 10x10 m pelagic mid-water trawl designed primarily to catch pelagic juvenile cod (Koeller et al. 1986). In the 1992-93 surveys it was towed at 1.25-1.5 m s^{-1} for 30 minutes with the head rope positioned at approximately 50-60 m depth. In 1994 the IYGPT trawl was towed between 20-50 m depth. Depth and net configuration were monitored in real time using acoustic net sensors (Scanmar) to measure net depth, net opening, wing and door widths. For both trawls, the net performance data were used to estimate the volume of water (m^3) filtered during the tow.

Bongo samples were preserved in 90% formalin and returned to the laboratory for processing. All ichthyoplankton were removed from the sample, identified to species and measured for standard and total length (mm). When sample size exceeded approximately 100 organisms then a sub-sample was taken following the procedures of van Guelpen et al. (1982). The Tucker and IYGPT trawl catches were processed at sea, identifying fish to species level where possible, and recording total length for capelin. Beginning in 1993, with the systematic use of the IYGPT trawl at all stations, one year old capelin were also processed at sea. One year old capelin were classified based on size (from 50-60 mm up to approximately 110 mm) and coloration (they are pigmented more than the translucent larvae but less so than older capelin).

Results

Comparison of Lengths Among Samplers

Comparison capelin sizes sampled each year by the different samplers indicates that the bongos sampled capelin representatively from approximately 3-25 mm, the Tucker trawl from 18-38 mm and the IYGPT trawl > 24 mm. These results are based on comparisons of the length- frequencies sampled in different years.

In 1991 there was only one dominant size mode of capelin present, ranging from approximately 10-30 mm (Fig. 2). There was a clear overlap in the lengths sampled by the bongo and Tucker trawls. The bongo sampler did not sample capelin abundantly > 25 mm length, whereas the Tucker trawl demonstrated that capelin were still relatively abundant up to 28 mm length. On the other hand, the Tucker trawl did not abundantly sample capelin < 18 mm, whereas the bongo sampler demonstrated that capelin were relatively abundant down to approximately 12 mm length. This comparison demonstrates that capelin were sampled representatively by both samplers in the 18-25 mm size range. Comparison between the two samplers demonstrated that there was a statistical difference in the sizes caught (Kolmogorov-Smirnov test, $P < 0.01$).

There was a statistical difference in the sizes of capelin caught by the Tucker and IYGPT trawls, based on a comparison of nine stations where both trawls were towed in 1992 (Kolmogorov-Smirnov test, $P < 0.01$). At these stations the Tucker trawl catch ranged in length from 13-45 mm and the IYGPT trawl catch ranged from 19-61 mm. There was a 6 mm difference in mean size between the two trawls (25 mm and 32 mm). The upper size sampled by the Tucker trawl appeared to be approximately 38 mm.

Larval Release Periods

The length frequency data indicates that there were differences in the periods of larval release from beach sediments among the four years (Figs. 2-5). In 1991 both the bongo and Tucker samplers demonstrated that there was a single length mode which ranged predominantly from 11-28 mm. In 1992 all three samplers demonstrate that there were two dominant modes, a small mode which ranged from 7-18 mm and a larger mode which ranged from 21-42 mm. The smaller numbers of capelin caught in the 18-24 mm length range is not due to sampler bias, as it falls within the common range sampled representatively by both the bongo and Tucker trawl samplers. In 1993 there were again two modes in the length data, although these modes were more widely separated than in 1992, the smaller mode ranging predominantly from 5-19 mm and the larger mode from 30-44 mm. In 1994 there was only one length mode present, ranging from 4-15 mm length. Only a very small number of larger capelin were caught in the range of 28-40 mm length.

It is noteworthy that none of the bongo length frequency data were skewed towards the smallest sizes, as would be expected if significant release of small larvae (3-4 mm length) from beach sediments was ongoing during the time of each survey. Also, examination of individual catches indicated that there was no apparent skewness in length data from within each bay. Therefore, it appears that the annual release of capelin from beaches was completed each year by the time of the surveys.

We used average growth rates of 0.25 mm d^{-1} (Jacquaz et al. 1977) and 0.35 mm d^{-1} (Frank and Carscadden 1989) to estimate release times for capelin each year, based on the dominant length frequency modes sampled during our surveys (Table 2). It is apparent that a growth rate of 0.25 mm d^{-1} overestimates the age of capelin as it estimates release times which occurred during May in 1992 and 1993; whereas the earliest recorded spawning dates were 4 July 1992 and 1 July 1993 (Nakashima and Winters MS1995). By comparison, the earliest calculated release times based on 0.35 mm d^{-1} growth rates were 21 June 1992 and 16 June 1993 indicating this higher growth rate also underestimates age to a small degree (Table 2). As a first approximation, a growth rate of 0.35 mm d^{-1} was used to estimate relative release times each year based on the length modes sampled during our surveys.

We estimate that release of capelin larvae from beaches occurred relatively early in 1992 and 1993 and continued into late September (Fig. 6). In 1992 the release of larvae from beaches appears to have been relatively continuous from June to September, whereas in 1993 there were two distinct periods of release; one early and one late. In 1991 larvae were released relatively late (August) as one continuous period of release. In 1994 release of larvae again began late in August. In 1994 we do not have a direct measure of any release of larvae which may have occurred in September.

Distributions

Distributions of smaller capelin sampled by the bongos demonstrated that capelin larvae were distributed widely throughout much of the offshore areas sampled in 1991-93, including the inshore bays along the northeast coast of Newfoundland and along the Avalon Peninsula (Fig. 7). Based on mean sizes and an average growth rate of 0.35 mm d^{-1}, these capelin averaged 5-6 weeks since their release from beach sediments. These data indicate that capelin are dispersed from the beaches over a scale of > 100-200 km within a relatively short period of time. In 1994 the capelin were not distributed extensively offshore, as might be expected from the earlier survey time. Capelin sampled in 1994 averaged three weeks of age, based on an average growth rate of 0.35 mm d^{-1}. The presence of small capelin offshore in the vicinity of Belle Isle Bank demonstrates that spawning occurred in southern Labrador in 1994. Notably, no capelin larvae were sampled over the southern Grand Bank.

Distributions sampled by the Tucker and IYGPT trawls demonstrated that the larger, older capelin were largely dispersed away from the inshore bays to the northern part of the Grand Banks in 1991-93 (Fig. 8). The 1991 Tucker trawl distribution offshore was similar to that sampled by the bongos, which would be expected given the similar length range sampled. In 1992 and 1993 the larger capelin sampled by the Tucker and IYGPT trawls demonstrate that the capelin were widely and evenly dispersed over the northern Grand Bank but were noticeably absent from the inshore bays. In 1994 there were very few larger capelin sampled by the IYGPT trawl. The distributions sampled in 1992 and 1993 are consistent with progressive dispersal (drift) of capelin from the inshore areas, where they were spawned, to the offshore shelf, particularly the northern Grand Bank.

Abundances

Mean abundance of capelin sampled by the bongos in 1991-93 indicates that abundance was approximately two times greater in 1993 (Table 2). Abundance estimates based on numbers m^{-3} are not available yet for 1994. Comparisons of mean catch/tow indicates that 1991 was less than either 1992 or 1994 ($P<0.007$), 1992 was not different than 1994 ($P=0.2745$), while 1993 was greater than either 1992 or 1994 ($P<0.016$). Based on these data we would rank year-class strength as 1991 < 1992 = 1994 < 1993. As the 1994 survey occurred approximately six weeks earlier, and sampled smaller larvae, the numbers are not directly comparable to the other years. Qualitatively, the abundance estimated for 1994 should be reduced compared to the other years, indicating that year-class strength in 1994 may be more similar to 1991.

Mean abundance measured by the Tucker trawl in 1991 was less than 1992, which is a significant difference given that the capelin were larger in 1992 (Table 2). Comparison of abundance sampled by the IYGPT trawl indicates that 1992 was greater than 1993. While standardized abundance estimates are not yet available for the 1994 data, the low numbers caught (Fig. 5) indicates that abundance was very low compared to all previous years. These comparisons indicate that year-class strength in 1994 < 1991 < 1993 < 1992. However, it is difficult to directly compare abundances among years when the mean sizes differ significantly. Qualitatively, the small sizes sampled in 1991 would adjust these abundance estimates lower compared to 1992 and 1993. Similarly, the smaller sizes sampled in 1992 adjust the numbers down compared to 1993. On the other hand, the total absence of larger capelin in 1994 demonstrates a very low abundance compared to 1992 and 1993.

One Year Old Capelin

In 1993 one year old capelin were distributed most abundantly over the northern Grand Bank and to a lesser extent on the southern part of the Northeast Newfoundland Shelf (Fig. 9). They also occurred within all of the inshore bays, but at relatively lower abundances and not at all locations. In 1994 one year old capelin again occurred most abundantly over the Northern Grand Bank and at a lesser extent over the Northeast Newfoundland Shelf and the Southern Grand Bank (Fig. 9). One year old capelin occurred at relatively high abundances extensively throughout the inshore area in 1994.

In 1993 one year old capelin from the 1992 year-class averaged 40.3/tow, compared to 836.5/tow for the 1993 year-class measured in 1994. The significantly greater abundance measured in 1994 indicates the 1993 year-class is relatively large compared to 1992.

Discussion

Capelin spawning periods remained relatively constant during 1991-94, ranging approximately from the end of June to the end of August each year (Nakashima and Winters MS1995). However, survival from these spawnings varied among years. In 1992 and 1993 the larger length ranges of larvae sampled in the fall indicates that conditions which favoured larval survival extended over a longer period of time. In contrast, in 1991 and 1994 there was little survival of larvae from the earliest spawning periods. Only larvae which were spawned late in the year survived and dispersed away from the beaches. In addition, years which favoured longer release periods directly scaled with mean measures of larval abundance.

Several factors are thought to contribute to the survival of capelin larvae. Successful release from beach sediments as a function of the frequency of onshore winds has been reported as a significant factor effecting survival (Leggett et al. 1984). There is some indication that this was an important factor in 1991-93, where the total number of emergent larvae measured near beaches (Nakashima and Winters MS1995) closely matched the mean numbers of larvae sampled in this study (Fig. 10). However, in 1994 the low abundance of larvae appears to result from relatively low levels of egg deposition, as opposed to successful release from beach sediments (op.\ cit.). This suggests that the size of the spawning stock may also have been a significant determinant of year-class strength during these years. It is notable that the spawning in 1994 was primarily made up of fish from the relatively weak 1991 year-class (op. cit.).

Previously, it was reported that warmer water temperatures were related to increase survival (Leggett et al. 1984). There is no indication that water temperature was an important determinant of survival during these years. While 1991 was the coldest year, both 1992 and 1993 were also relatively cold. In contrast, 1994 was much warmer. Therefore, the warmest and coldest years during 1991-94 relate to the lowest estimates of year-class strength. The broad distributions of larval capelin throughout the offshore areas, particularly on the northern Grand Bank, indicates that dispersal from the inshore bays where capelin spawn to the offshore shelf is an important phase in the early life history of capelin. In the Gulf of St. Lawrence downstream dispersal of capelin to important feeding areas was reported (Bailey et al. 1977, Jacquaz et al. 1977, Fortier and Leggett 1983, 1985). It may be that the offshore environment enhances survival of larval capelin. In particular, the northern area of the Grand Bank appears to be an area where capelin concentrated, both as larvae and as one year old capelin.

The absence of larval capelin from the southern Grand Bank in 1994 contrasts with observations made during September 1985 and 1986 (Frank and Carscadden 1989). Our observations indicate that there was no successful emergence of capelin from spawning on the SE Shoal up to the beginning of September 1994.

The greater abundances and larger size ranges of larval capelin in 1993 indicate that the 1993 year-class is greater than 1992. This comparison is confirmed by abundances measured for these year-classes at one year of age. Larval abundances were less in 1991 than either 1992 or 1993. The abundances measured in 1994 are not directly comparable due to the earlier sampling time. However, based on the absence of larger capelin in 1994 we estimate the 1994 year-class will be less than either 1992 or 1993, and may be similar to 1991. Therefore, we rank year-class size as: 1993 > 1992 > 1991 = 1994.

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Table 1. Summary of pelagic juvenile fish survey dates and sampling each year 1991-94.

Year	Start Date	End Date	Total Days	Survey Mid-date	Locations Sampled Tucker	IYGPT
1991	11 October	22 October	13	289	57	
1992	30 September	15 October	16	281	35	32
1993	27 September	20 October	24	281		87
1994	22 August	3 September	13	239		99

Table 2. Estimated dates of peak release periods of capelin in 3K and 3L based on dominant length frequency modes and growth rates averaging 0.25 mm d^{-1} and 0.35 mm d^{-1}, 1991-1994.

Year	Length Modes (mm)	Release Dates		Release Days	
		0.25 mm d^{-1}	0.35 mm $^{-1}$	0.25 mm d^{-1}	0.35 mm $^{-1}$
1991	12-24	12 Jul-10 Sep	8 Aug-20 Sep	193-253	220-263
1992	8-17	13 Aug-18 Sep	29 Aug-24 Sep	225-261	241-267
	21-41	9 May-28 Jul	21 Jun-18 Aug	129-209	172-230
1993	7-16	17 Aug-22 Sep	1 Sep-27 Sep	229-265	244-277
	33-43	1 May-10 Jun	16 Jun-14 Jul	121-161	167-195
1994	5-12	22 Jul-19 Aug	1 Aug-21 Aug	203-231	213-233

Table 3. Summary of capelin mean abundances sampled each year by the different gear types. Means are based on all stations where capelin were caught. Abundances calculated for Tucker and IYGPT trawls are for capelin $\leq$ 60 mm length. (N/A - refers to Not Available as gear not used; N/C - refers to Not Calculated at this time)

Year	Bongo (number m^{-2})	Bongo (catch/tow)	Tucker (number m^{-2})	IYGPT (number $10^5 m^{-3}$)
1991	7.51	22.2	2.50	N/A
1992	9.27	60.7	3.89	4.79
1993	21.87	175.6	N/A	3.45
1994	N/C	87.7	N/A	$\sim$0.5

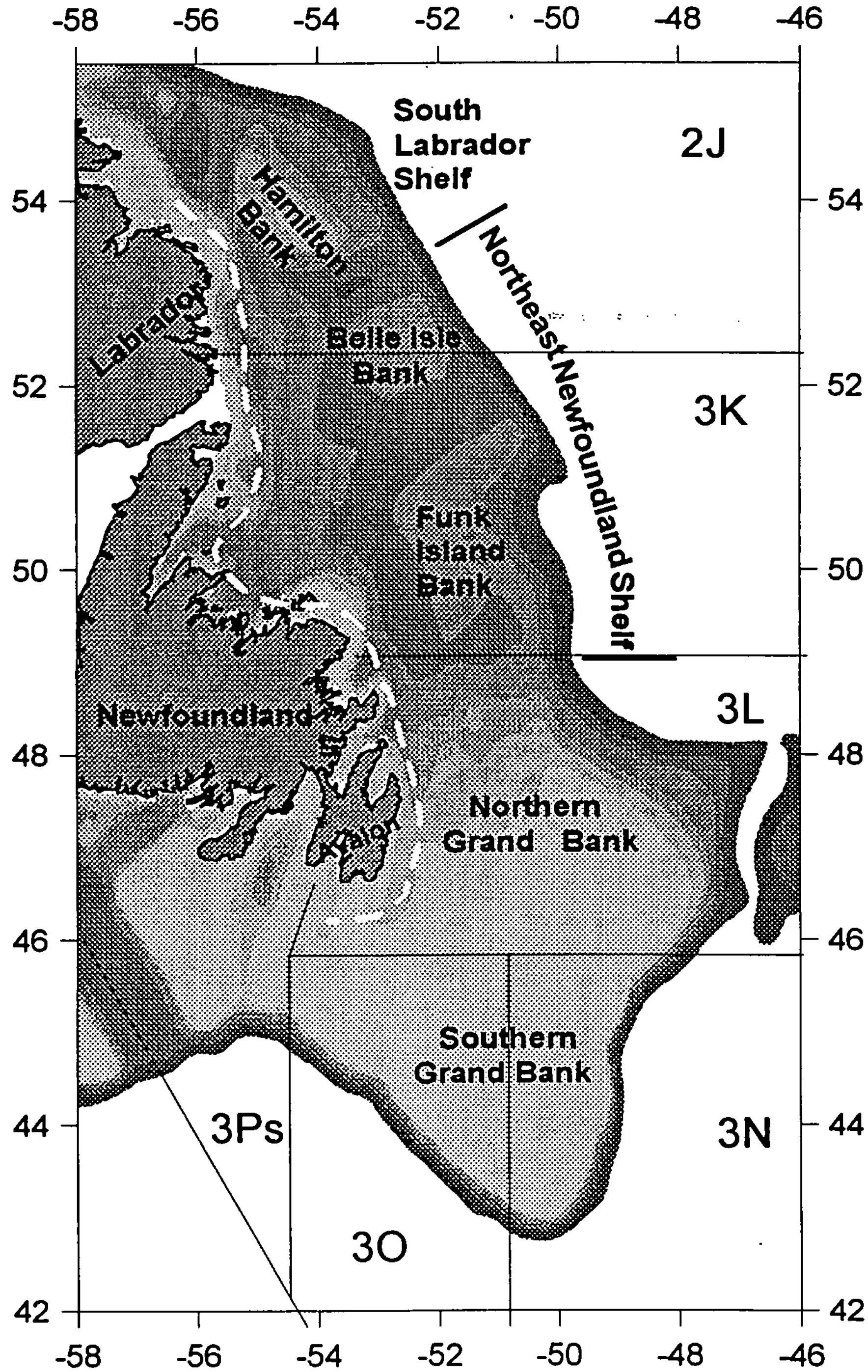

Fig. 1. Study area of the offshore shelf areas and associated names and the inshore area which lies shoreward of the white dashed line. (2J, 3K etc. refers to NAFO Statistical Divisions)

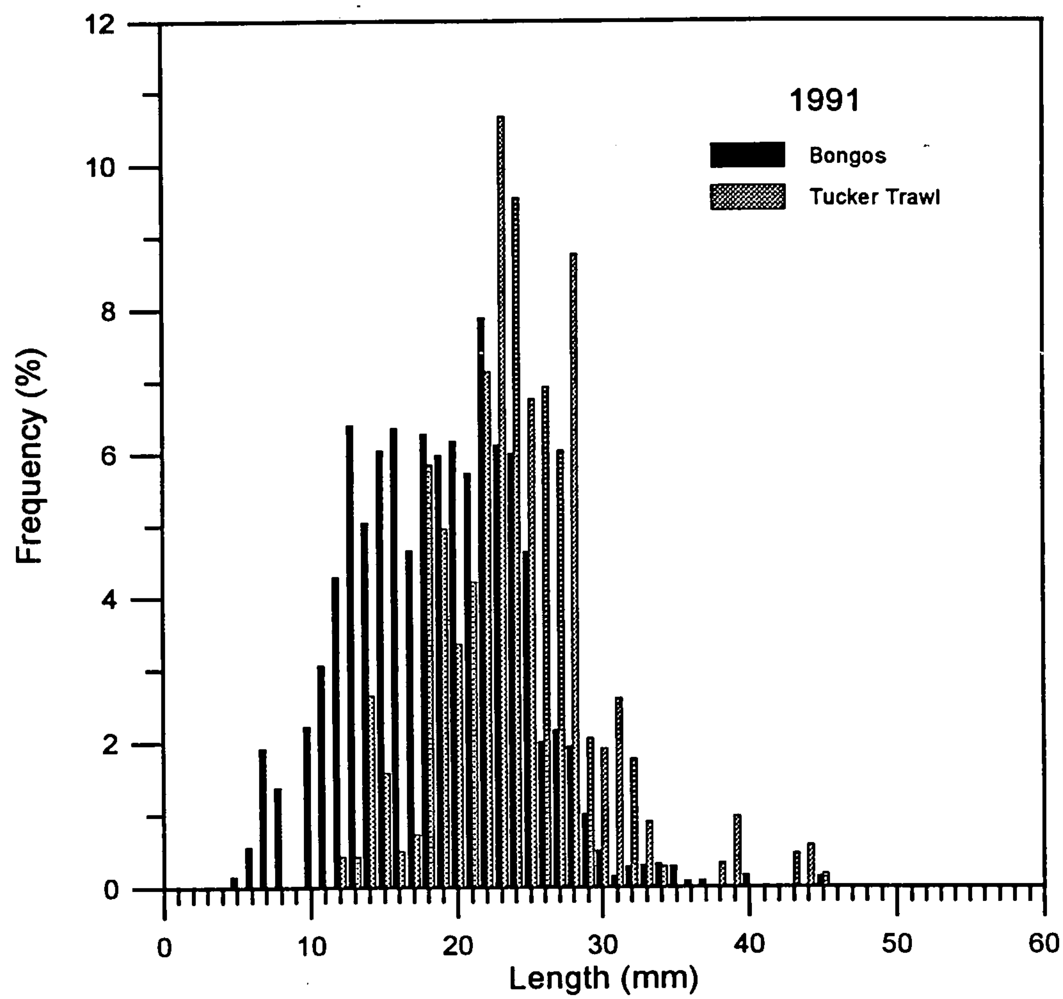

Fig. 2. Length frequency distributions sampled by the bongo and Tucker trawl samplers in 1991.

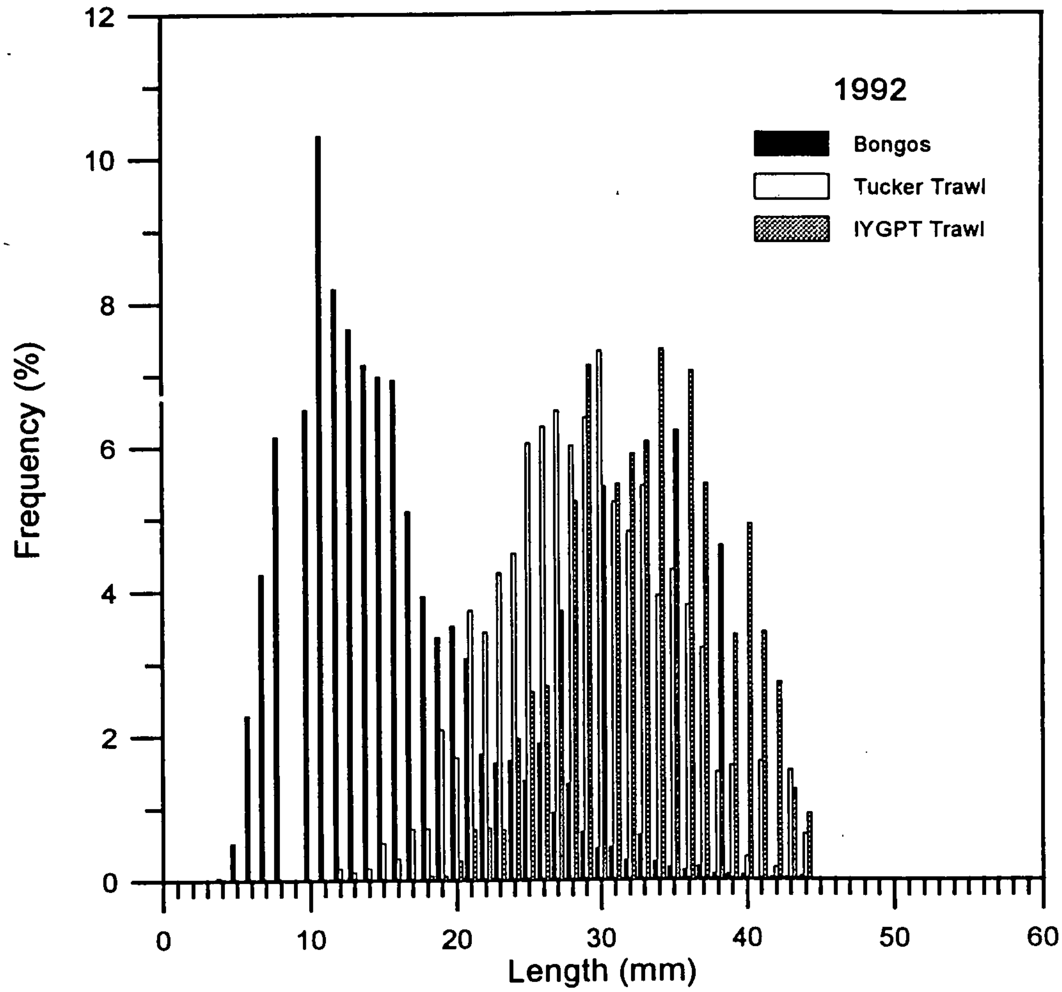

Fig. 3. Length frequency distributions sampled by the bongo, Tucker trawl and IYGPT (International Young Gadoids Pelagic Trawl) samplers in 1992.

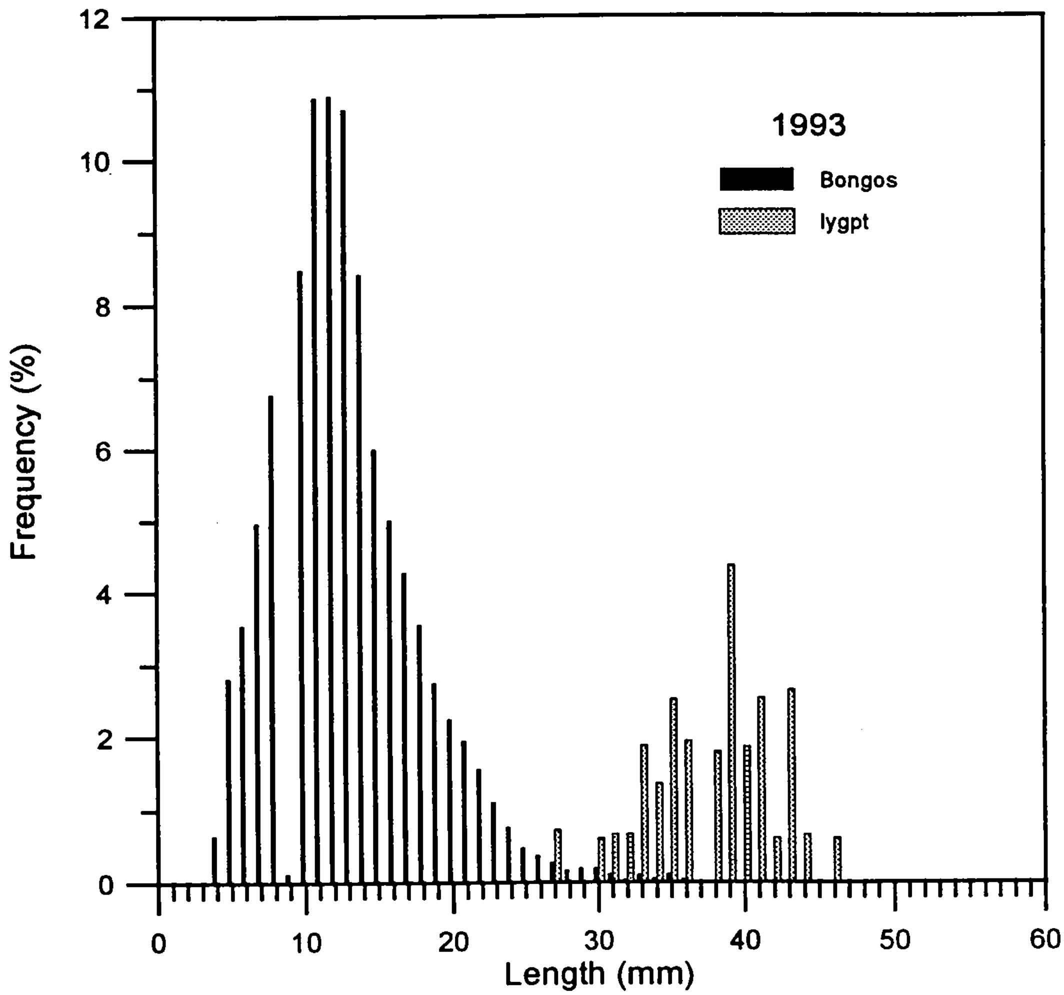

Fig. 4. Length frequency distributions sampled by the bongo, and IYGPT (International Young Gadoids Pelagic Trawl) samplers in 1993.

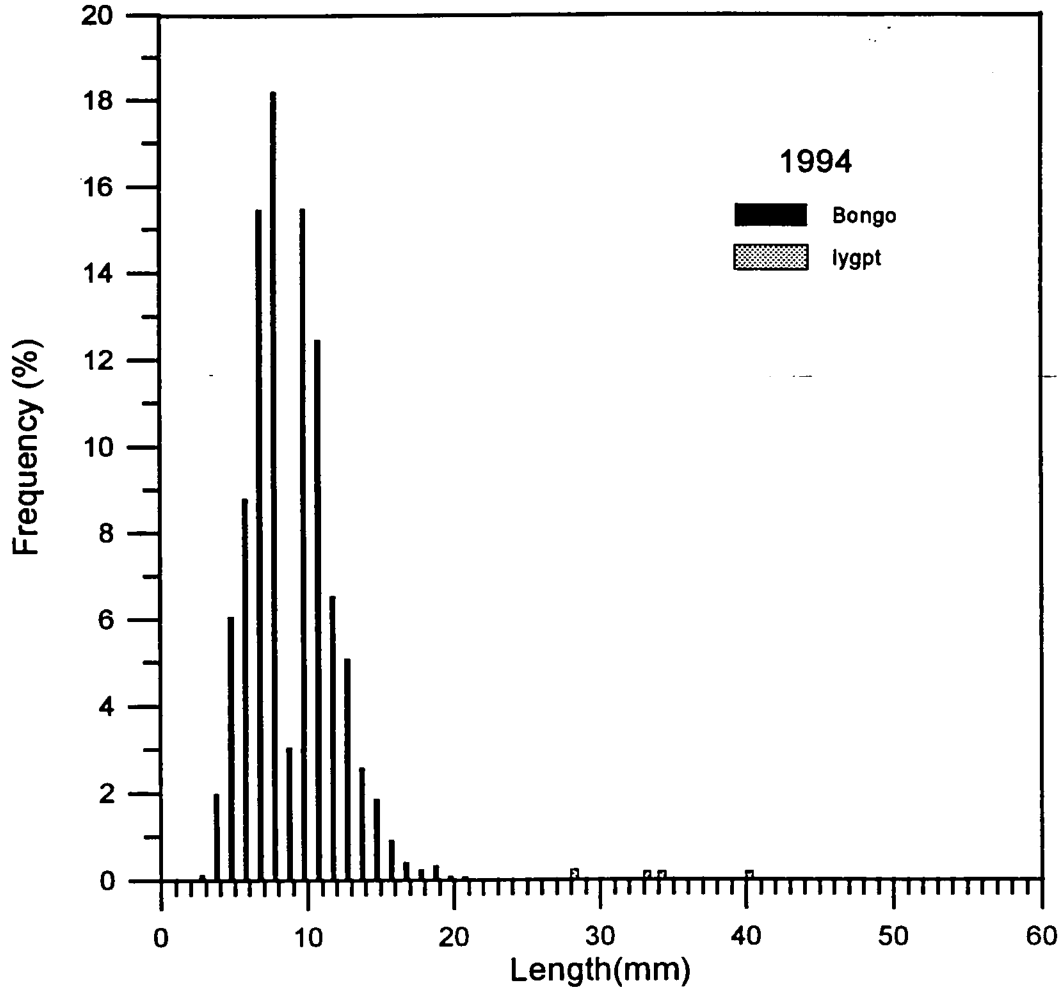

Fig. 5. Length frequency distributions sampled by the bongo, and IYGPT (International Young Gadoids Pelagic Trawl) samplers in 1994.

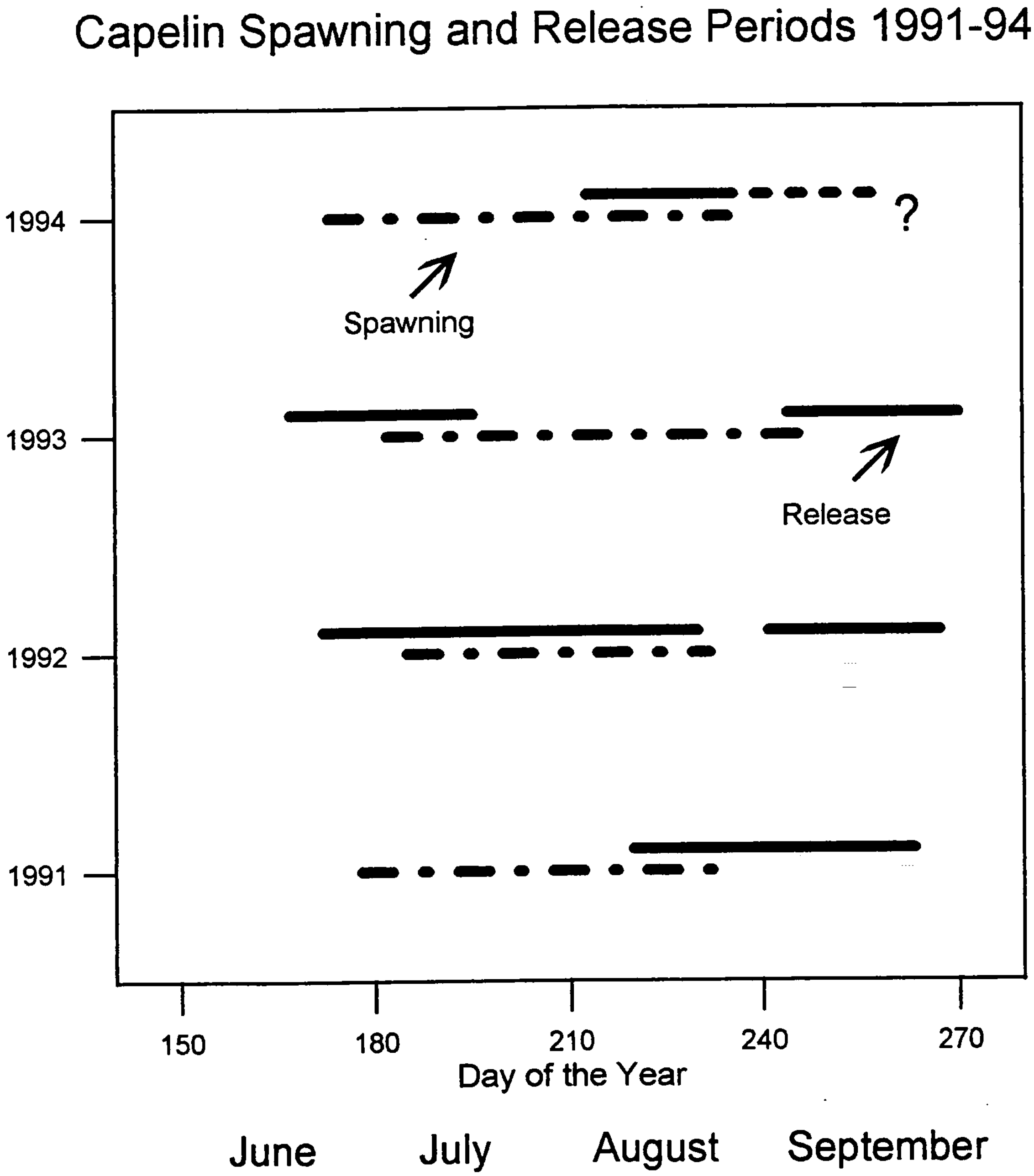

Fig. 6. Estimated periods of capelin release from beach sediments each year, based on the dominant length modes and an assumed growth rate of 0.35 mm d^{-1} (solid line), and the measured spawning times sampled by Nakashima and Winters (MS1995) (dash-dot line). The dashed line following the release period estimate in 1994 indicates that release may have occurred into September 1994 but was not sampled by the 1994 survey.

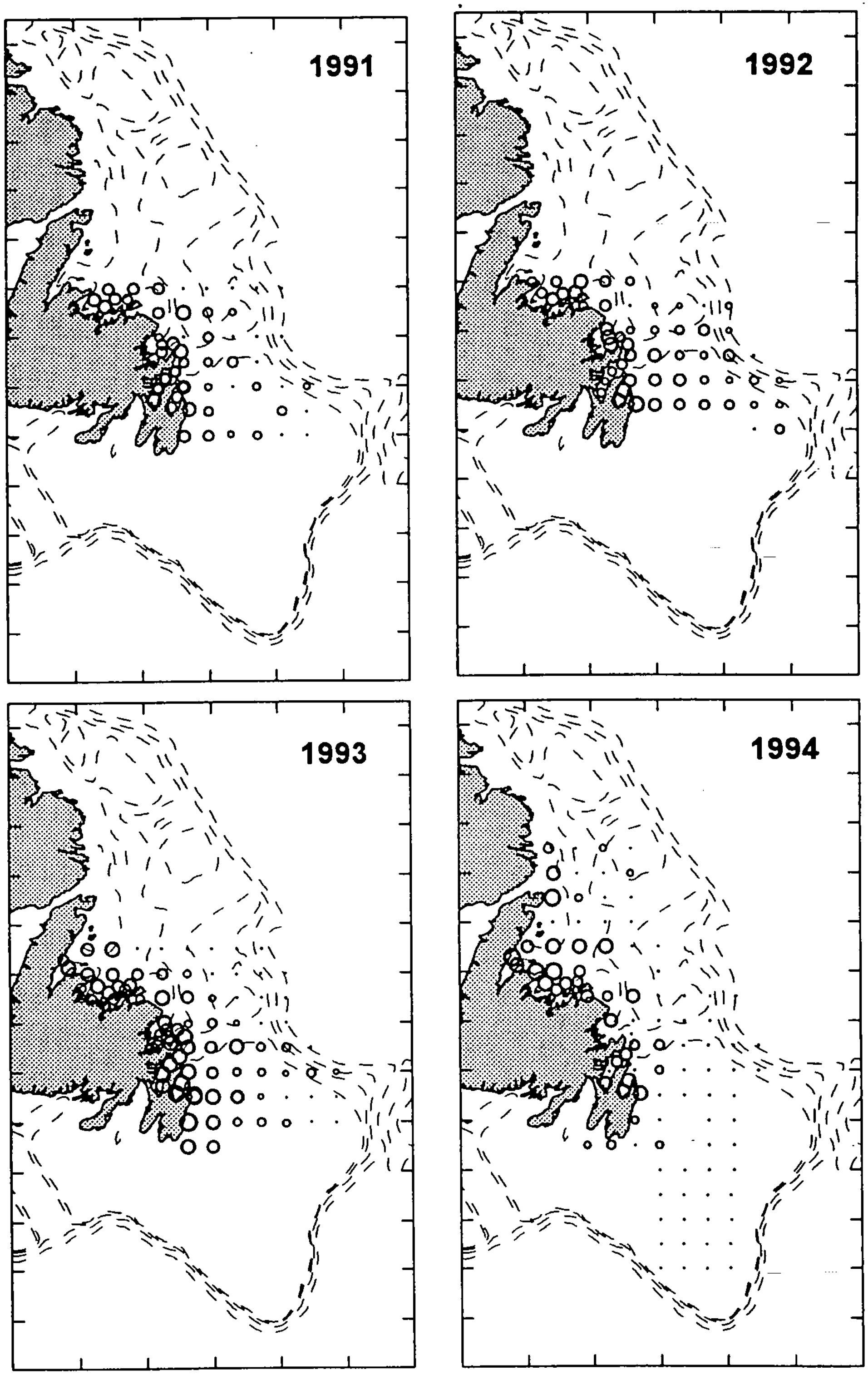

Fig. 7. Distributions of larval capelin sampled by the bongo sampler 1991-1994. Expanding symbols represent abundance ($\log_{10}$ number m^{-2}) and a solid dot indicates a null sample.

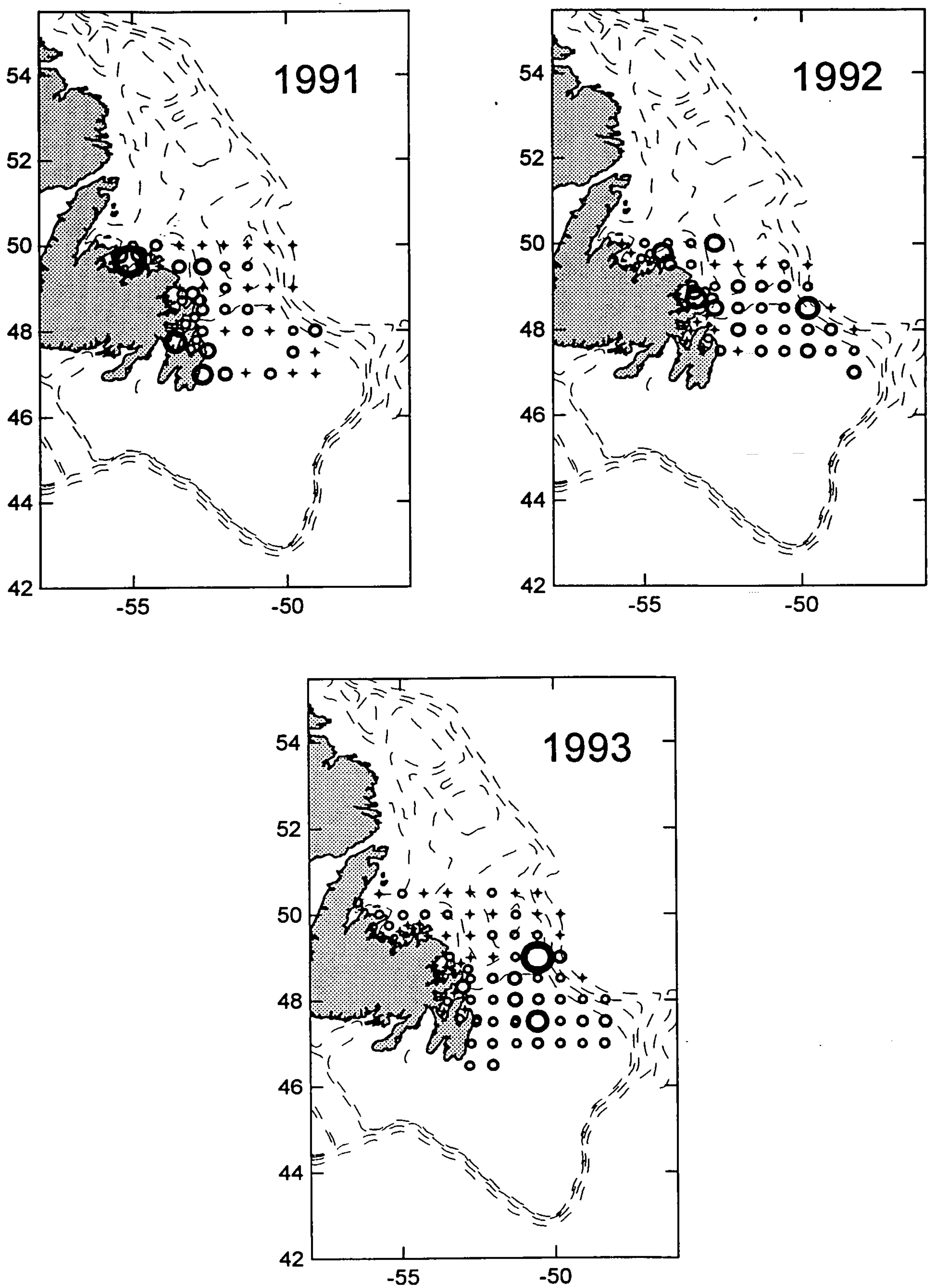

Fig. 8. Distributions of larval capelin sampled by the Tucker and IYGPT (International Young Gadoids Pelagic Trawl) trawls 1991-1993. Expanding symbols represent abundance ($\log_{10}$ number m^{-3}) and a solid dot indicates a null sample.

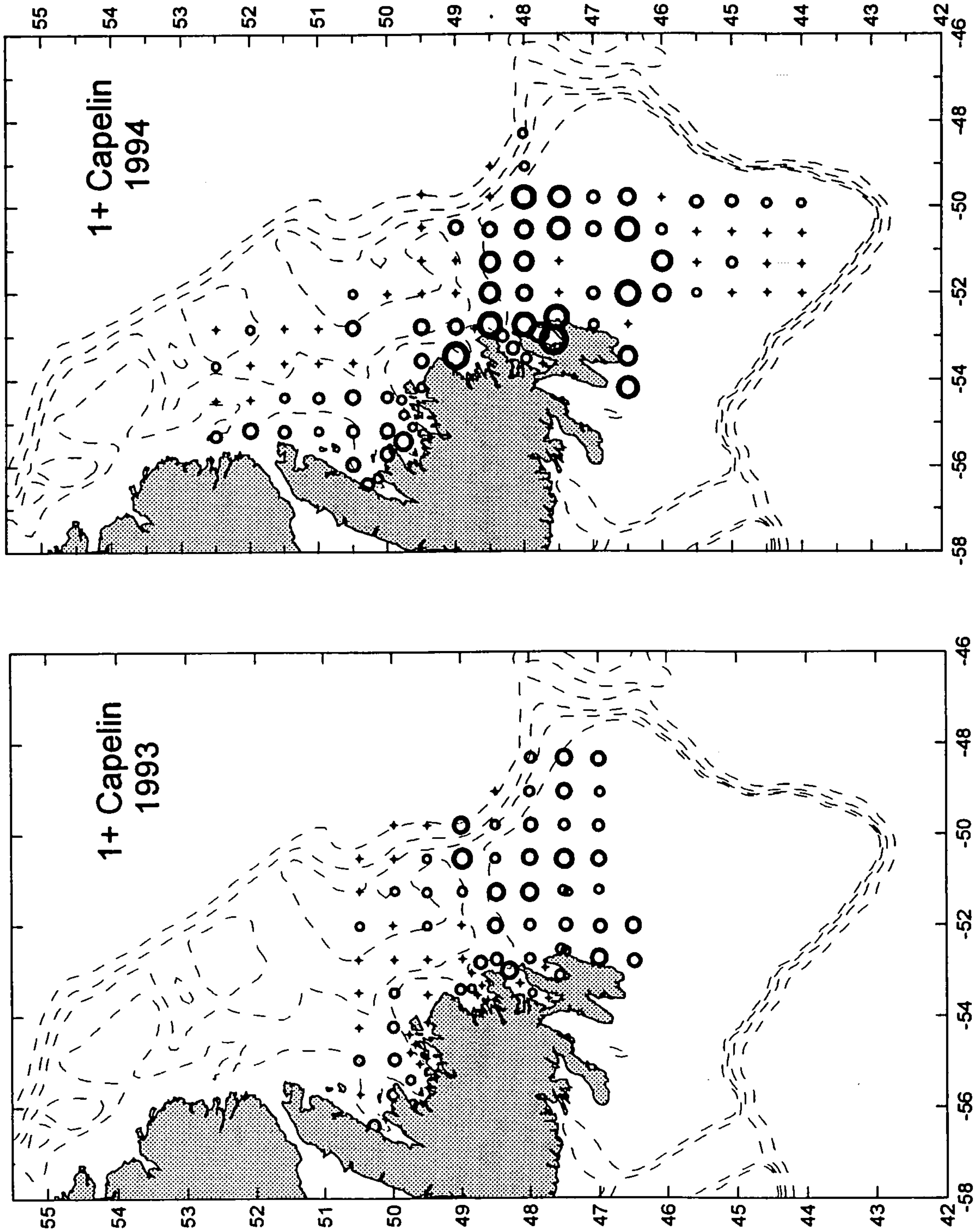

Fig. 9. Distributions of one year old capelin sampled the IYGPT (International Young Gadoids Pelagic Trawl) trawl 1993 and 1994. Expanding symbols represent abundance ($\log_{10}$ number m^{-3}) and a solid dot indicates a null sample.

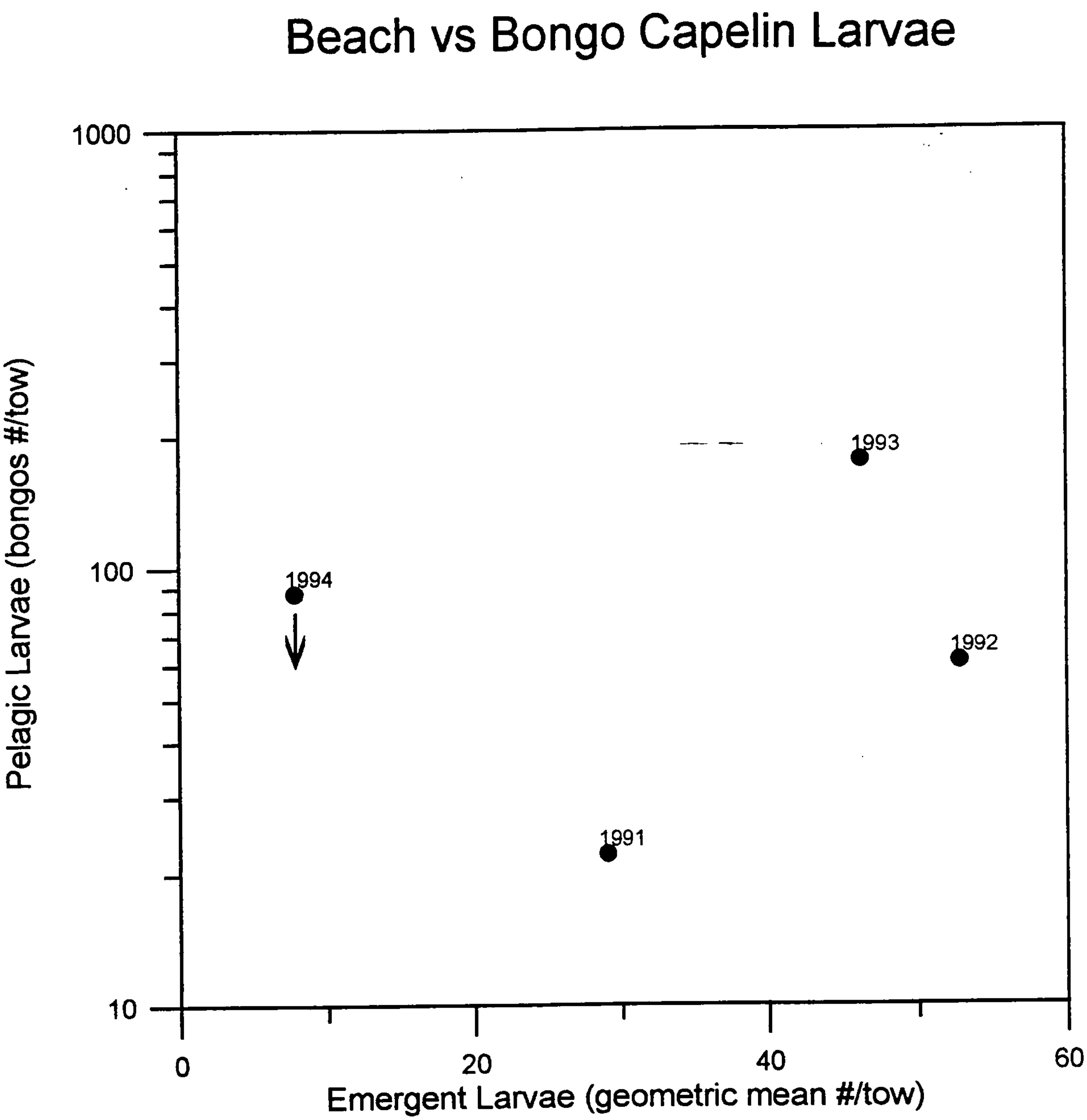

Fig. 10. Comparison of the geometric mean of the total number of larvae emerging from six beaches sampled along the northeast coast of Newfoundland (Nakashima and Winters MS1995) versus the number of capelin larvae (log scale mean number per tow) sampled inshore and offshore by the bongos, 1991-1994. The 1994 bongoestimate is biased high due to a significantly earlier sampling time compared to 1991-1993.

Interaction Between Timing, Capelin Distribution and Biomass Estimates from the Div. 2J3K Capelin Acoustic Survey

by

G. H. Winters
Science Branch
Department of Fisheries and Oceans
P. O. Box 5667
St. John's, NF A1C 5X1

Introduction

Temporal and spatial distribution patterns of fish are often a reflection of feeding and spawning strategies. These strategies, in turn, are closely linked with environmental changes through oceanographic influences on food production and availability. In the Northwest Atlantic water temperatures have been below normal since the early 1980's and have been particularly severe and sustained since 1990. Since 1981 systematic hydroacoustic surveys of capelin abundance have been conducted during October by Canada in NAFO 2J3K. The biomass estimates from these surveys have shown large interannual variations which have not been reflected in subsequent inshore indices of mature fish (Fig. 1) which they were designed to measure. In particular, anomalously low biomass levels were observed in 1983, 1986, 1987, and from 1990 onwards. Lilly and Davis (1993) (but see also references contained therein) have reviewed the 2J3K acoustic estimate in relation to distribution patterns inferred from bycatches of capelin in the 2J3K groundfish survey and from capelin in cod stomachs. The authors observed that the anomalously low acoustic estimates were consistently associated with shifts in capelin distribution to the south and east towards the outer portions of the survey blocks. They recommended that further studies were required to determine whether or not low biomass levels from the October hydroacoustic survey are associated with southerly capelin distribution in 2J3K in November-December. In this regard Vilhjalmsson (1994), in an extensive review of Icelandic acoustic surveys of capelin, has noted that the behaviour and distribution patterns of capelin are consistently shifting and that the success of an acoustic survey depends critically on appropriate timing even to the extent of cancelling, delaying, or repeating the survey at a later date. The 2J3K acoustic survey has always been conducted in October (also September - beginning in 1993) because of timing restraints imposed by research vessel schedules. The purpose of this paper is to examine the hypothesis that an acoustic survey which is fixed in time and which does not cover the entire distribution area of the stock will exhibit periodic failures to reliably and consistently measure abundance levels. Groundfish bycatch data and cod stomach percentage fullness index (PFI) data (G. R. Lilly, pers. comm.) collected during the November-December 2J3K bottom trawl survey will be the major data sources used to describe statistical associations between capelin distribution patterns and interannual variability in the 2J3K capelin acoustic biomass estimates.

Materials and Methods

The reader is referred to Lilly and Davis (1993) and Lilly (1994) for details on the 2J3K groundfish survey methodology and the sampling methods, and statistics for the capelin PFI data. Lilly (1994) also provides an excellent pictorial review of annual shifts in capelin distribution as inferred from PFI data. Miller ((1994) and references therein) provides information on the survey methodology for the 2J3K hydroacoustic surveys for the period 1981-93.

Results

A. Generalized View of Stock Structure and Migrations

In order to set the stage, it is necessary to provide a composite description of the stock model for which estimates of capelin abundance are derived.

The 2J3KL capelin stock is a mixture of several subpopulations that mix offshore but likely form separate (and probably homing) spawning populations. Spawning occurs inshore in June and July with the majority of spawning occurring on coastal beaches but with a variable amount of bottom (i.e. off-beach spawning (Templeman 1948)) depending upon the match/mismatch of maturation trajectories and optimum requirements for beach spawning. After incubation and emergence it is believed that the larvae are largely advected out of the bays to north-central 3L where they reside until their second year of life. During the summer of their second year (and likely following the spring plankton bloom in 3L) the larger individuals undergo extensive contranatent feeding migrations to northern and northwest 2J where the maturation process begins. According to Gulimov and Kovalov (1975) this northward feeding migration is along the eastern regions of Funk Island Bank and Belle Isle Bank, an area that roughly corresponds to the polar front associated with the offshore branch of the Labrador Current (G. Mertz, pers. comm.). In normal years the summer-fall feeding aggregations are located on Hamilton Bank and the coastal Shelf off southern Labrador. In October these capelin begin their southward migration along the coastwards portions of the Shelf into central 3K (Carscadden and Atkinson 1986). At this time bottom temperatures increase and the CIL decreases as a result of the fall destratification process (G. Mertz, pers. comm.) which also coincides with the fall phytoplankton bloom in 2J and 3K (Myers et al. 1994). By late November these maturing capelin have largely moved out of 2J and by December they are located northeast of Notre Dame Bay (Kovalev and Kudrin 1973) in a broad distribution from Funk Island Bank to the coastal bays. They remain in this area until February when they move southwards into Div. 3L and mix with the immature recruits (Gulimov and Kovalev 1975). As feeding resumes in March-April the mature fish begin their southward and westward migrations to coastal waters (Shackell et al. 1994) and thence contranatantly northwards to spawn along eastern Newfoundland. Thus the population of capelin surveyed in Div. 2J3K in the fall are mainly maturing fish, those in Div. 3L (in the fall) are almost exclusively immature and those in Div. 3L in the spring are a mixture of both. This is the general picture extracted from the literature but the details of the migration and annual distribution patterns are much more complex and less predictable than described above.

B. Effect of Timing

The distribution patterns of pelagic fish (and, indeed, most fish) have a distinct and predictable seasonal component. Pelagic fish are typically aggregated into large aggregations during the overwintering period. These aggregations begin to disperse into feeding schools during the pre-spawning period. As spawning approaches, these schools of mature fish re-form into aggregations and migrate to their spawning areas. After spawning is completed a period of intense feeding begins which lasts throughout the summer and into early fall. During this feeding season the fish are typically dispersed into smaller schools, often located near the surface waters. These feeding schools form up into large concentrations during the fall when the overwintering migration begins. Pelagic fishers take these seasonal distribution patterns into account and usually concentrate on the fall, winter and pre-spawning aggregations.

According to Vilhjalmsson (1994) these seasonal distribution patterns can be an important variable in the success of an acoustic suvey. This observation reflected the Icelandic experience with acoustic surveys for capelin which began in the early 1970's and produced unrealistically low estimates of abundance. These initial surveys were carried out in August-September when the maturing capelin were still in their main feeding season and were distributed into small schools which were often observed feeding at the surface layers above the transducer depth. The Icelandic acoustic surveys were subsequently shifted to October-November when feeding had largely ceased and capelin were concentrated into larger schools and a smaller area more suited for acoustic mensuration.

How does the Icelandic experience apply to the fixed timing of the 2J3K acoustic survey? We know that the biological cycle of our capelin stocks have been out of phase by 4-8 weeks since the early 1990's and that this has likely had consequences for the 3L spring acoustic survey (Shackell et al. 1994). For the 2J3K fall acoustic survey there are two data sources that provide an insight into the effects of timing, viz. the USSR 2J3K acoustic survey which usually occurs in November, and the Canadian 3L acoustic survey which is conducted usually in May of the following spring.

The USSR acoustic surveys of 2K3K which began in the early 1970's. These surveys cover approximately the same geographic areas as the Canadian survey but generally do not include areas near the coast and therefore the actual area surveyed is somewhat smaller. Significantly, however, the Soviet surveys usually take place in November after the Canadian survey has been completed (Table 1). In all years with one major exception (1984, when the USSR survey was conducted in December) the Soviet estimates are substantially higher than the Canadian estimates until 1991 when both surveys produced very low estimates. In particular the Soviet surveys do not show the catastrophic collapse of capelin abundances that would have been inferred from the Canadian surveys in 1983, 1986, 1987, and 1990. In 1991 and 1992 the acoustic estimates had collapsed for both surveys; this period coincides with the changes in biological cycles associated with the unusually cold temperature conditions since 1990 and will be discussed further below. Table 1 also contains estimates of the biomass of mature fish (age 3+) in the Canadian 3L acoustic survey in May, six months later. Despite predation mortality during the intervening six months, the 3L acoustic estimates of mature fish are generally 2-3 times higher than those obtained during the previous fall by either Canada (in October) or the USSR. Thus evidence from the USSR acoustic survey and the Canadian 3L spring survey indicate that differences in timing by only a month can have large and systematic effects on biomass estimates and these biases can mask the year effects of actual abundance changes. Accepting the 3L acoustic estimates also suggests that, regardless of timing, a substantial component of the mature biomass remains outside the survey area and/or is not detected during the 2J3K fall acoustic surveys. This is a constraint only when the 2J3K acoustic estimates are viewed as absolute abundance; it should not necessarily invalidate the survey when it is used as an index.

C. Interaction Between Timing, Distribution and Acoustic Estimate in Div. 2J3K

Lilly and Davis (1993) and Lilly (1994) have extensively reviewed the fall distributions of capelin in 2J3KL as inferred from bycatch data and PFI data collected from the November-December groundfish survey. This survey occurs immediately after the capelin acoustic survey and the midpoint of the survey is about 5-6 weeks later than the midpoint of the acoustic survey. This point should be kept in mind during the following analyses. Lilly and Davis (1993) and Lilly (1994) show that in normal years, eg. 1981, 1988 and 1989 capelin are largely distributed north of 51° latitude and west of 53° longitude in the northern and northwestern portions of 2J3K during November. There is also a distinct spatial break between the capelin distribution in 2J3K (mainly maturing fish) and those in 3L (mainly immatures). However, in 1986, 1987, and 1990 onwards the fall distribution of capelin shifted towards the south (generally less than 51° latitude) and east (generally east of 53° longitude) into 3K such that by 1991 there was a continuous distribution of capelin along the outer regions of 3K and 3L. Analyses of the USSR capelin catch and effort data show a similar pattern of fleet movements (south and east) in 1987 and 1990 (D. Kulka, pers. comm.). Bakanev (1981) describes a similar shift in the Soviet capelin fishery for 1973-74 (another cold period) compared with later years. In addition, the Canadian and USSR acoustic surveys in 2J3K also show these shifts in distribution. Bakanev and Zubov (1991) report that the Soviet acoustic survey underestimated biomass levels in 1990 because the capelin distribution had shifted 120-150 km to the east and outside the survey transects. Likewise, the Canadian surveys report very few capelin in 2J since the 1980's and most of the acoustic estimates are obtained from areas east of 53° longitude in 3K (Miller 1994 and references therein).

This shift in capelin distribution (from north and shoreward to south and seaward) has been examined in more detail from analyses of bycatch success (% of sets containing capelin) in the fall groundfish survey for the period 1981-94. Bycatch success (i.e. presence or absence) should reflect both local density changes and, more importantly, changes in abundance associated with expansion or contraction of range within the area of study. Interannual changes in range (i.e. habitat occupied) have been shown to be closely associated with population abundance changes for both pelagic and demersal fish species (eg. see Winters and Wheeler (1985), Rose and Leggett (1991) and references therein).

The shift in distribution from 2J to 3K noted by Lilly and Davis (1993) is clearly shown in Figure 2. There has been a steady increase in the bycatch success of capelin in 3K since the early 1980's such that in recent years about 60% of the sets contain capelin. This increase in bycatch rates in 3K should not be construed as only representing a distributional change since inshore indices of mature biomass have shown a general increase since the early 1980's and these indices are positively correlated with bycatch rates in 2J3K (Winters 1994). In Div. 2J there are large year effects but little in the way of trends up to 1990 but a significant decline since then. It is interesting to note that the 2J3K acoustic survey estimates are anomalously low for all years in which the 2J bycatch rates fell below 20%.

Associated with this shift in the centroid of capelin distribution into eastern 3K has been a general increase in mean depths at which capelin have been caught by the groundfish trawl (Fig. 3 and Table 2). Typically, capelin are now most frequently caught in 300-350 m whereas in the early 1980's capelin were found most commonly in depths of 200-250 m. There is also a close inverse relationship between bycatch success of capelin in Div. 2J and mean depths (Fig. 3) in which capelin have been caught during the groundfish survey. This undoubtedly reflects the large year effects associated with periodic shifts in distribution towards eastern 3K. There is a general correspondence in annual variations in capelin depth with the extent of the CIL area (Fig. 3) estimated from the Seal Island data (E. Colbourne, pers. comm.). Despite an apparent movement to deeper waters since the early 1980's the mean bottom temperatures at which capelin have been caught have remained fairly stable in the range of 1-2°C. This may reflect a temperature preference but it could also reflect a distributional response to other factors (eg. food supply).

There is also a general correspondence between capelin bycatch success and interannual variations in the CIL (Fig. 4a, 4b). When CIL levels are high bycatch success in 2J is reduced but shows an increase in 3K. There are obvious exceptions (eg. 1984) but it should be remembered that these bycatch rates reflect, as well, interannual changes in stock abundance which could confound the above-noted relationships.

The relationship between mean depths at which capelin are caught in the November groundfish survey and biomass estimates from the 2J3K acoustic survey is shown in Figures 5a and 5b. There is a strong inverse relationship between acoustic estimates and mean depth (Fig. 5a); the acoustic survey has failed to detect significant biomass levels in every year in which mean depths have exceeded 300 m (Fig. 5b). This relationship lends credence to the possibility, noted by Lilly and Davis (1994) that in certain years capelin may be dispersed and remain near the bottom at all times of the day. In this situation, they may be less detectable by the hydroacoustic survey but more vulnerable to the bottom-trawl and to predation by cod. There is some support for this possibility since capelin have not been observed undertaking nightly migrations to surface waters in recent years (J. Carscadden, pers. comm.). Analyses of diurnal patterns in capelin bycatches during the groundfish survey do not support this scenario (Fig. 6). The possibility of poor detectability of capelin when schools are dispersed in deep water must remain open since the hydroacoustic system is configured on the assumption that capelin are aggregated into schools and concentrations (integration using a TVG gain = 20 log R) and the system is limited by depth (500 m). Bakanev and Seleverstov (1978) and Seleverstov and Serebrov (1978) provide photographic evidence that capelin occurred in dispersed, tiny schools in 3K during their hydroacoustic surveys in 1977-78. Likewise, Vilhjalmasson (Report on Acoustic Assessments of the Icelandic Capelin Stock in January and February 1995) reports that capelin were distributed into extremely scattered fish which never schooled but remained in low density-scattering layers during their

January 1995 acoustic survey. Alternately, the relationship in Figures 5a and 5b could reflect a distribution shift to the south and east in deeper waters largely outside the eastern boundaries of the acoustic survey transects.

Lilly (MS 1992 and pers. comm.) subdivided the groundfish survey area in 2J3K into nine spatial blocks (Fig. 7) for ease of description of shifts in capelin distribution noted above, and presented capelin bycatches and PFI indices for each block. Lilly (MS 1992) noted that years in which capelin were distributed to the south and east (i.e. blocks 6-9) were also years of anomalously low acoustic estimates. In essence this area represents southern 2J and Div. 3K east of longitude 53°W. This will be referred to as the "offshore" area whereas blocks 1-5 (western, northern 2J and western 3K) will be referred to as "inshore" areas. Bycatches have been calculated for each of these two areas for the period covering the acoustic surveys (1981-94). In Figures 8a and 8b "inshore" and "offshore" bycatch levels respectively have been plotted against the 2J3K acoustic biomass estimates. Clearly, there is a close positive association between high bycatch of capelin in the "inshore" area and high levels of biomass estimated in the acoustic survey (Fig. 8a). Conversely, high bycatches of capelin in the "offshore" area are negatively associated with the year effects in the acoustic survey (Fig. 8b). These effects are statistically described in Figures 9a and 9b. The relationships demonstrate that significant biomass levels are only detected in the 2J3K acoustic survey when the centroid of capelin distribution is located to the north (in 2J) and inshore (western 3K). When the centroid is located to the south and east (in the deeper eastern areas of 2J and particularly 3K) the available biomass (as inferred from bycatch rates) is largely undetected.

The relationships in Figure 9 include the year effect of annual changes in abundance as measured by capelin bycatch rates and PFI values. This effect can be removed by expressing the annual distribution shifts as a ratio of the "inshore" (NI) to the "offshore" (SO) abundance, i.e. annual values of (NI/SO). These annual indices of distribution shift are plotted against annual 2J3K acoustic estimates for the bycatch and PFI series in Figure 10a and the statistical relationships are shown in Figures 10b and 10c. There is little doubt that shifts in capelin distribution from "inshore" to "offshore" can explain a large proportion of annual variations in the 2J3K acoustic estimates and that this factor (particularly in cold years) has obscured and distracted the real abundance changes. This conclusion is supported in Figures 11a and 11b in which the acoustic abundance deviates from annual inshore mature fish indices (Winters et al., this meeting) are plotted against the corresponding annual indices of distribution shifts.

It may be argued that the period 1991-94 is somehow different than the period 1981-90 when, from acoustic comparisons in Table 1, the Canadian 2J3K acoustic estimates were obviously underestimating biomass levels. Comparisons of the slopes and intercepts of the regression lines in Figures 10b and 10a show no statistical difference for the periods 1981-90 and 1981-94. Using only the period 1981-90 the relationship in Figure 10b predicts 1993 and 1994 acoustic estimates to be 55,000 mt and 46,000 mt respectively and similar prediction for Figure 11a gives 61,000 mt and 48,000 mt for the 1993 and 1994 acoustic estimates respectively. These clearly are no different than the observed estimates.

It has been demonstrated that the 2J3K fall acoustic estimates are likely contaminated by systematic biases resulting from periodic distribution shifts perhaps outside the area surveyed, i.e. the relative acoustic estimate contains an abundance component and a distribution component. The distribution component is functionally described in Figures 10a and 10b and these relationships can be used to remove the distributions effect, thereby exposing more clearly the annual abundance component of the acoustic estimates. The algorithm is simply described as follows:

$$\text{Log (ABUN)}_t = \text{Log 2J3K Acoustic}_t - (\text{Log NI}_t - \text{Log SO})$$

The relative abundance component (log-scale) of the 2J3K acoustic estimates obtained from this relationship is as follows:

Year	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Log ABUN	2.72	-	3.82	5.41	6.59	5.72	5.13	5.96	5.11	6.55	7.10	6.60	3.96	6.19

Discussion

The picture of the distribution and migrations of maturing capelin in 2J3K during the fall, as inferred from a coalition of data sources, can be summarized as follows. In normal years (usually the warmer periods) the northward feeding migration penetrate extensively in 2J particularly the areas to the northwest of longitude 53°N. During October and November, as waters cool and feeding ceases, a denatant overwintering migration takes place towards central and western 3K and eventually by early winter these fish have extended their distribution to coastal bays where they are fed upon by such predators as seals (Sergeant 1973, G. B. Stenson, pers. comm.). By mid-winter these maturing fish have moved into 3L where they mix with the immature recruits.

In certain years (nearly always cold years but not all cold years) however, this migration is altered and is perhaps characterized by less extensive penetrations in 2J during the summer. The southern denanant migration begins earlier (likely completed by October) and is deflected to the east across Hamilton Bank and thence southwards along the Polar Front forming the eastern boundaries of the Newfoundland Shelf. At the time (October) of the acoustic survey these capelin may be located to the east of the survey area. By November these fish have begun their cross-shelf migration but are still located mainly east of 53°N longitude at the time of the fall groundfish survey. By mid-January bottom trawl surveys in 1993-94 (Anderson and Dalley, this meeting) show these capelin have broad distributions across the northeast Newfoundland Shelf and have penetrated into the coastal bays.

It is likely that temperature is the major, though not exclusive, variable influencing these periodic distribution shifts. Temperature changes have been closely associated with shifts in the distribution and migration of Barents Sea capelin (Tjelmeland 1987). Shackell et al. (1994) have shown that maturing capelin in Div. 3L showed distributional anomalies that were associated with interannual changes in water temperature. During the same general time period (1991-94) Carscadden (1994) described extra-territorial distributions of mainly mature capelin to the Flemish Cap, an occurrence that was also observed to take place in 1973, another cold period. Likewise, Frank and Simon (1994) have reported the association between the appearance of capelin on the Scotian Shelf to periods of below normal water temperature particularly since the late 1980's. It is also known that water temperatures largely determine maturation trajectories of capelin (J. Carscadden, pers. comm.) and in the recent cold period (1991-94) the spawning cycle of Newfoundland capelin have been delayed by 4-8 weeks (Nakashima 1994) i.e. there is clear evidence that the biological cycle of these capelin stocks have been out of phase for several years and this effect is largely temperature-induced. Other fish species in the 2J3K area have also shown similar extensions and shifts (generally southwards and eastwards to deeper waters) in distribution since the mid-1980's. These include Polar cod (Lilly et al. 1994), cod (Deyoung and Rose 1994), turbot and American plaice (Bowering, pers. comm.) and shrimp (D. Parsons, pers. comm.). The relationship between ocean temperature, food production and fish physiology is complex but its vortex likely contains the answers to many changes in fish behaviour and migration. Unfortunately information on interannual variability in plankton distribution and production in the Newfoundland area is sparse, to say the least.

In summary, the inability of the Canadian 2J3K fall acoustic survey to predict subsequent inshore capelin abundance is likely due to the fact that the acoustic estimates are responding more to annual distribution shifts than to interannual changes in capelin abundance. It cannot be determined from available data sources whether this is a problem of detectability (i.e. anomalous distribution characrteristics within the survey area) or a problem of non-availability to mensuration equipment (i.e. fish being distributed outside (likely to the east) of the survey blocks). Resolution of this problem will best be achieved through development of appropriate hypotheses which can be tested in a rigorously designed experimental survey. Finally, until capelin distributional anomalies can be identified, predicted and taken into account in a flexible survey design, offshore acoustic surveys for capelin will continue to be occasionally vulnerable to periodic failures to reliably measure abundance. Alternative indices of abundance will continue to be important in order to distinguish real abundance changes from non-abundance effects.

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Table 1. Comparison of Canadian and USSR acoustic estimates in 2J3K during 1982-93. Included also are equivalent 3+ biomass levels for the 3L spring survey in Div. 3L (year t+1).

Year	2J3K Canadian	2J3K USSR	3L acoustic (age 3+, t+1)	Survey timing (USSR)
1982	-	611	59	Oct. 14-25
1983	94	852	234	Nov. 12-19
1984	826	480	1418	Dec. 4-24
1985	1035	1540	3286	Oct. 21-Nov. 7
1986	430	1491	1936	Oct. 30-Nov. 20
1987	112	1164	2598	Nov. 2-18
1988	1803	-	2053	-
1989	1744	-	4451	-
1990	96	631	69	Nov. 6-21
1991	55	30	36	Oct. 28-Nov. 15
1992	34	16	-	-
1993	-	-	-	-

Table 2. Depth distribution (m) of capelin caught as bycatch in the 2J3K fall groundfish survey (numbers in brackets represent kg/tow).

	Depth range (m)							
Year	<150	150-200	200-250	250-300	300-350	350-400	400-450	>500
1981	15 (27.0)	16 (3.0)	9 (3.7)	8 (.2)	2 (.4)	1 (<.1)	2 (.1)	
1982	1 (<.1)	6 (58.9)	4 (3.4)	5 (.5)	6 (.2)	2 (.4)	1 (.2)	
1983	6 (.2)	10 (2.6)	14 (.3)	14 (.6)	5 (.1)	4 (.4)	4 (.1)	1 (<.1)
1984	12 (.2)	20 (.6)	18 (.5)	5 (.1)	6 (.3)	1 (.3)	4 (.2)	1 (.3)
1985	25 (.2)	25 (.4)	26 (.6)	21 (.9)	16 (.7)	7 (.2)	6 (.1)	
1986	5 (1.2)	15 (3.8)	10 (.5)	10 (.4)	6 (.2)	1 (.2)	2 (.1)	2 (<.1)
1987	6 (.5)	15 (11.7)	22 (3.9)	19 (1.2)	12 (1.4)	7 (.2)	8 (.3)	4 (<.1)
1988	24 (3.3)	13 (.7)	16 (.2)	12 (.1)	9 (.4)	8 (.2)	1 (.5)	
1989	26 (.2)	34 (1.4)	35 (.3)	17 (.3)	16 (.2)	9 (.3)	7 (.1)	1 (<.1)
1990	7 (<.1)	9 (.1)	19 (.2)	37 (.1)	22 (1.3)	6 (.1)	10 (.2)	4 (.1)
1991	7 (<.1)	14 (1.9)	30 (.7)	41 (2.2)	17 (1.1)	7 (1.3)	4 (.1)	1 (.2)
1992	10 (<.1)	24 (1.9)	36 (.8)	53 (1.1)	15 (.2)	6 (.1)	1 (<.1)	5 (<.1)
1993	1 (<.1)	9 (<.1)	10 (.1)	16 (.6)	33 (.9)	18 (1.3)	6 (1.1)	2 (.1)

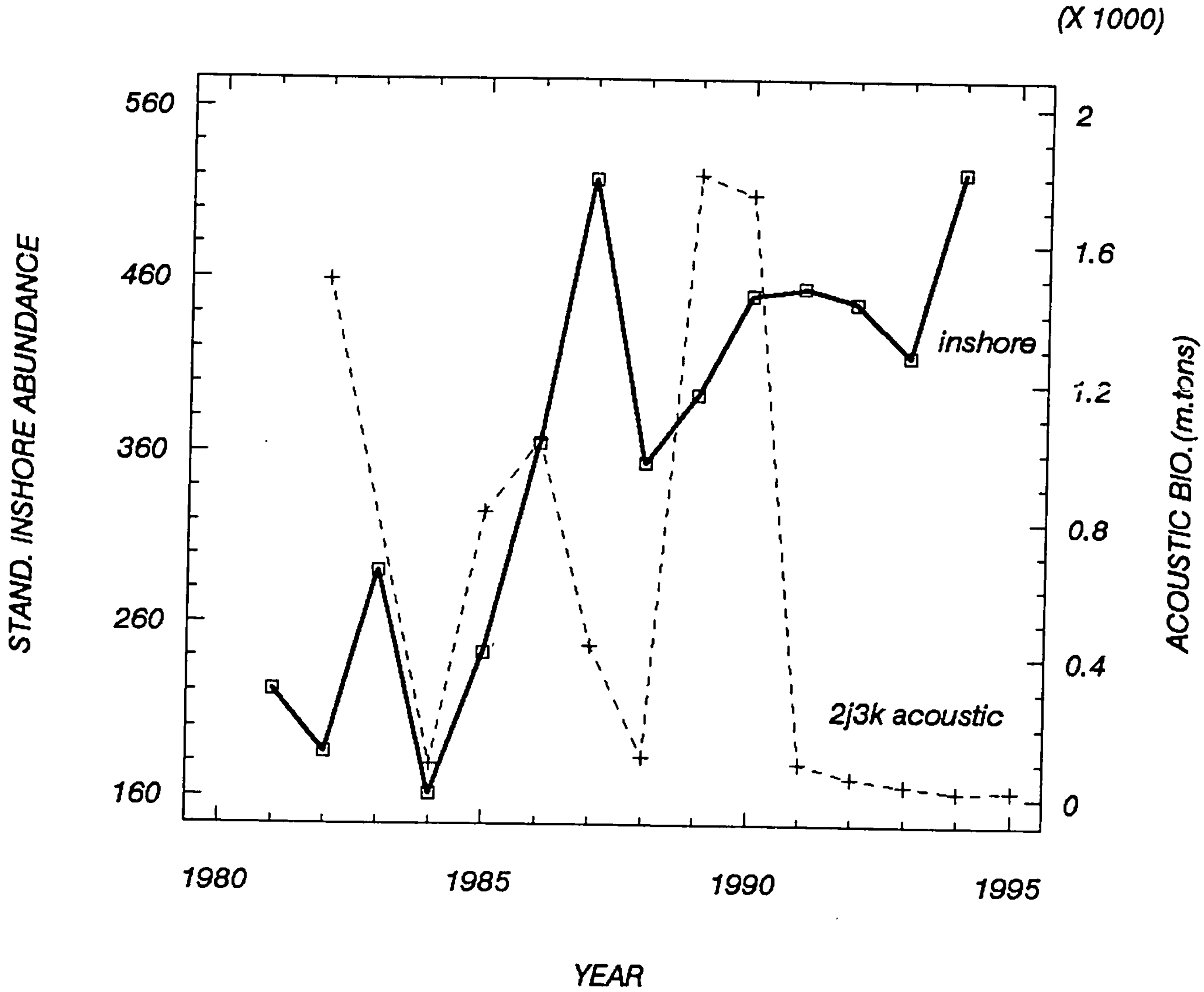


Fig. 1. Relationship between the inshore mature capelin index (Winters et al., this meeting) and the 2J3K acoustic estimates (advanced one year).

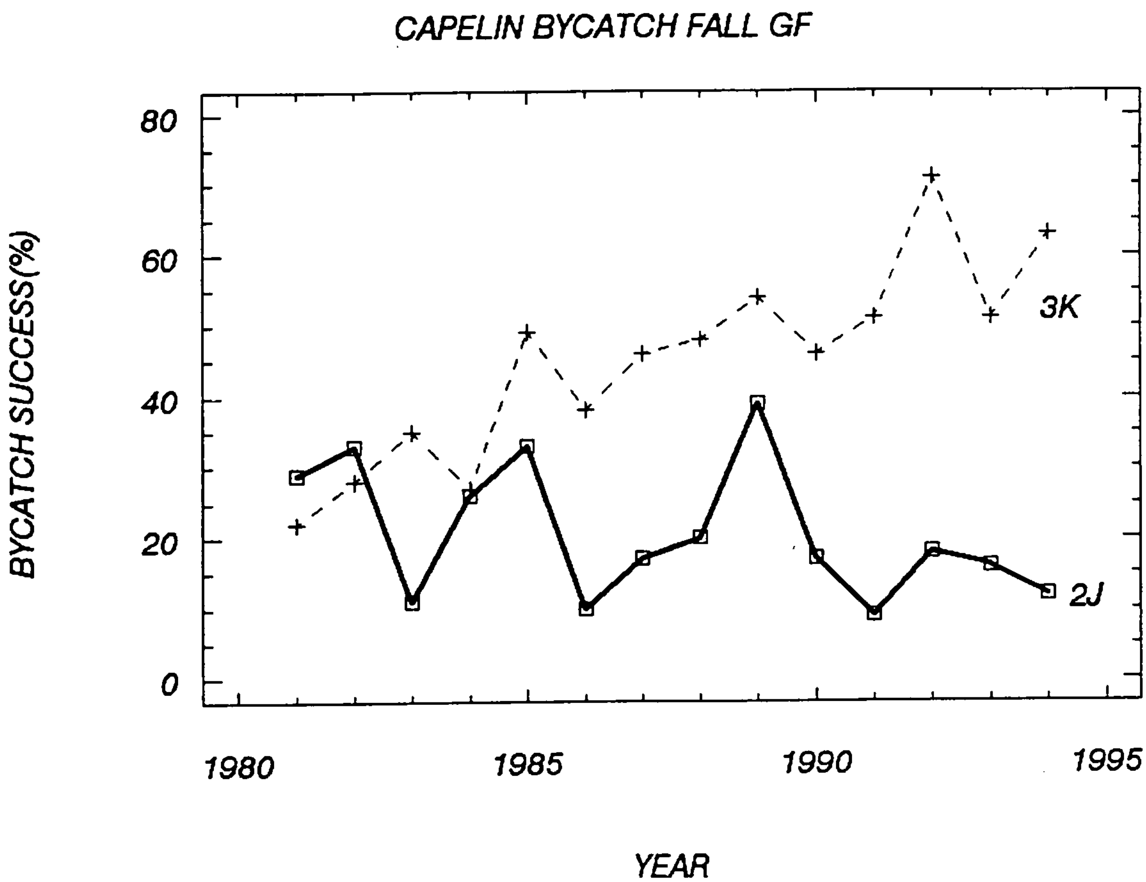


Fig. 2. Bycatch success (% of sets containing capelin) of capelin caught in 2J and 3K during the fall groundfish survey 1981-94.

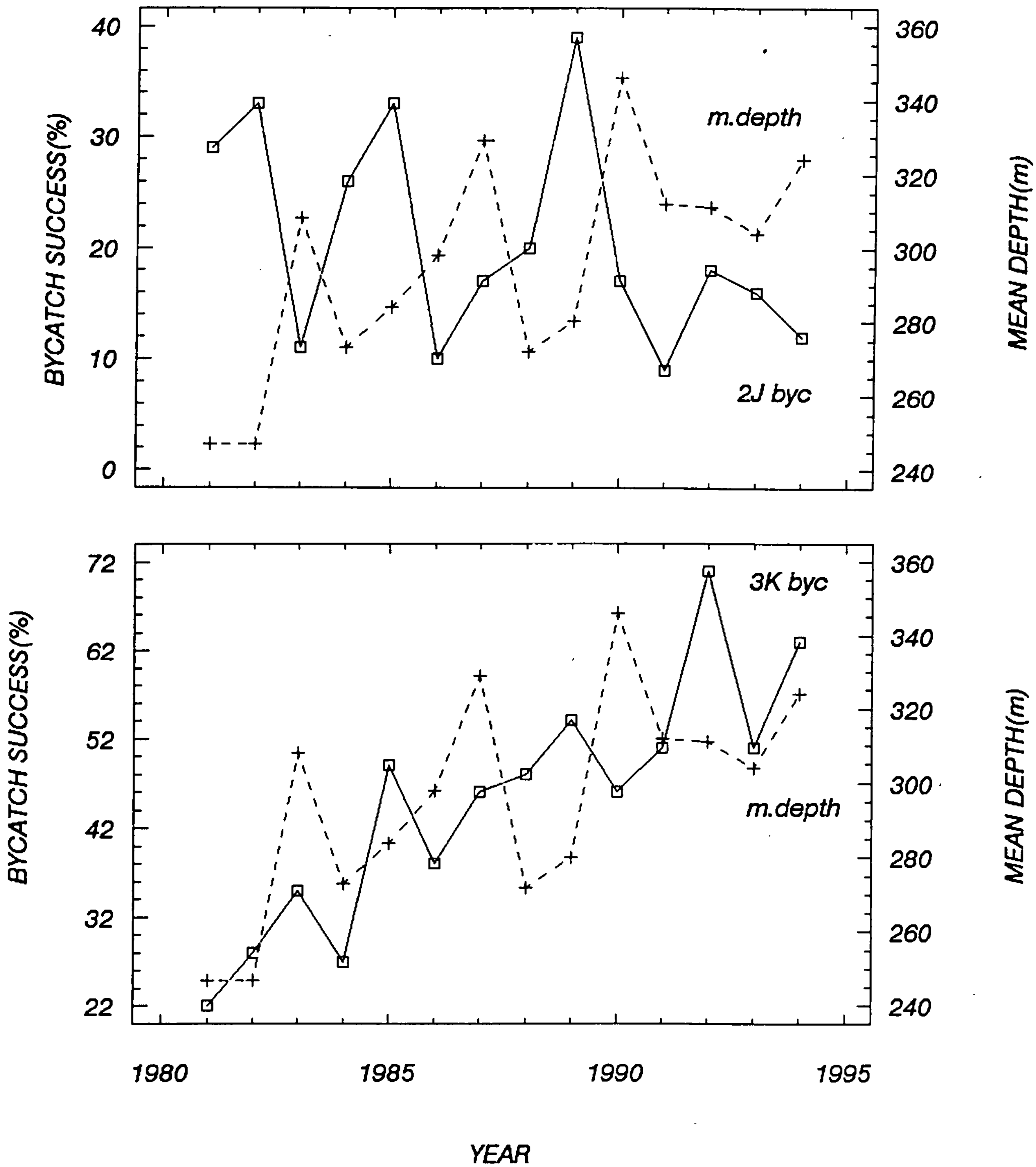


Fig. 3. Bycatch success of capelin in Div. 2J (top panel) and Div. 3K (lower panel) in relation to mean depth at which capelin were caught during the fall groundfish survey.

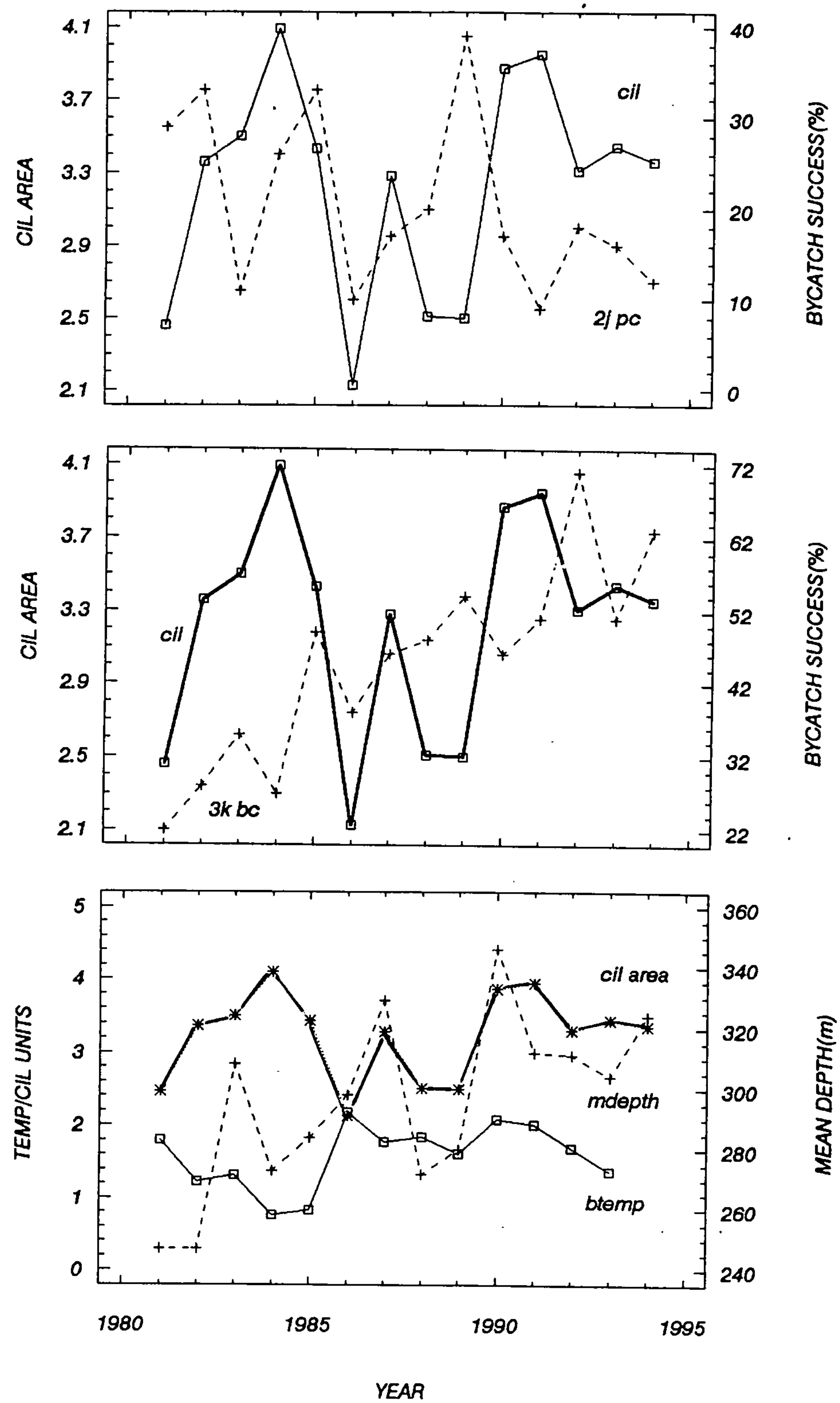


Fig. 4. Bycatch success of capelin in Div. 2J (top panel) and Div. 3K (middle panel) in relation to the Seal Island CIL area (Colbourne 1995). The lower panel shows these data for Div. 2J3K combined, including mean bottom temperatures at which capelin were caught.

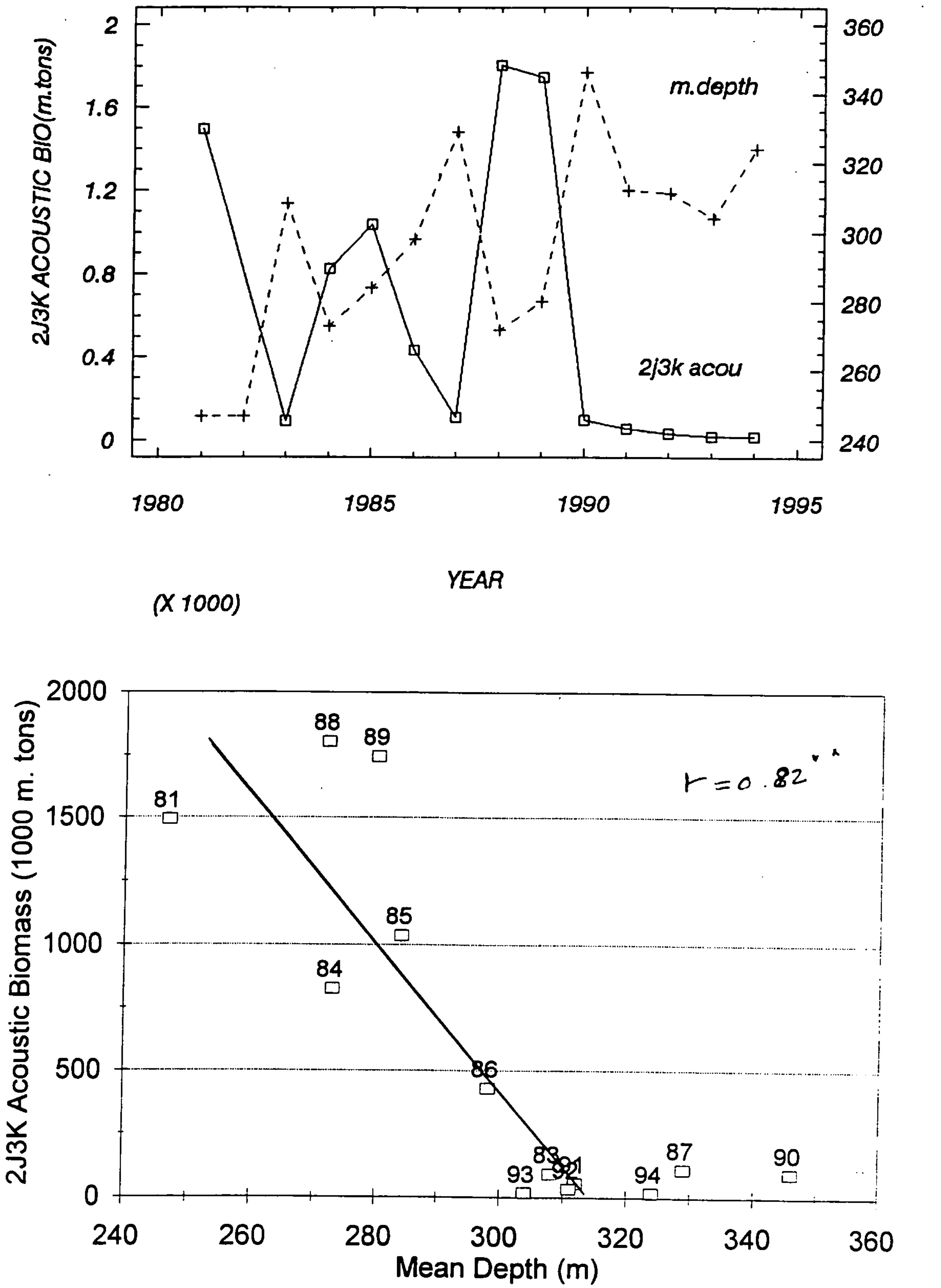


Fig. 5. Time series plot of 2J3K acoustic biomass estimates and mean depths at which capelin were caught in the fall groundfish survey (top panel). The lower panel shows the statistical relationship.

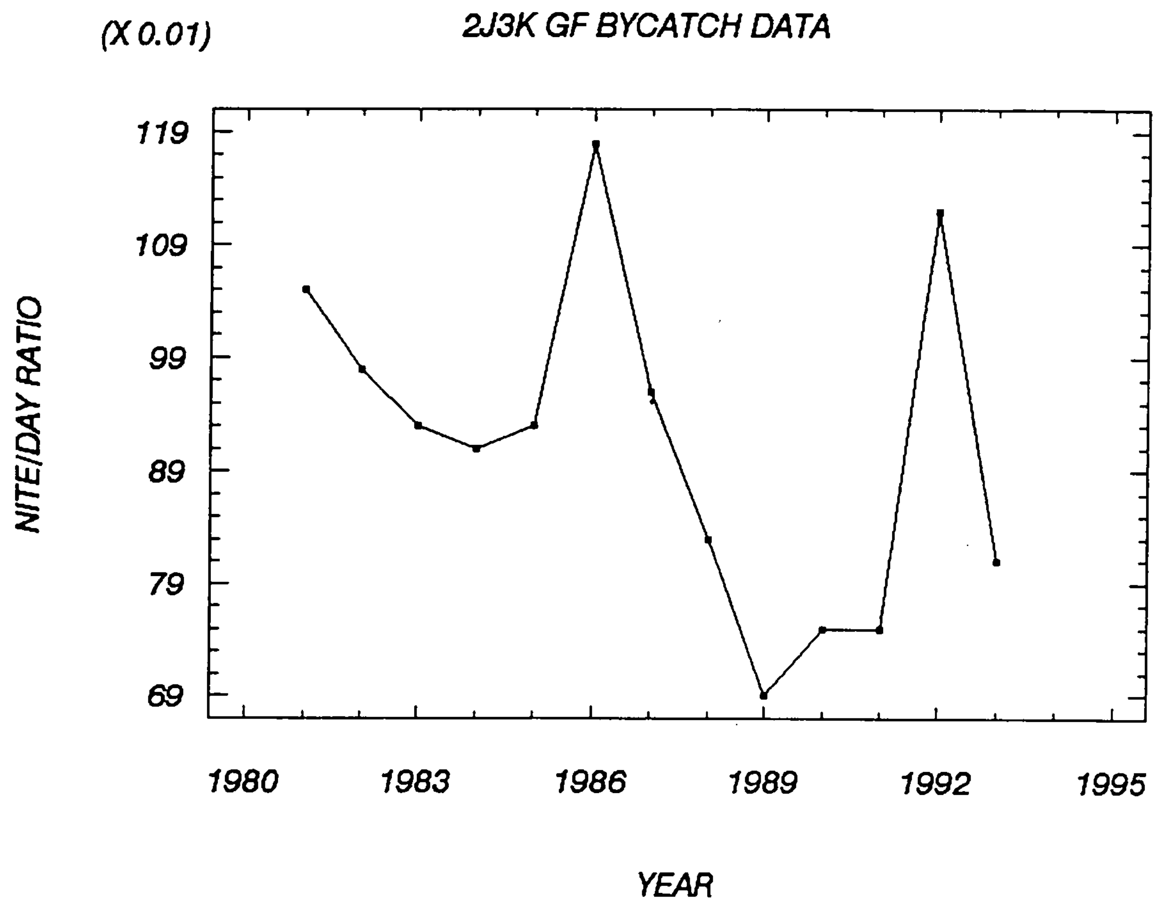


Fig. 6. Ratio of night to day (0600-1800) bycatch rates of capelin in the fall groundfish survey.

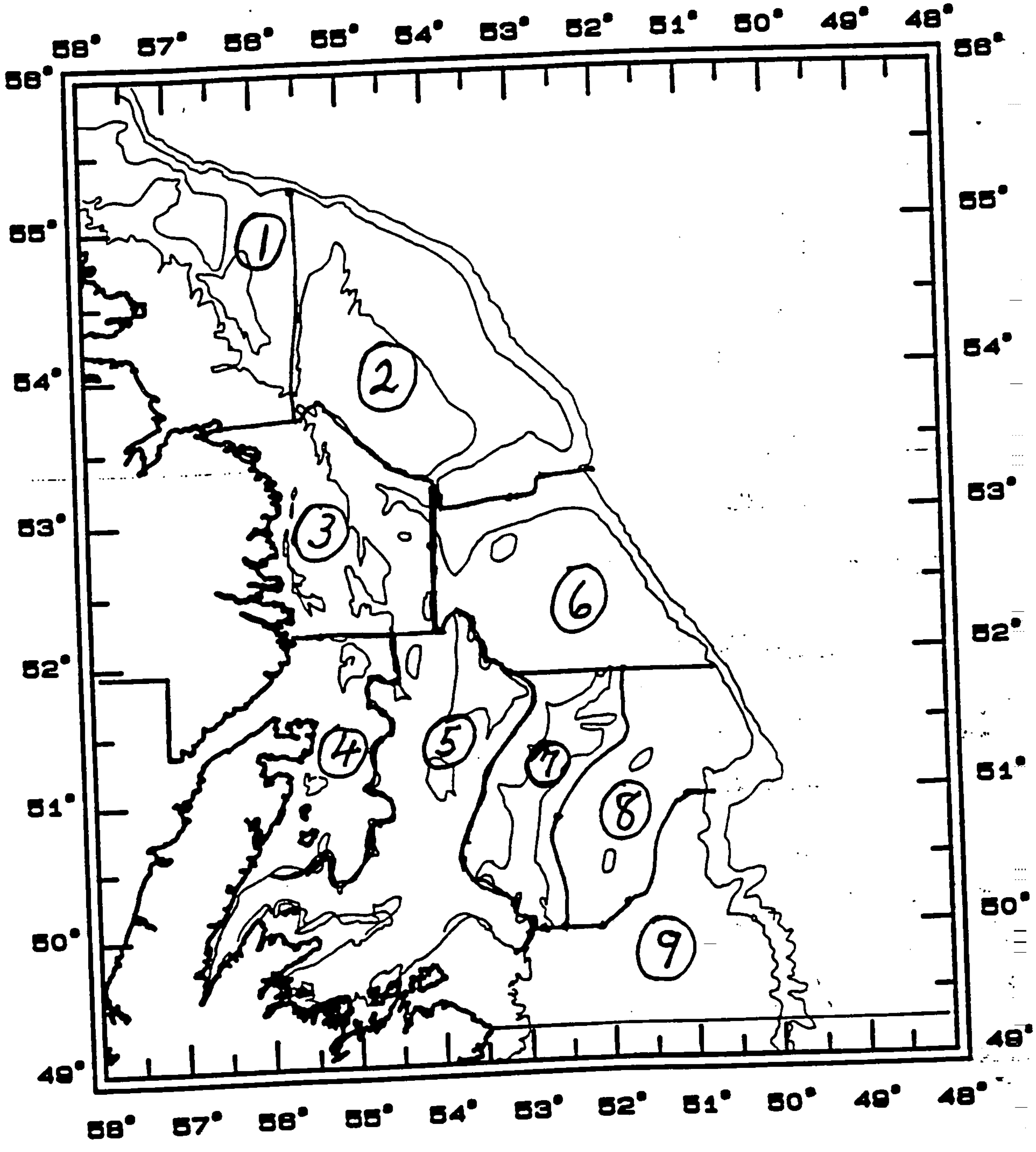


Fig. 7. Map showing Lilly's (pers. comm.) spatial blocks for describing shifts in capelin distribution during the fall groundfish survey.

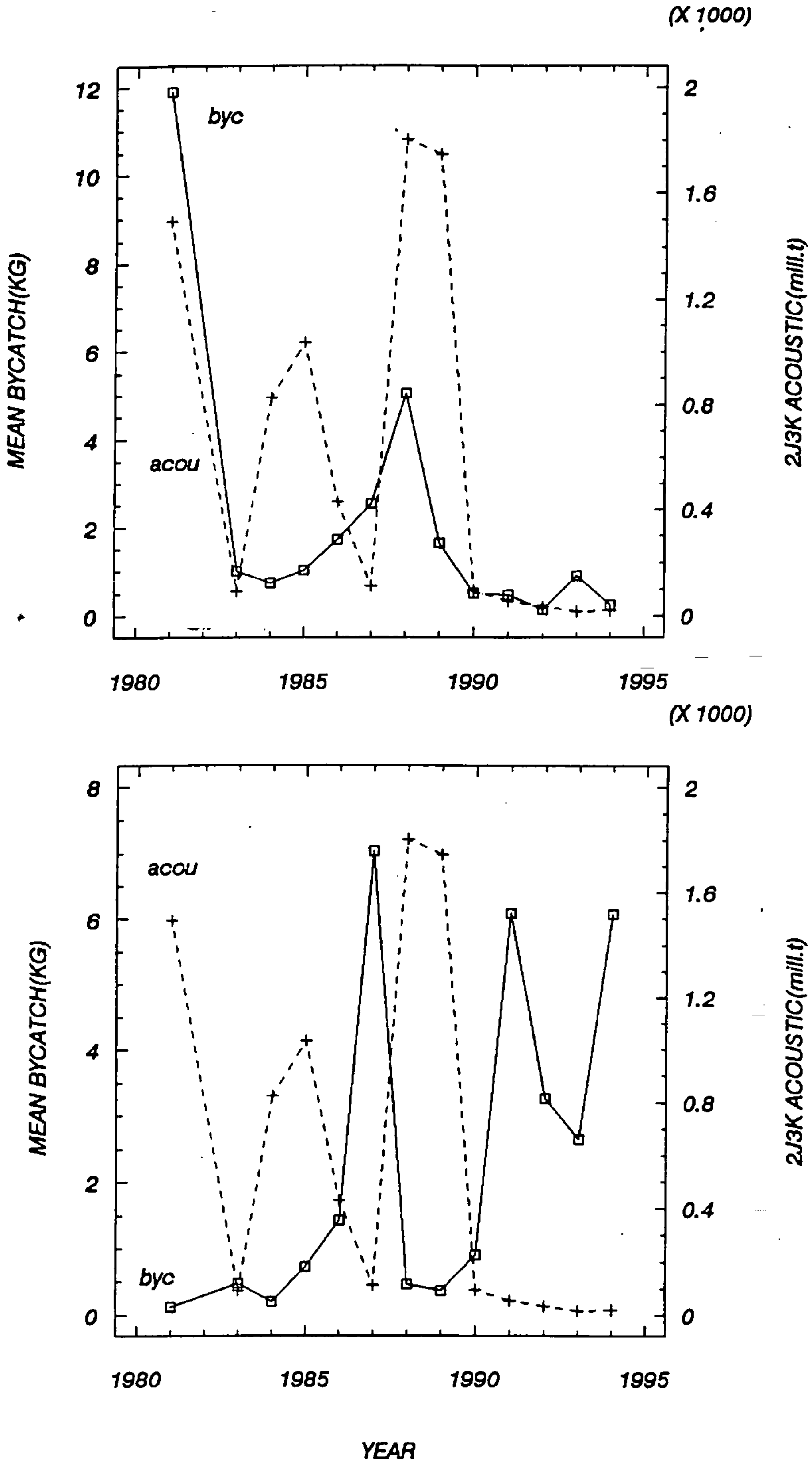
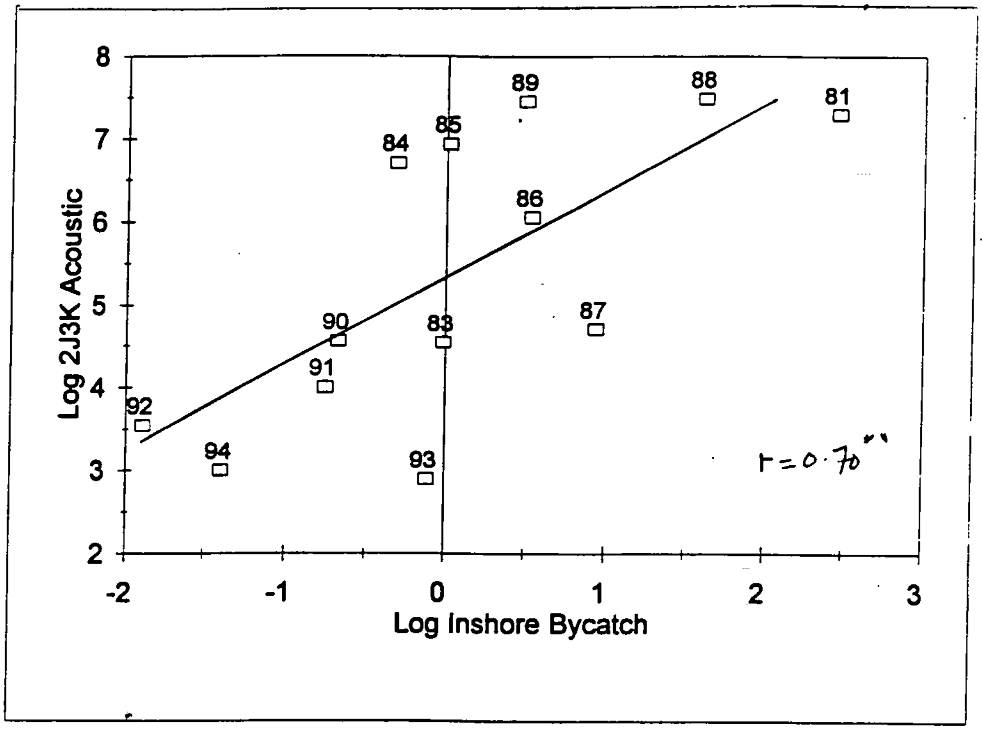


Fig. 8. Mean bycatches of capelin in the "inshore" area (Lilly's blocks 1-5) (top panel) and the "offshore" area (Lilly's blocks 6-9) (lower panel) in relation to annual estimates of acoustic biomass.



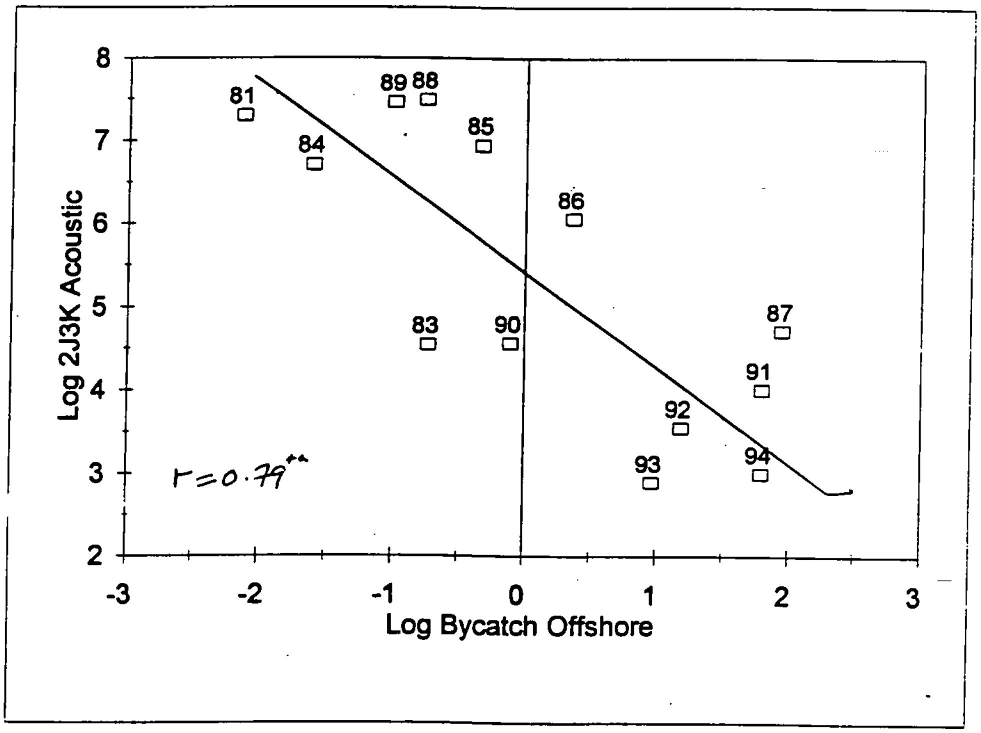


Fig. 9. Statistical relationship between the "inshore" bycatch rate of capelin and the 2J3K annual acoustic biomass (top panel); the bottom panel shows the same relationship for the "offshore" bycatch rate.

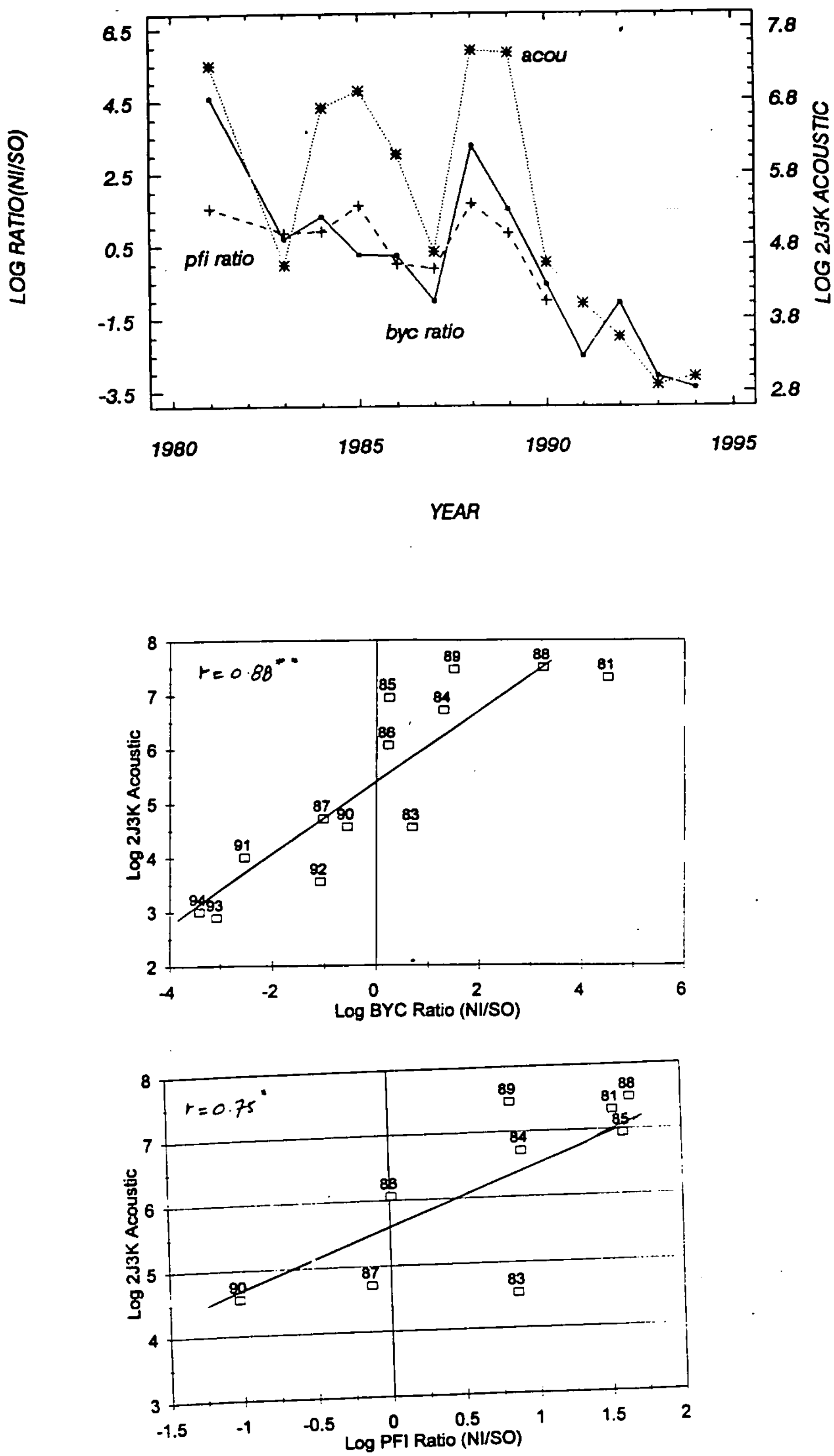


Fig. 10. Time series plot of the 2J3K acoustic biomass in relation to the PFI and bycatch ratios of "inshore"/"offshore" capelin abundance (top panel). The middle and lower panels describe the statistical nature of this relationship for the PFI and bycatch data respectively.

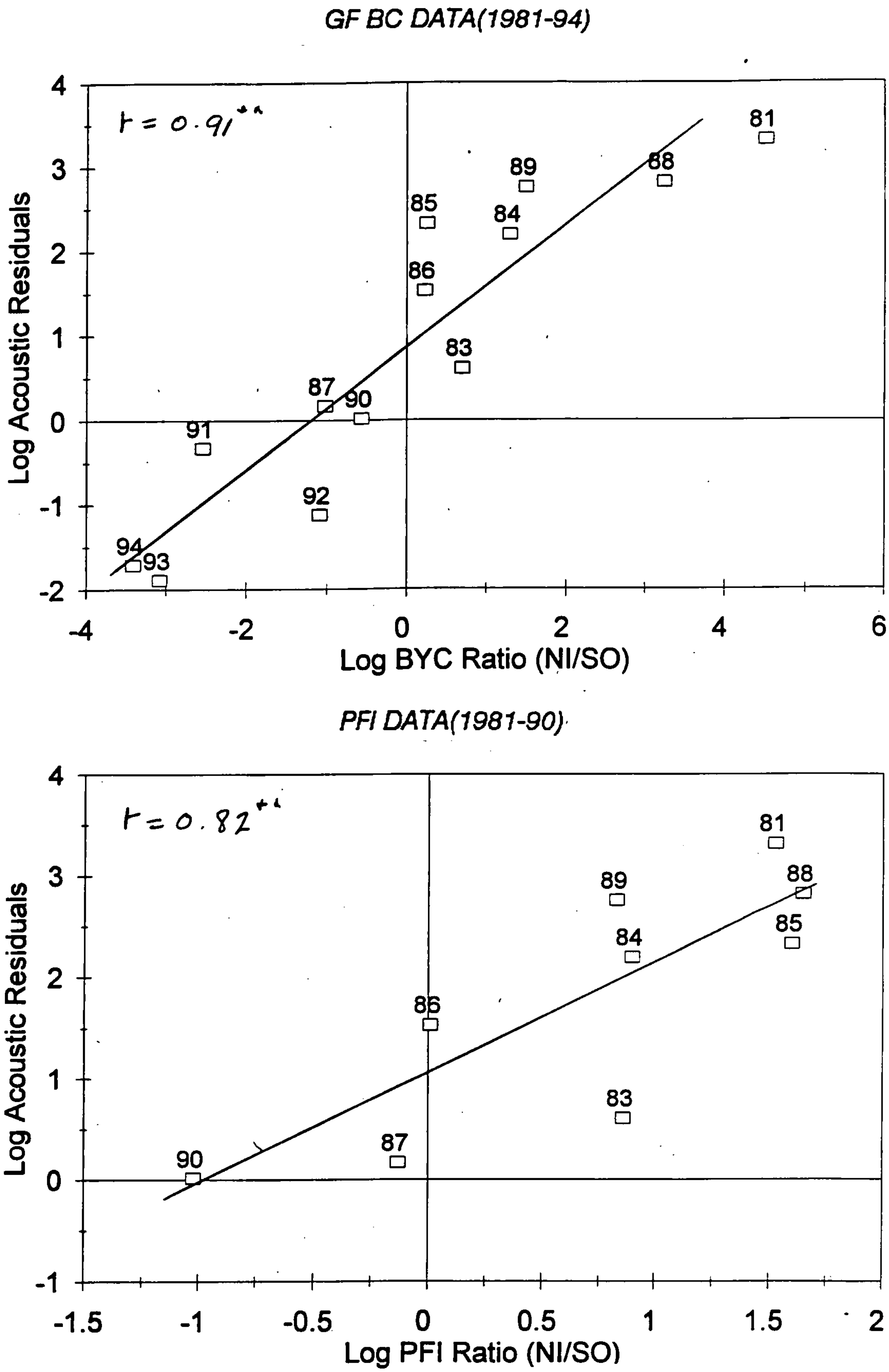


Fig. 11. Statistical relationship between the index of distribution shift of capelin and the deviations of the annual acoustic estimates from the inshore index. The top panel refers to the bycatch data and the bottom panel refers to the PFI time series (NI = north and inshore; SO = south and offshore).

Mean Lengths and Age Compositions of Capelin, Offshore and Inshore

by

J. Carscadden
Science Branch
Department of Fisheries and Oceans
P. O. Box 5667
St. John's, NF A1C 5X1

Introduction

Acoustic surveys to estimate the abundance of recruiting year-classes of capelin are routinely conducted in the Barents Sea, Iceland and the Northwest Atlantic and in the former two areas, the results of these surveys are the basis for predicting maturing biomass. In the Northwest Atlantic, the power of these surveys to predict mature biomass has been variable and seemingly weaker for the fall surveys. Although the biomass estimated from these fall surveys has been extensively reported, there has been little effort expended to examine other data from them. In this paper, I examine the patterns of mean lengths and age compositions collected in the fall acoustic surveys in relation to the mean lengths and age compositions of capelin the following year in the fishery.

The timing and location of the fall acoustic surveys were based on observations from the Soviet commercial fishery and acoustic surveys during the 1970's (see Carscadden et al. 1985). These authors also noted that a high proportion of the capelin captured in the fall commercial fishery were maturing and would spawn the following year. Furthermore, age compositions from catches in the fall fishery were similar to age compositions in the spawning population next year. It would seem reasonable to assume that mean lengths in the fall and in the following spawning season would be correlated. This relationship might be compromised by the fact that the spring is known to be an active feeding period for capelin. If this energy is put into somatic growth, then it is possible that variations in growth at this time would result in no relationship between mean lengths in fall and the following spring. However, there is evidence in the literature that this may not be an important consideration. During the spring feeding period, gonad development is rapid (Fig. 1), fat content declines, and the weight to length ratio decreases (Winters 1970). Gerasimova (1994) suggested that spring feeding by mature capelin is more important for gonad maturation than growth. Further, spawning mortality is relatively high (Shackell et al. 1994) indicating that capelin energy allocation is favouring gonad production rather than post-spawning survival.

Age compositions in the fall would also be expected to be similar to the age compositions the following spring. Variations in mortality between the fall and spring periods could compromise similar patterns. However, given the historical persistence of strong year-classes (eg. 1973, 1983, 1986) throughout the life span of capelin, this compromise probably is not a serious problem.

With these considerations in mind, I conducted a preliminary exploration of the relationship between mean lengths and age compositions of capelin in the fall survey and the same parameters in the spawning population the following year.

Results

a) Length comparisons

I first plotted the relationship between acoustic mean lengths for the entire survey and inshore mean lengths, all ages and both sexes combined (Fig. 2). The relationship was not statistically significant and it was determined largely by the 1992 point. In some years, the acoustic survey encounters small, immature capelin which will not move inshore to spawn the following spring. Therefore, I turned my attention to the portions of the acoustic survey which contained predominantly maturing fish. The survey blocks I used are found in Table 1. In most years, the total biomass in the selected blocks accounted for most of the survey biomass. Most notable exceptions occurred in 1993 and 1994, when the blocks chosen accounted for 43% and 12% of the total biomass. However, in all years, the maturing biomass occurring in the selected blocks accounted for a large proportion of the overall maturing biomass.

I also examined the proportions of mature individuals at each age by sex in the survey blocks selected. For one-year-olds, the proportion of mature individuals was variable and low. However, for ages 2 and older, the proportions mature-at-age were much higher, especially for females.

Using the combined data for the survey blocks shown in Table 1, I plotted mean lengths by sex for ages 2, 3, and 4 in the acoustic survey with mean lengths for ages 3, 4, and 5 respectively in the commercial fishery inshore in Div. 3KL. (Because of the very low catches inshore in 1994, data for 1994 was not included in the analysis.) In each figure, the years and ages shown are for the inshore, eg. a point labelled 82 in the figure Male Lengths Age 3 compares the length of males at age 2 from the 1981 acoustic survey to the length of males at age 3 in the 1982 inshore fishery. Comparisons for males are found in Figure 3, 4, 5, and 6 and for females in Figures 7, 8, 9, and 10.

The relationships for males are not significant except for age 3 acoustic - age 4 inshore (Fig. 4). The poor statistical relationship at age 2-3 may be a result of low proportions of mature males in the acoustic samples. At ages 4-5, the sample sizes are relatively small. Since females are the focus of the commercial fishery, I concentrated on the relationships with females in the remainder of the paper. The relationships for females are stronger. For age 3 females, the relationship is not significant unless the 1991 point (1990 acoustic - 1991 inshore) is treated as an outlier (Fig. 7). For age 4 females, the relationship is significant and the 1991 point does not appear to be an outlier (Fig. 8). For age 5 females, the relationship is significant although the relationship is heavily influenced by 1993 (Fig. 9). The 1991 point does not appear to be an outlier here.

When all ages are combined, the correlations are significant even including the 1991 point which again appears to be an outlier (Fig. 10).

An examination of the length-length regressions indicates a pattern of recent years (1991-93) to be below the line. These are years of anomalously cold temperatures with 1991 generally regarded as the most severe. To investigate the possible influence of temperature on the relationships especially on the 1991 point which appears to be an outlier in some plots, I compared the residuals from the length-length residuals to water temperatures during the winter-spring period. As an indicator of temperatures during this period, I used mean monthly temperatures from 0-20 m from Station 27, February-June summed (Tempsum) (Fig. 11). January temperatures had missing values so this month was not used and the February-June period spans the time period when gonads are developing.

In all cases, the relationships between the residuals and temperature were positive and statistically significant (Figs. 12, 13, 14 and 15). Although such relationships do not necessarily mean there is a direct cause and effect relationship, they are suggestive that in cold years, the growth between fall and spring is less than in warmer years.

b) Age compositions

I used the same selected survey blocks as in the length comparisons. Age compositions from the combined selected blocks were then compared to the inshore age compositions (Fig. 16). In all of the plots, fish from the fall surveys are aged one year older and age compositions are labelled with the year corresponding to the inshore samples, eg. 1982 shows that 1981 survey age compositions, age +1, and the 1982 inshore age composition. I did not perform any statistical tests but instead visually inspected the age compositions for patterns, especially for the occurrence of dominant year-classes or for obvious differences. In general, the offshore age compositions agreed with the inshore age compositions with notable exceptions being 1984 and 1990. In both years, the relative strengths of the two dominant age groups, three and four, were reversed. Generally, the acoustic surveys tended to produce age compositions with younger fish although in 1991, 1992 and 1993, age 2 (age 1 in the acoustic survey) were not detected, at least not in the blocks I used. Interestingly, 1991 (1990 survey - 1991 inshore) did not appear to be an outlier here as it had in the length comparisons. The strong 1986 year-class was detected in both the acoustic surveys as age 4 in 1990 and inshore as age 5.

Discussion

Both the length and age composition comparisons indicate that the acoustic surveys contain information of relevance to the inshore spawning population, even if the biomass estimates continue to be questioned. The length analysis for females is of particular relevance to the inshore fishery. Size has been more important to the industry in recent years with the market preferring larger females. The 1994 (and the provisional 1995) management plan contained a provision that the fishery would not open unless the female count was 50 (or less) females per kg. The mean size (137 mm) of females age 2 in the 1994 acoustic survey was slightly smaller than previous estimates of age 2; females at age 3 (158 mm) were smaller than average but larger than females of the same age in 1992, and 1993 and females at age 4 (164 mm) were the second smallest on record (1993 were smaller and 1994 the same size). If these estimates of mean length are indicative of the population, growth between November 1994 and the 1995 inshore fishery would have to be above average for these fish to be comparable in size at age as those in the 1980's.

The blocks from the 1994 survey used in this comparison contained 38% one-year-old and 56% two-year-old males and 37% one-year-old, 48% two-year-old and 11% three-year-old females. Even if the proportions are not exact in predicting, it suggests that the inshore stocks in 1995 will again have a substantial proportion of two- and three-year-olds. Surveys in 1990, 1991, and 1992 all tended to underestimate the proportions of one-year-olds that later appeared as two-year-olds inshore (Fig. 16), again suggesting that there will be a substantial proportion of two-year-olds in 1995. These indications plus the overall small size of females in the 1994 survey would be indicative of small fish in 1995.

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Table 1. Blocks in each survey from which data were used in the length analysis. Column labelled total contains the total biomass in these blocks as a percentage of the total biomass estimate for the survey. Column labelled mature contains the total mature biomass in these blocks as a percentage of the total mature biomass for the survey.

Survey year	Survey blocks	Total	Mature	Reference
1981	A, B	90	82	Miller et al. 1982
1983	C, D	58	90	Miller and Carscadden 1984
1984	C, D	96	97	Miller and Carscadden 1985
1985	C, D	86	87	Miller and Carscadden 1986
1986	B, C	100	95	Carscadden et al. 1987
1987	A, C	86	85	Carscadden et al. 1988
1988	G, H, I, J	73	91	Carscadden et al. 1989
1989	E, F, G, H, I	91	91	Miller 1990
1990	A, B, D, E, F, G, H, I	99	99	Miller and Lilly 1991
1991	A	74	82	Miller 1992
1992	B, C	100	92	Miller 1993
1993	F, G, H, I, J, K	43	91	Miller 1994
1994	G, H, I, J, K	12	85	Miller 1995

Table 2. Percent mature-at-age in the survey blocks used in the age analysis.

	Year	Age 1	2	3	4	5	6
Males	1981	82	99	100	100	-	-
	1983	50	91	99	88	-	-
	1984	30	99	100	100	100	-
	1985	4	81	99	100	-	-
	1986	0	78	98	100	-	-
	1987	4	81	99	-	-	-
	1988	27	63	85	88	-	-
	1989	49	83	100	-	-	-
	1990	-	82	98	100	-	-
	1991	20	93	100	-	-	-
	1992	50	97	100	100	-	-
	1993	47	92	100	100	-	-
	1994	51	99	100	100	-	-
Females	1981	92	100	100	100	100	-
	1983	67	98	99	99	100	-
	1984	38	100	100	100	100	-
	1985	30	99	100	100	100	-
	1986	9	96	99	100	100	100
	1987	29	91	98	100	100	-
	1988	39	97	100	100	100	100
	1989	69	97	99	100	100	100
	1990	1	98	99	100	100	100
	1991	30	93	100	100	100	-
	1992	81	99	100	100	-	-
	1993	56	92	100	100	100	-
	1994	77	98	100	100	-	-

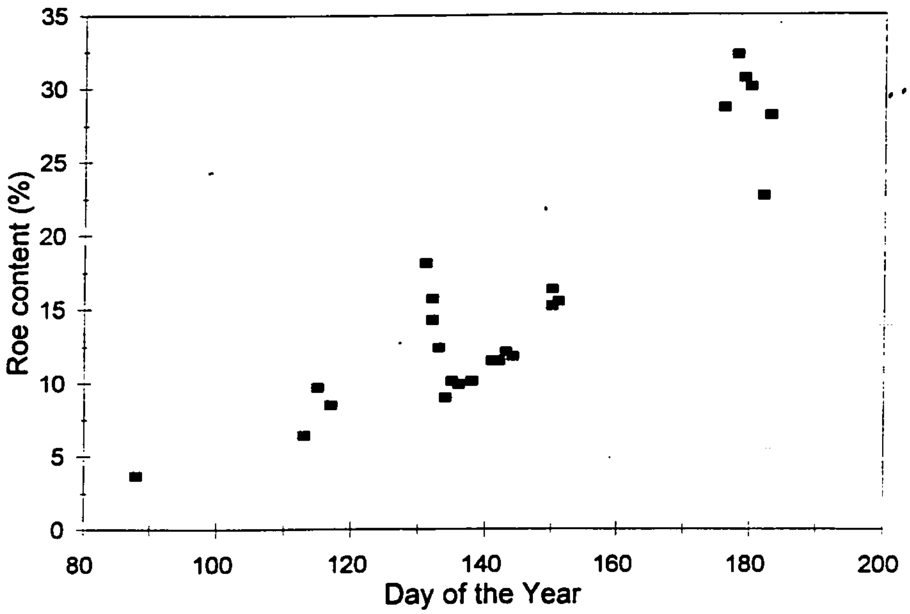


Fig. 1. Ratio of weight of roe to whole body weight (including roe) during pre-spawning period for capelin caught offshore in Div. 3LNO.

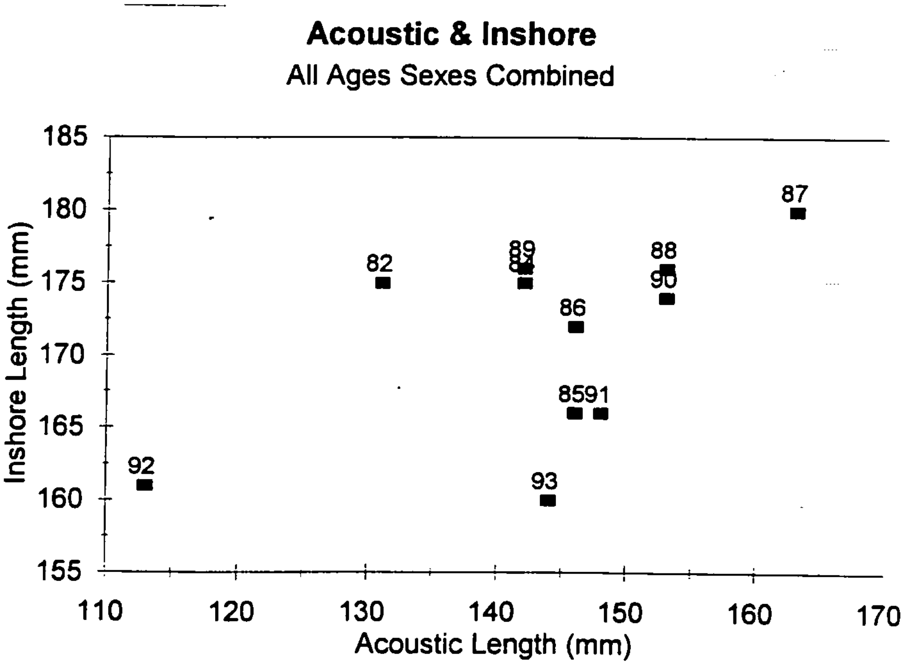


Fig. 2. Relationship between mean length of all capelin from offshore acoustic surveys and mean lengths of mature fish taken inshore the following year ($r = .53$, $p = .10$). Years plotted correspond to inshore years (acoustic lengths from the previous year).

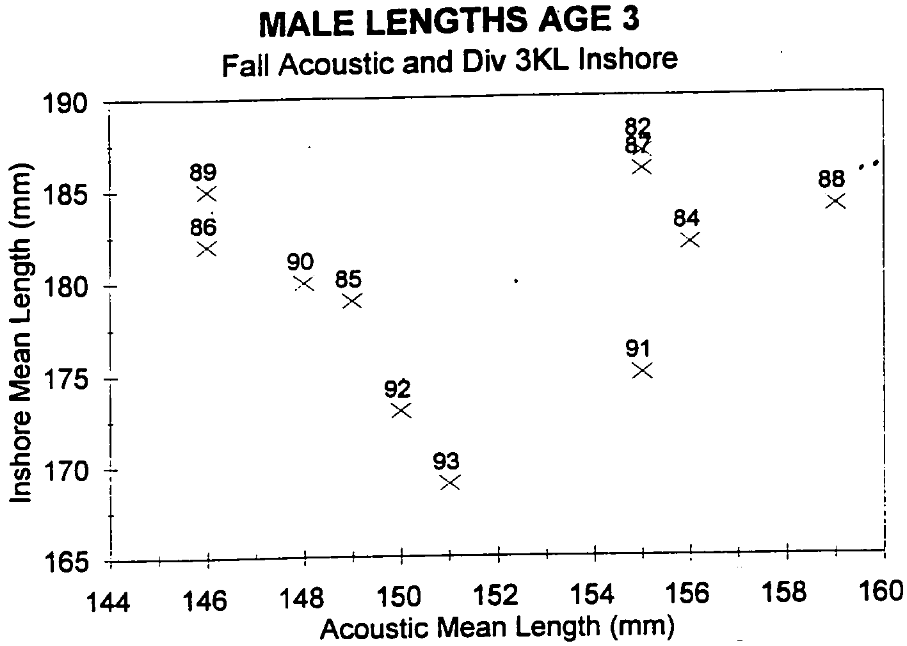


Fig. 3. Relationship between mean lengths of males age 2 in offshore acoustic survey and mean lengths of age 3 males inshore the following year (r = .14, p = .69). Years plotted correspond to inshore at age 3.

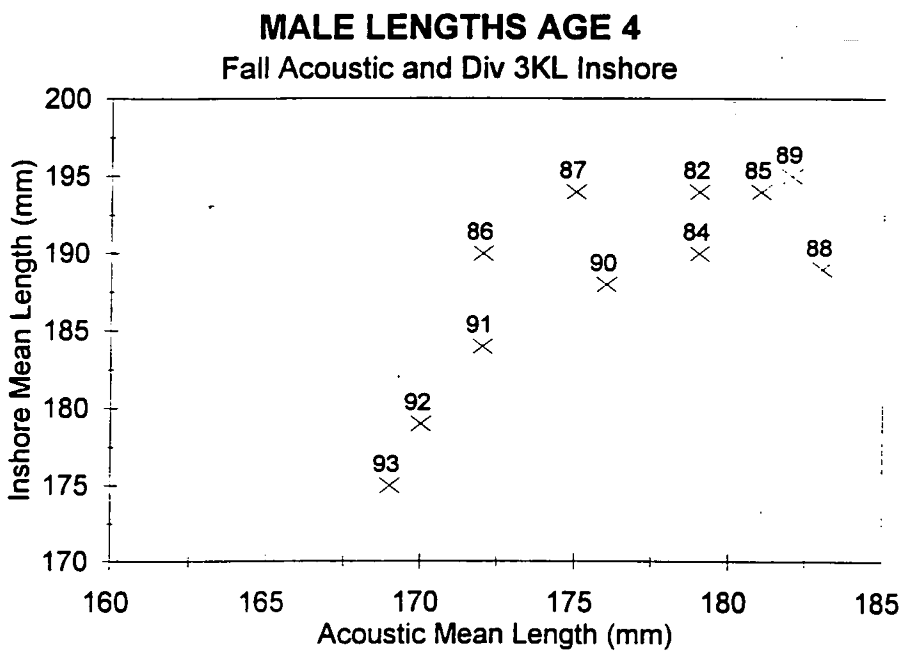


Fig. 4. Relationship between mean lengths of males age 3 in offshore acoustic survey and mean lengths of age 4 males inshore the following year (r = .77, p = .01). Years plotted correspond to inshore at age 4.

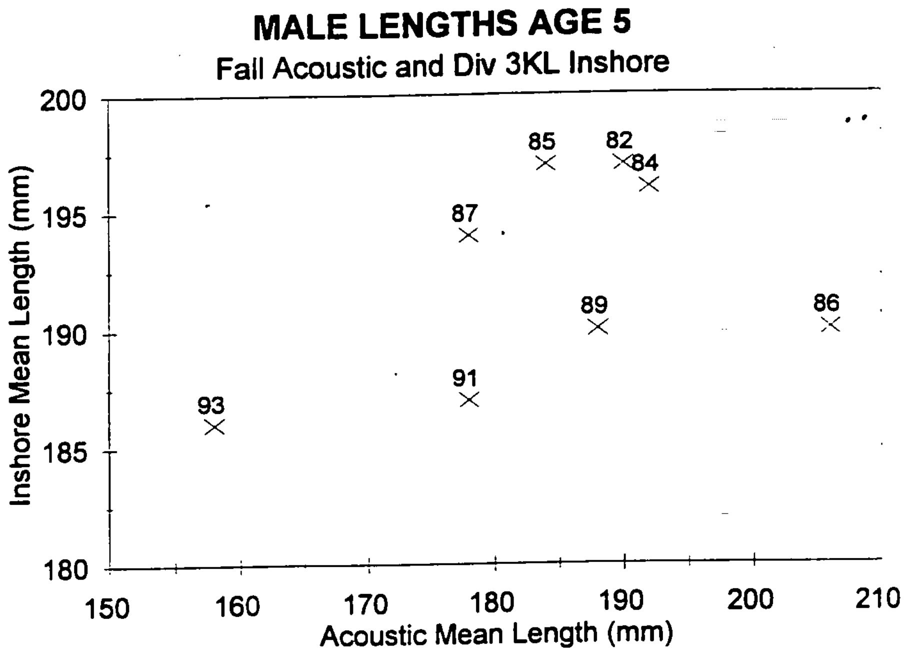


Fig. 5. Relationship between mean lengths of males age 4 in offshore acosutic survey and mean lengths of age 5 males inshore the following year (r = .42, p = .29). Years plotted correspond to inshore at age 5.

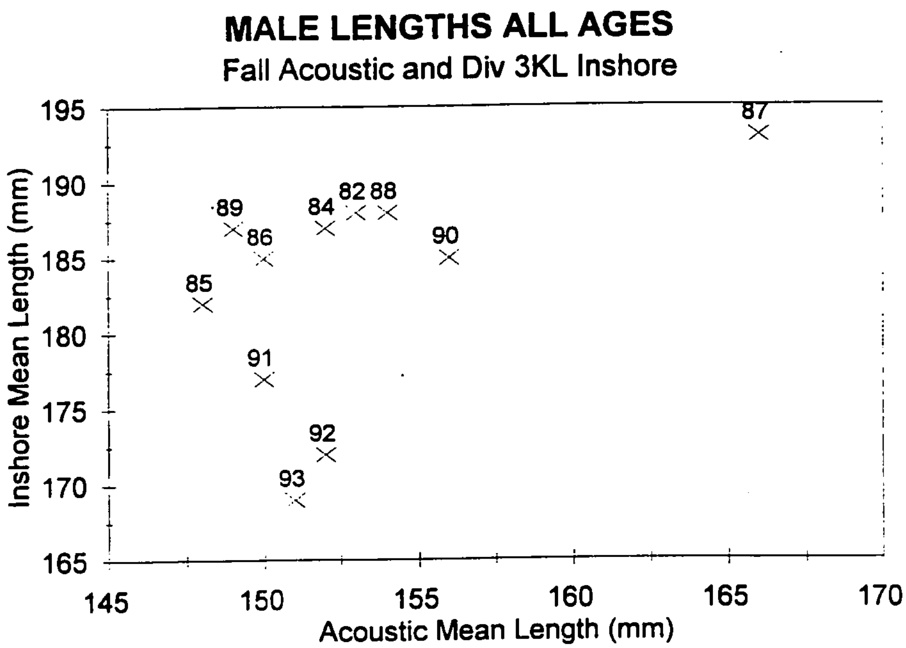


Fig. 6. Relationship between mean lengths combined of males ages 2, 3, and 4 in offshore acoustic survey and mean lengths combined of ages 3, 4, and 5 males inshore the following year (r = .49, p = .13). Years plotted correspond to inshore ages combined.

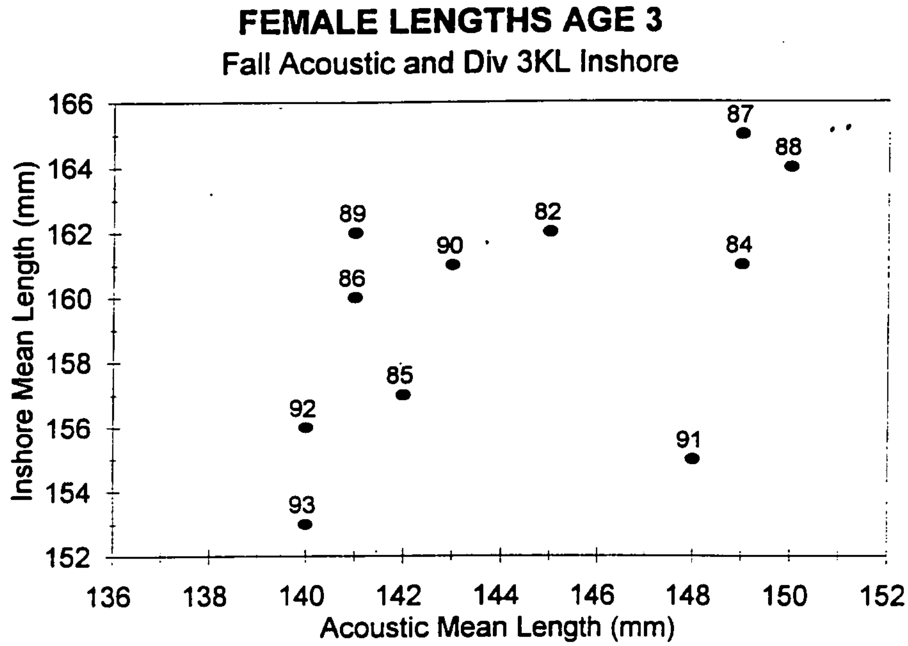


Fig. 7. Relationship between mean lengths of females age 2 in offshore acoustic survey and mean lengths of age 3 females inshore the following year ($r = 0.53$, $p = .10$). Years plotted correspond to inshore at age 3.

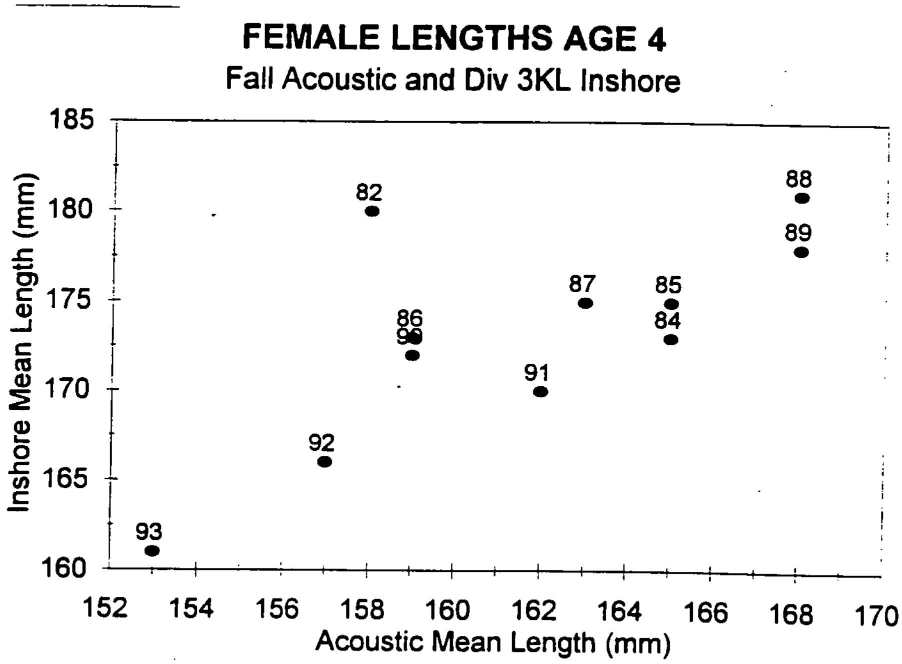


Fig. 8. Relationship between mean lengths of females age 3 in offshore acoustic survey and mean lengths of age 4 females inshore the following year ($r = 0.72$, $p = .01$). Years plotted correspond to inshore at age 4.

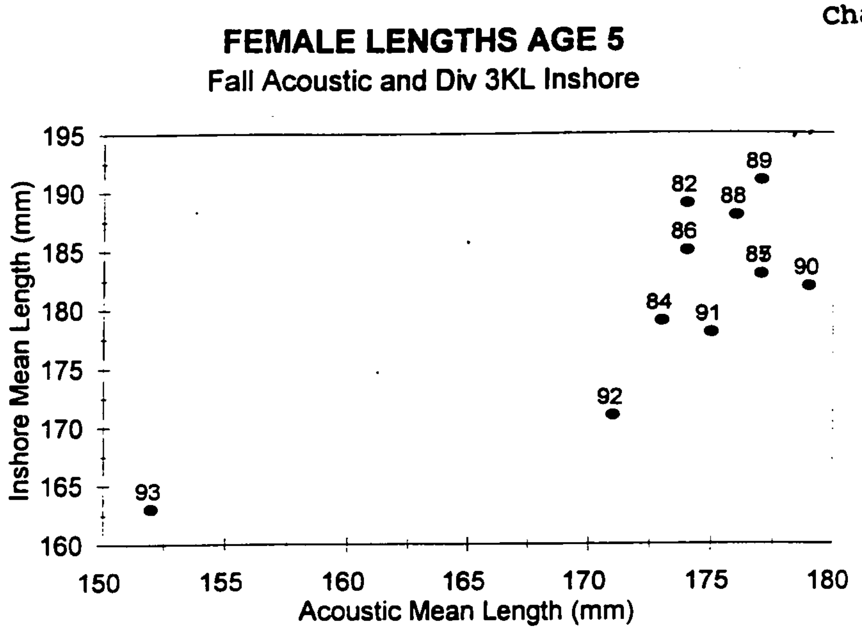


Fig. 9. Relationship between mean lengths of females age 4 in offshore in offshore acoustic surveys and mean lengths of age 5 females inshore the following year (r = .82, p = .002). Years plotted correspond to inshore at age 5.

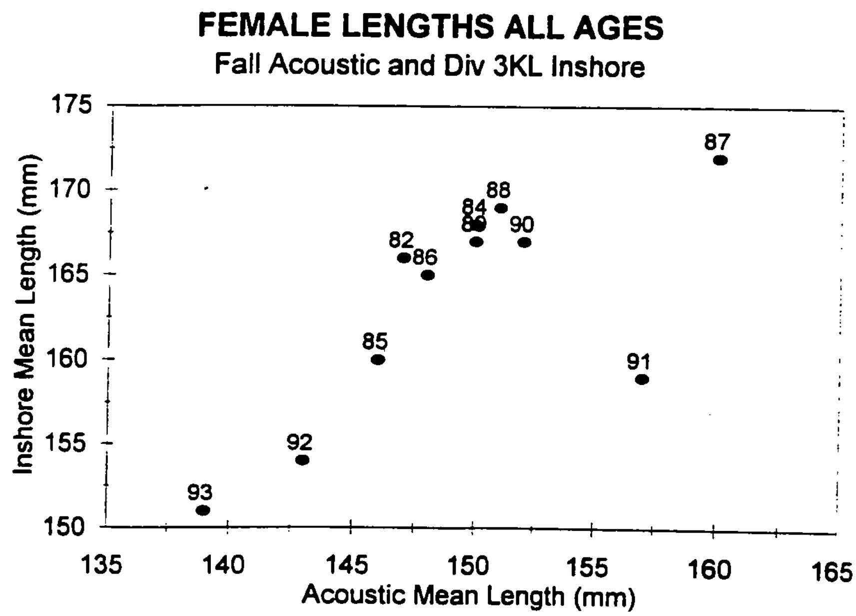


Fig. 10. Relationship between mean lengths of females ages 2, 3 and 4 in offshore acoustic surveys and mean lengths of ages 3, 4 and 5 females inshore the following year (R = .70, p = .02). Years plotted correspond to inshore ages combined.

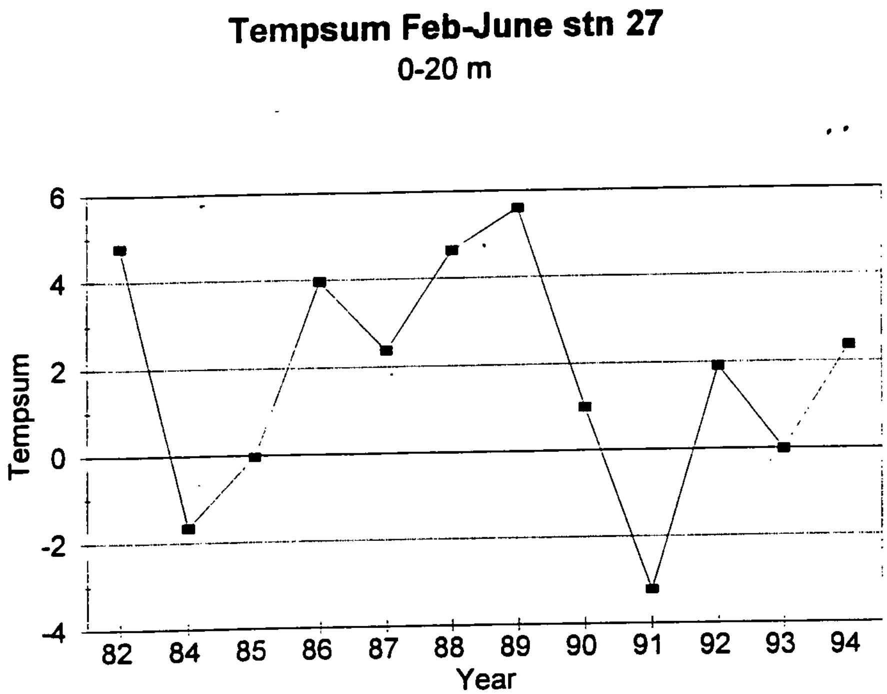


Fig. 11. Annual values of TEMPSUM, February-June combined, 0-20 m, Station 27.

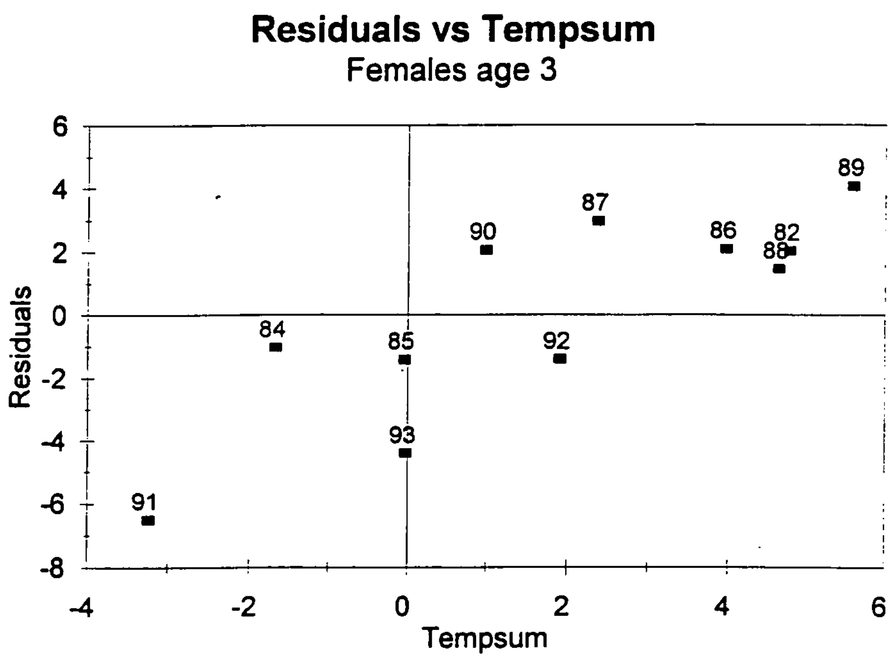


Fig. 12. Relationship between residuals from regression in Figure 7 and tempsum ($r = .83$, $p = .002$). Years plotted correspond to inshore ages and the year tempsum data collected.

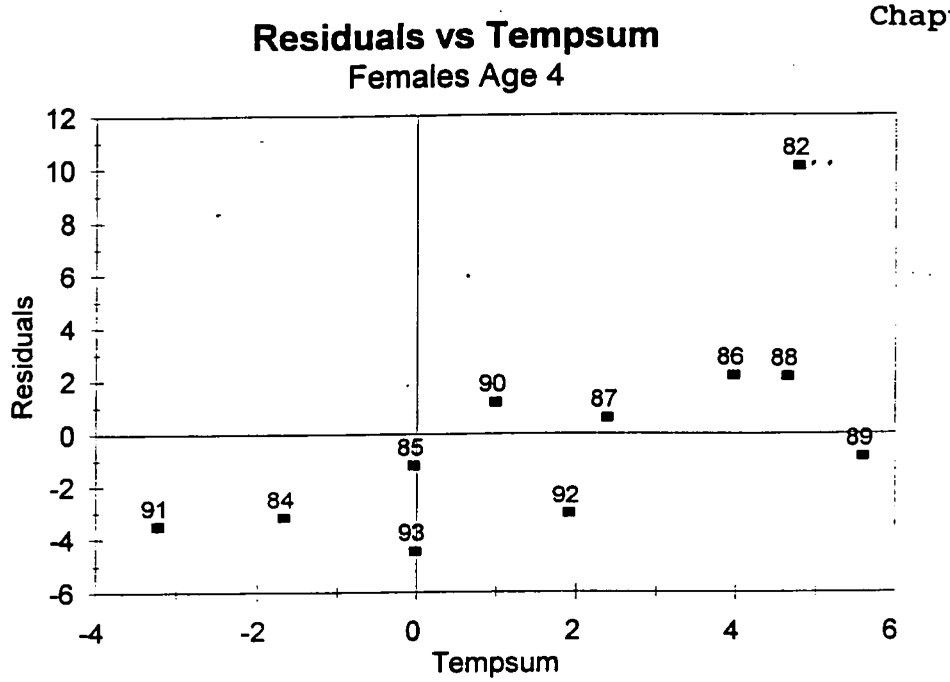


Fig. 13. Relationship between residuals from regression in Figure 8 and tempsum (r = .65, p = .03). Years plotted correspond to inshore ages and the year tempsum data collected.

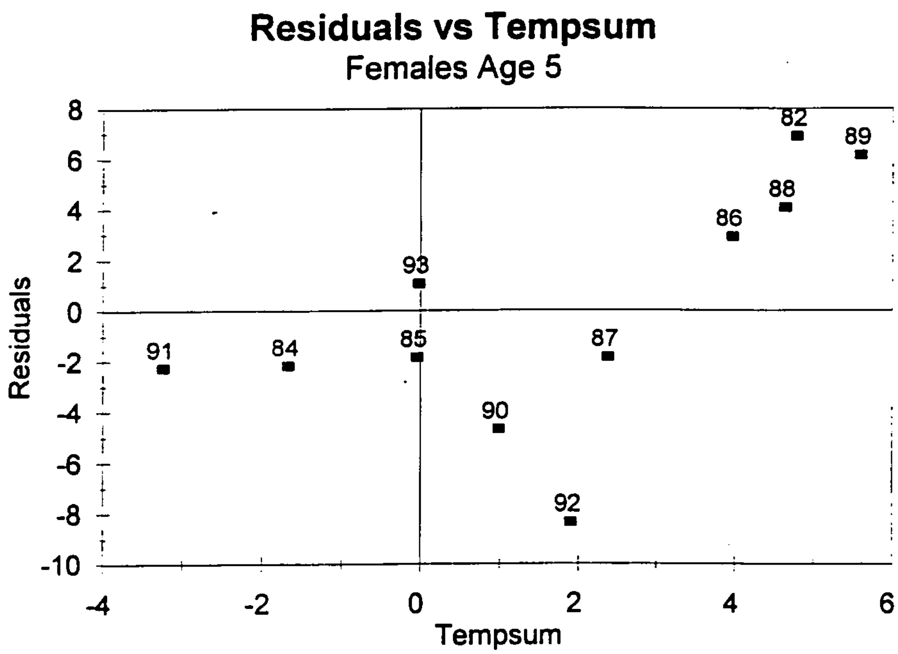


Fig. 14. Relationship between residuals from regression in Figure 9 and tempsum (r = 0.63, p = .04). Years plotted correspond to inshore ages and the year tempsum data collected.

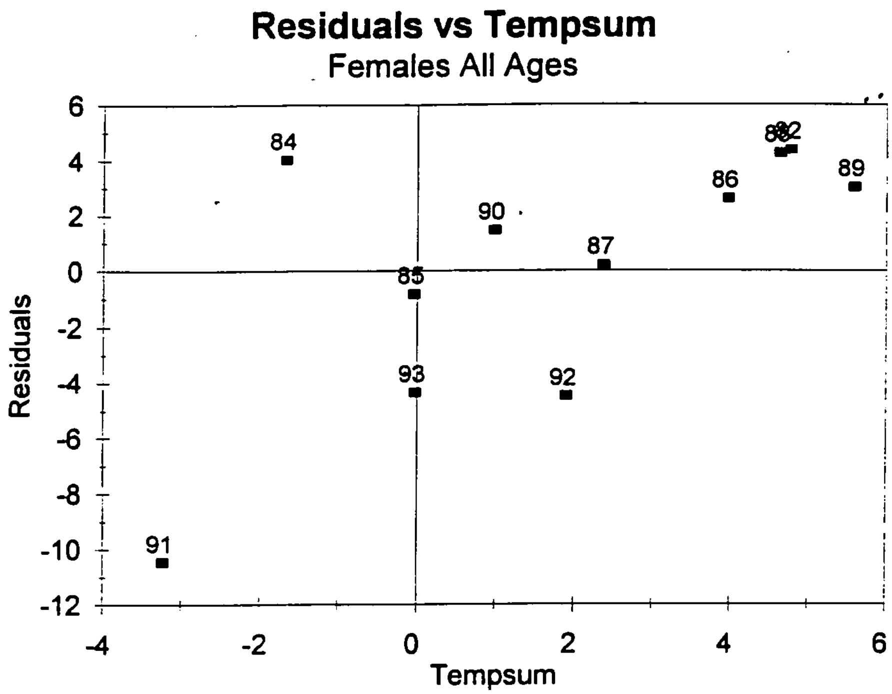


Fig. 15. Relationship between residuals from regression in Figure 10 and tempsum ($r = .66$, $p = .03$). Years plotted correspond to inshore ages and the year tempsum data collected.

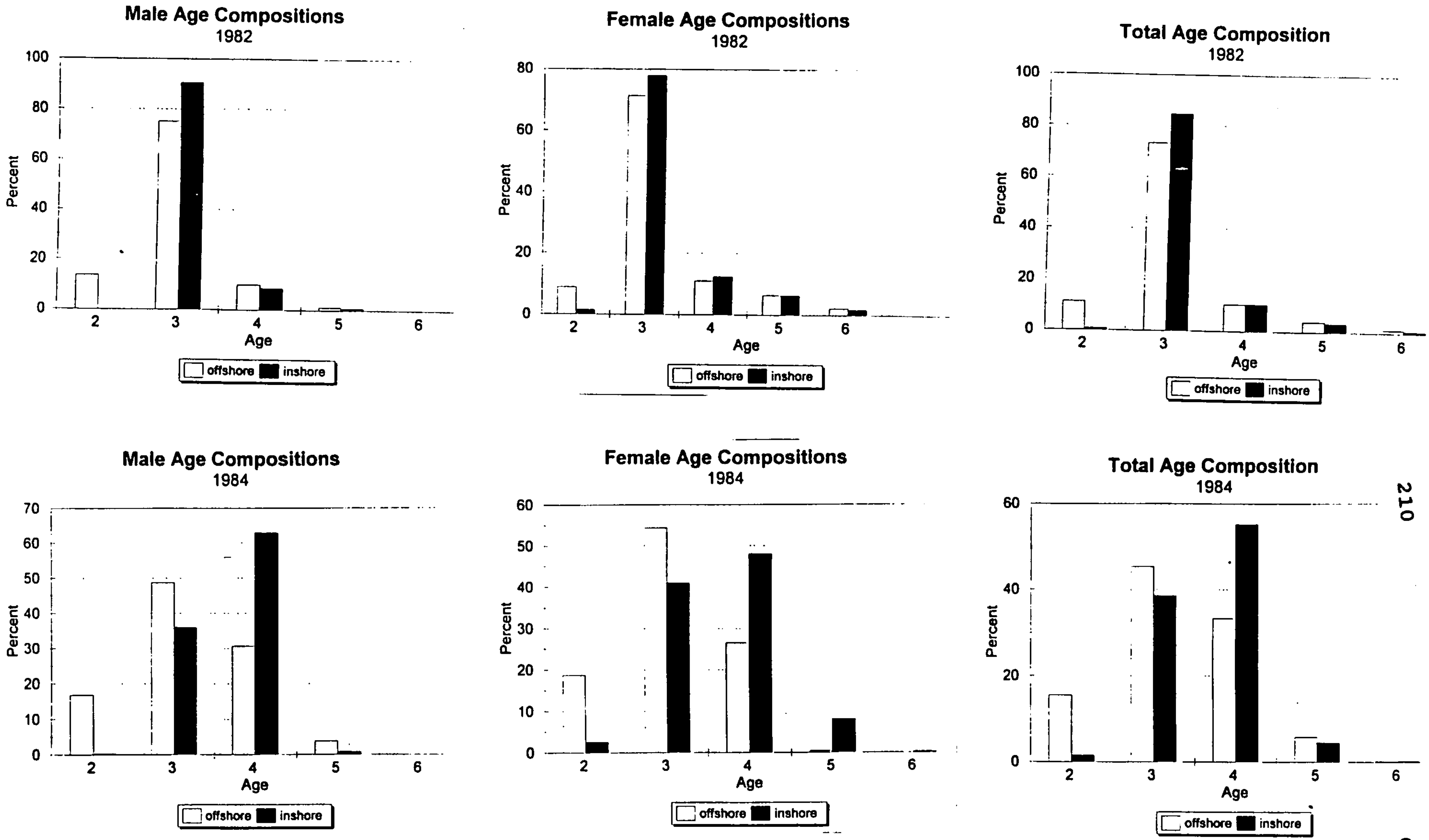


Fig. 16. Age compositions from offshore acoustic surveys correspond to age compositions inshore the following year. The years shown are from the inshore year therefore offshore age compositions are from the survey from the previous year and aged one year.

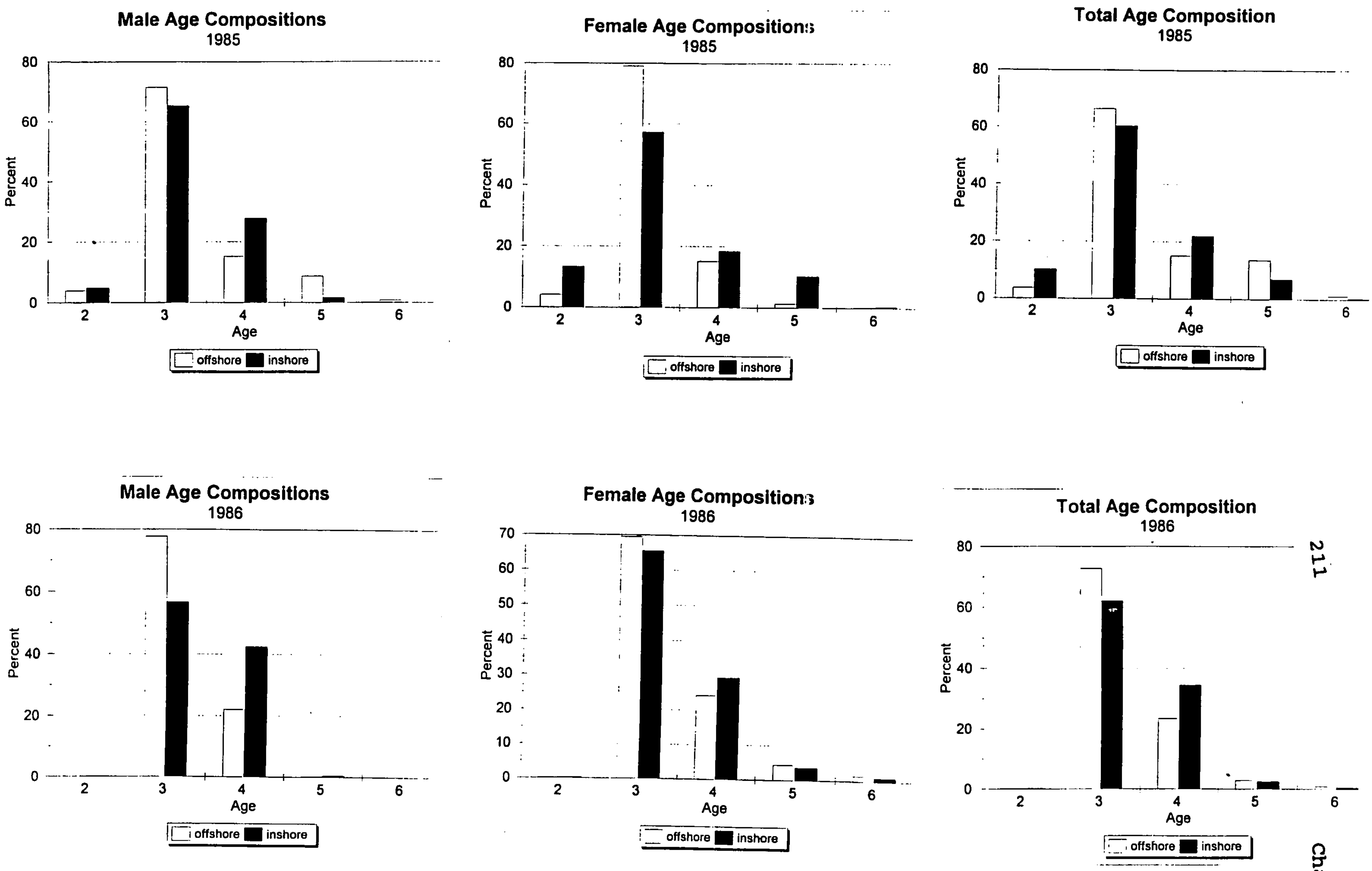
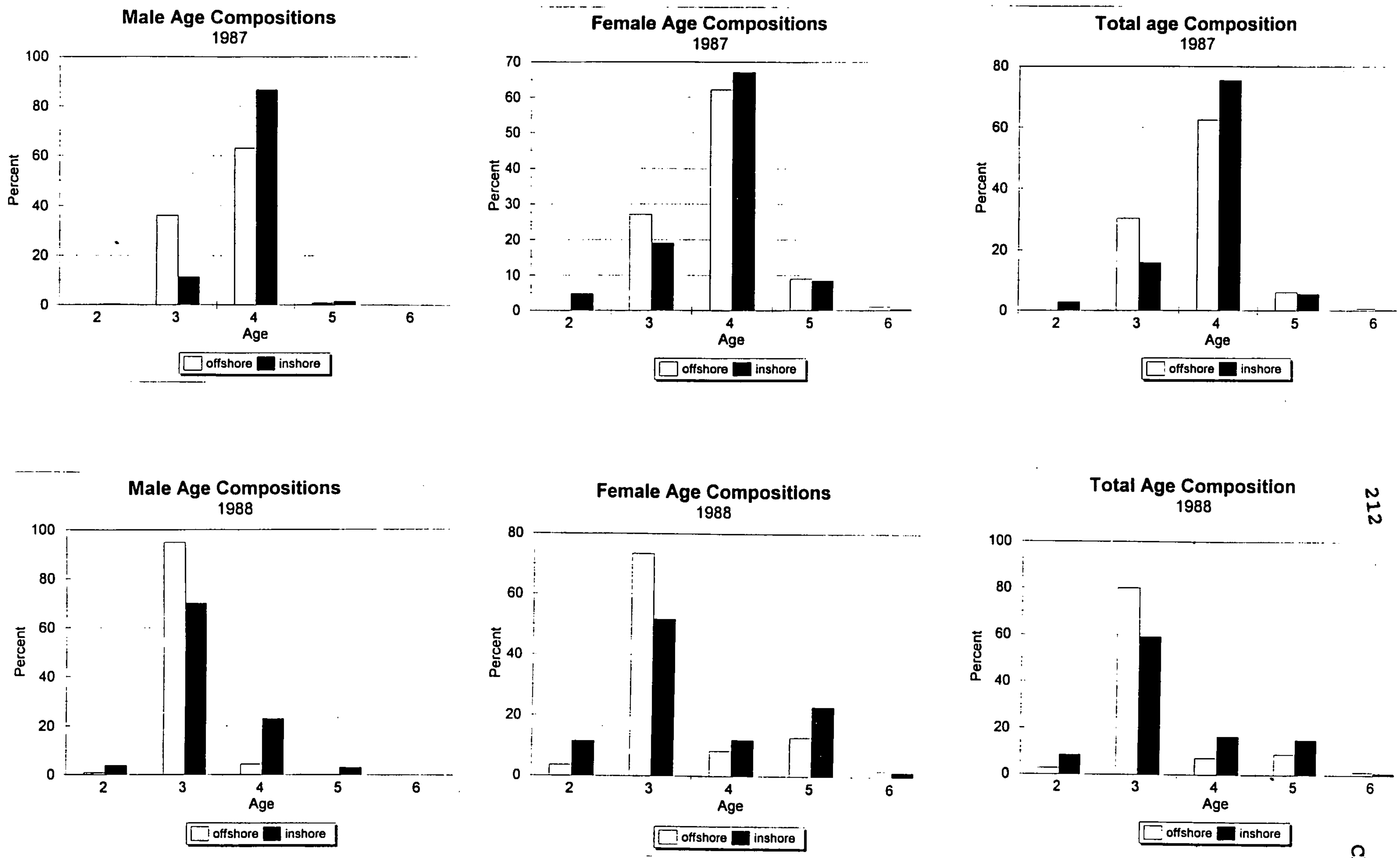


Fig. 16. Age compositions from offshore acoustic surveys correspond to age compositions inshore the following year. The years shown are from the inshore year therefore offshore age compositions are from the survey from the previous year and aged one year.



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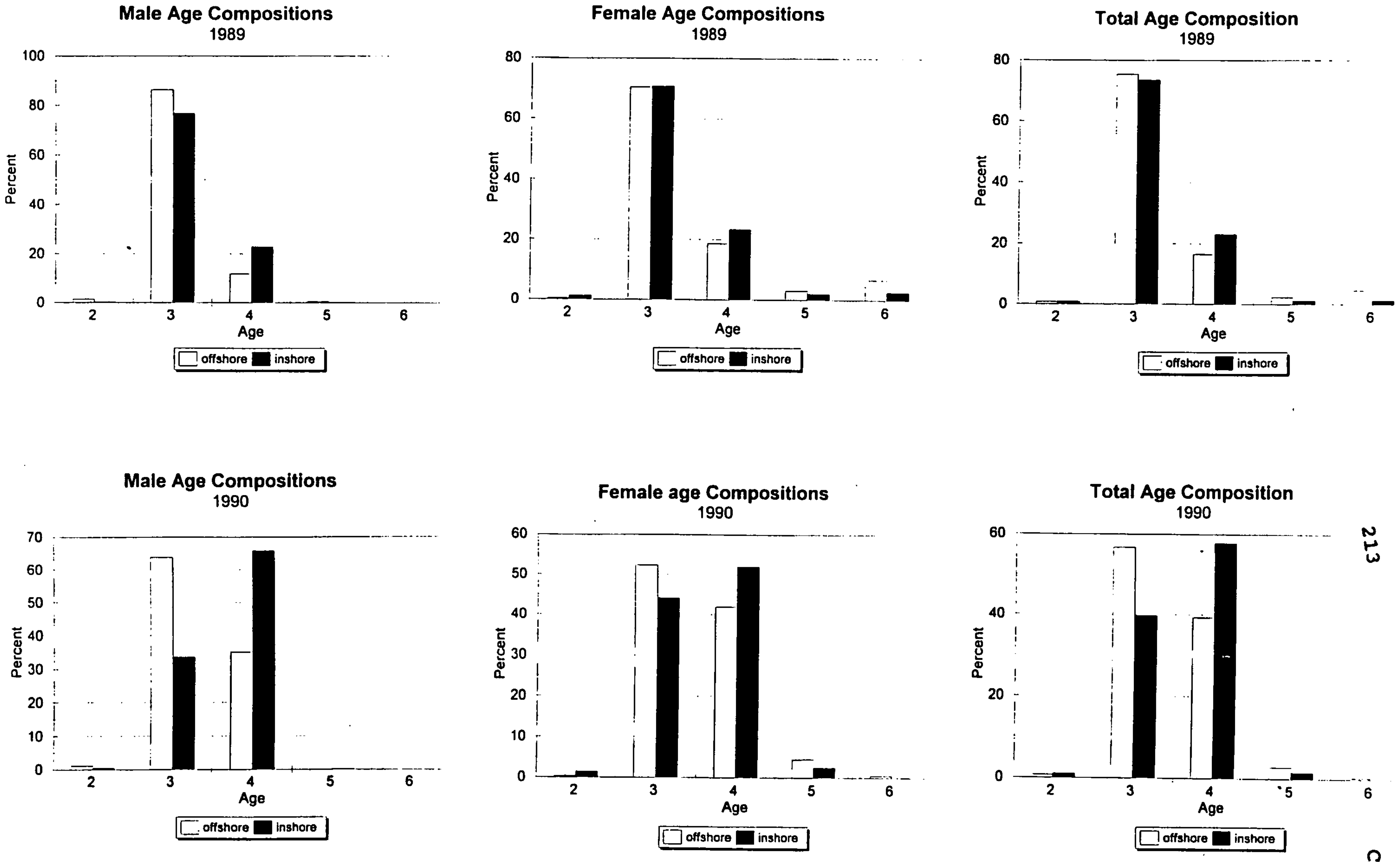

Fig. 16. Age compositions from offshore acoustic surveys correspond to age compositions inshore the following year. The years shown are from the inshore year therefore offshore age compositions are from the survey from the previous year and aged one year.

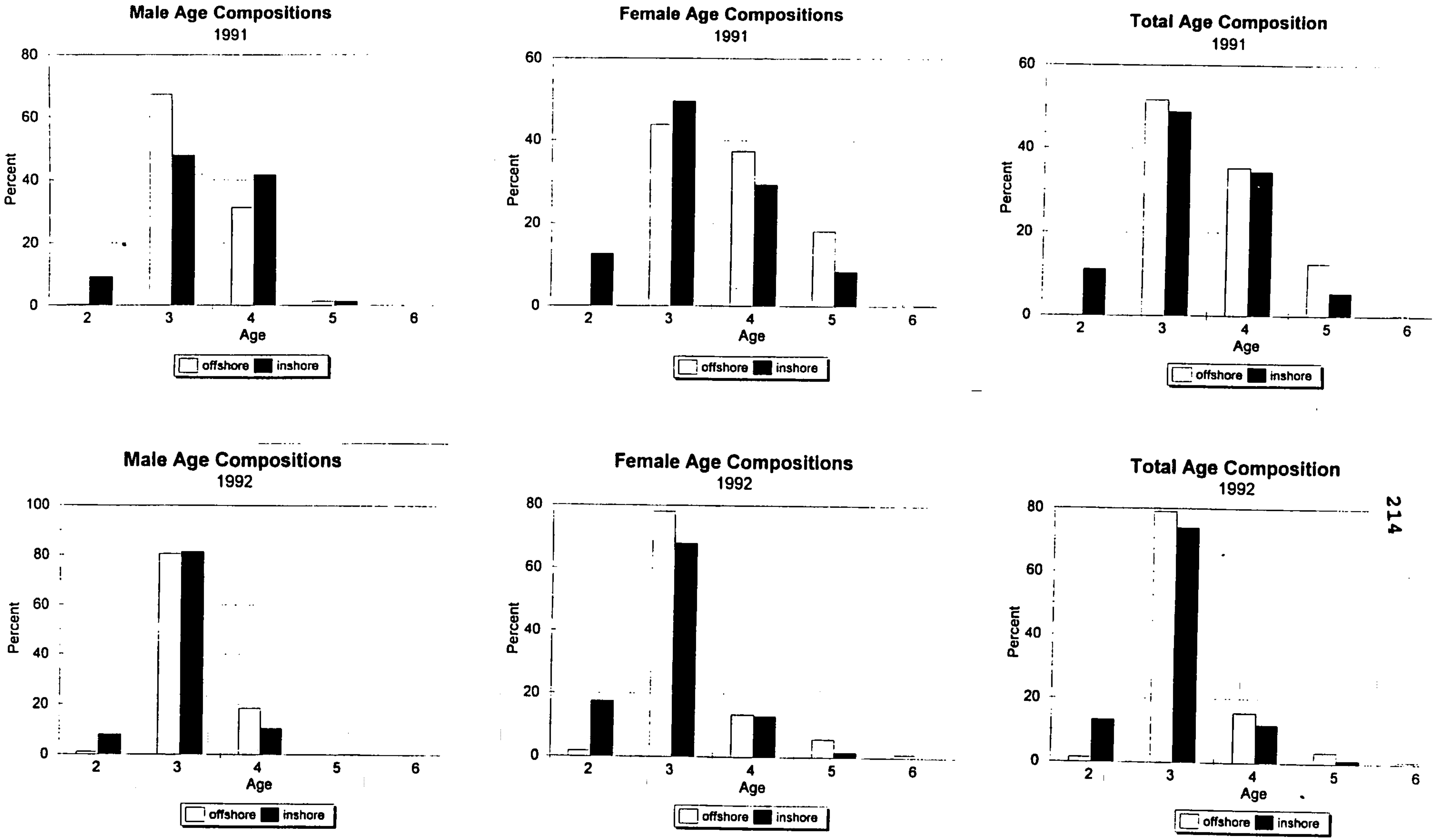

Fig. 16. Age compositions from offshore acoustic surveys correspond to age compositions inshore the following year. The years shown are from the inshore year therefore offshore age compositions are from the survey from the previous year and aged one year.

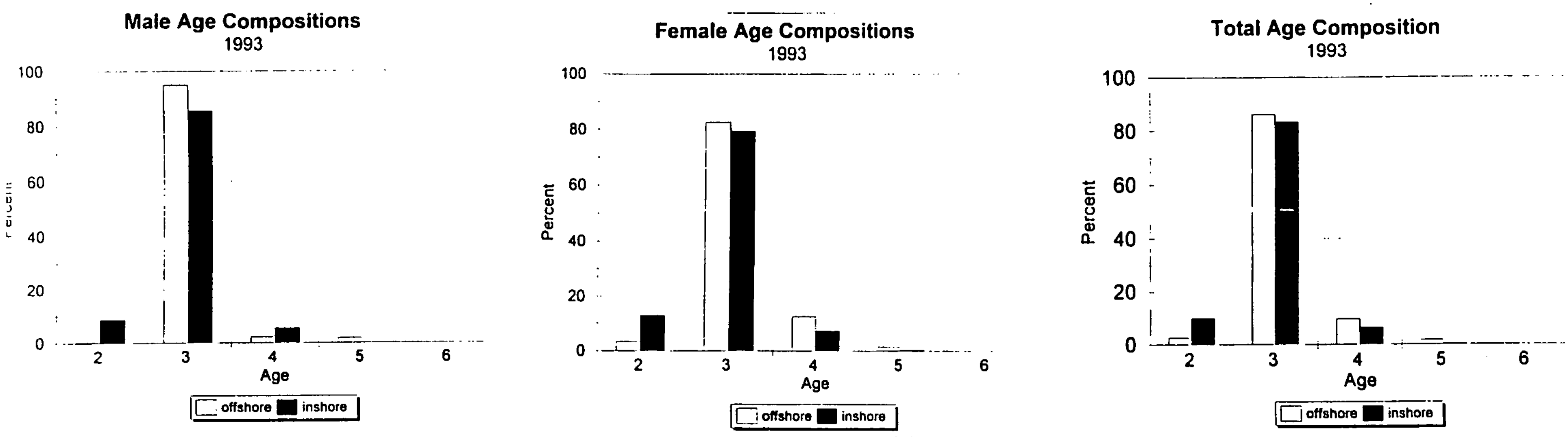

Fig. 16. Age compositions from offshore acoustic surveys correspond to age compositions inshore the following year. The years shown are from the inshore year therefore offshore age compositions are from the survey from the previous year and aged one year.

Comparisons of Capelin Ageing

by

J. Carscadden
Science Branch
Department of Fisheries and Oceans
P. O. Box 5667
St. John's, NF A1C 5X1

Introduction

This study was initiated by apparent differences in age-compositions for capelin collected inshore since 1991. Otoliths collected for different studies and read independently by two readers resulted in dissimilar age compositions, even though both age compositions were assumed to be indicative of the same population. Differences in sampling could have contributed to the differences but the possibility of differences in age interpretations could not be eliminated without a formal ageing comparison.

The study was designed to compare readings between two age readers as well as determine whether age interpretation change over time. The two readers who participated in the experiment are experienced at reading capelin otoliths. Reader A had read capelin otoliths during the mid to late 1960's as part of directed capelin research during that time period. He had not read capelin otoliths during the 1970's and 1980's but had resumed age-reading during the 1990's as part of new capelin research. Some of his earlier capelin age readings as well as the otoliths were still on file thus affording an opportunity to compare age readings from this study with ages assessed during the 1960's. Reader B has been the only person assigning capelin ages since the early 1980's. As a result, we were able to compare ages determined during this study to ages determined more than 10 years ago. At the same time, we were able to compare the ageing by Readers A and B.

This study does not determine accuracy, therefore, readings made by either reader cannot be declared correct or incorrect. The study does determine precision (sensu Beamish and McFarlane 1983) in that the degree of agreement is a measure of the precision of the determinations, but not the accuracy. The results allow us to assess whether ages are different and whether there is a tendency for either reader to read older or younger (bias).

Materials and Methods

The study was conducted in two parts, herein called Phase I and Phase II. Some of the same otoliths were read in both phases which for each reader were read about 5 months apart.

Capelin otoliths are permanently mounted in shallow depressions in black plexiglass trays. During reading, the otoliths are immersed in alcohol. Usually otolith pairs are available and ages are read using a binocular microscope and reflected light. Each otolith tray can accommodate up to 50 otolith pairs which usually comprise a sample.

Otoliths were not randomized within a tray because of the danger of breakage and loss if detachment of the otolith was attempted. However, each phase contained several trays and presentation of the trays was randomized. The readers received the trays numbered in the same way but order of reading was left to the readers. Ages were assessed by each reader independent of the other reader.

During routine otolith reading, ancillary information such as catch data (date, time, location) and biological information are available. However, for this study only location (NAFO Division), date of capture (month, day, but not year), length, sex and maturity of fish were given. Thus, the information available approximated that available during routine ageing with the major exception being year. Since we wished to examine consistency of readings over years, knowledge of the years was withheld.

Otolith trays were chosen randomly from existing collections. Biological data were examined to ensure that a range of sizes and ages was available in the chosen samples and individual otoliths were visually examined to ensure that otoliths were not obviously damaged or missing.

Phase I

Enough trays were chosen from 1967/68, 1987 and 1992 to give between 200 and 250 otolith pairs for each time period (Table 1). In total, there were 701 ages and the trays were labelled in the order shown in Table 1.

This selection of otoliths permitted the following comparisons.

Between Reader Comparisons

a) Readings from all otoliths were used to compare ageing by Reader A and B.

b) Readings from otoliths from 1967-68 were used to compare ageing by Reader A and B.

c) Readings from otoliths from 1987 were used to compare ageing by Reader A and B.

d) Readings from otoliths from 1992 were used to compare ageing by Reader A and B.

Within Reader Comparisons

e) Since Reader A had originally read the ages from 1967-68, his ageing from that time period could be compared to his ageing of the same otoliths in 1994.

f) Since Reader B had originally read the ages from 1987, his ages from that year could be compared to his ages from the same otoliths in 1994.

g) Since Reader B had originally read the ages from 1992, his ages from that year could be compared to his ages from the same otoliths in 1994.

Phase II

The main objective of this phase was to compare the readings from a selection of otoliths from Phase I read about 5 months apart to determine whether individual readers differed over this relatively short time period. From the Phase I group of otoliths, two trays were randomly selected from each of the three time periods, 1967-68, 1987 and 1992. In an attempt to ensure that individual readers did not recognize these otoliths, additional samples were selected and all trays were randomized. In this case, I selected about 200-250 otoliths from each of two years, 1982 and 1993 (Table 2). Nineteen eighty-two was chosen because Reader B had originally read these ages so it permitted a further comparison of his ageing over a longer time period. Nineteen ninety-three was chosen because it allowed another comparison over a short-time period. In addition, hydrographic conditions since 1990 have been negatively anomalous and readers had noted that otoliths had been more difficult to read, perhaps because of unusual growth patterns.

Therefore this selection of otoliths permitted the following comparisons.

Within Reader Comparisons

a) A comparison of short-term readings for both readers from otoliths from Phase I.

b) Since Reader B had originally read the ages from 1982, his ages from that time could be compared to his ages from the same otoliths in 1994.

c) Since Reader B had originally read the ages from 1993, his ages from that time could be compared to his ages from the same otoliths in 1994.

In addition to the basic comparisons above, the following comparisons were also made. These between reader comparisons for individual years augmented the previous comparisons in Phase I.

Between Reader Comparisons

d) Reader A and Reader B's 1994 readings of 1982 otoliths were compared.

e) Reader A and Reader B's 1994 readings of 1993 otoliths were compared.

Statistical Analysis

The ageing comparisons were analyzed using a test of symmetry originally developed by Bowker (1948) and recently applied to ageing data by Hoenig et al. (1995).

Hoenig et al. (1995) briefly describe the test as it is applied to ageing data and this description is extracted directly from their description.

"Bowker's technique (1948) was designed to test the hypothesis that an m x m contingency table consisting of two classifications of a sample into categories (eg., ages given by two readers) is symmetric about the main diagonal. The test statistic is distributed as a chi-square variable with m(m-1)/2 degrees of freedom for a table that has no empty cells. The test statistic is:

$$\chi^2 = \sum_{i>j}\sum \frac{(n_{ij}-n_{ji})^2}{n_{ij}+n^{ji}}$$

where: n_{ij} = the observed frequency in the ith row and jth column

n_{ji} = the observed frequency in the jth row and ith column

The summation is over all the cells above the diagonal. These cells are paired with the corresponding cells below the diagonal. If there is a systematic difference between methods then the test statistic will tend to be large. If, however, the differences are due to simple random error, then the value of n_{ji} will be very similar to that of n_{ij} and the test statistic will not be significant. The number of degrees of freedom is equal to the number of comparisons. If both cells in a pair (n_{ji} and n_{ij}) are zero, the pair is dropped from the test statistic and the degrees of freedom is reduced by one."

Results

Phase I

Between Reader Comparisons

a) Comparison between readers using all otoliths.
When all samples are combined the agreement between the readers was 72% (Table 3). The test of symmetry shows differences were significant (χ^2 = 167.2, df = 7, $p \leq 0.001$) with Reader B showing a tendency to assign younger ages (Table 3, Fig. 1).

b) When the 1994 readings of 1967-68 otoliths were compared, there was 84% agreement between readers (Table 4). The test of symmetry indicated a significant difference (χ^2 = 35.1, df = 6, $p \leq 0.001$). Where differences occurred, the tendency was for Reader B to assign younger ages (Table 4, Fig. 2).

c) When the 1994 readings of 1987 otoliths were compared, there was 77% agreement between readers (Table 5). The test of symmetry indicated a significant difference (χ^2 = 40.7, df = 7, $p \leq 0.001$). The major differences occurred in the assignment of younger ages by Reader B (Table 5, Fig. 3).

d) There was only 52% agreement between readers for 1994 age readings of 1992 otoliths (Table 6). The test of symmetry showed significant differences (χ^2 = 94.5, df = 5, $p \leq 0.001$). The asymmetry in ageing was reflected in the assignment of younger ages by Reader B compared to Reader A (Table 6, Fig.4).

Within Reader Comparisons

e) Reader A had originally assigned ages to otoliths collected during 1967-68. His original and 1994 readings showed 83% agreement (Table 7). The mean ages (Table 7) and age compositions (Fig. 5) were similar suggesting that there was no systematic bias in ageing. However, the test of symmetry showed a significant difference (χ^2 = 11.18, df = 5, $p \leq 0.05$). There were more differences above the diagonal in Table 1 indicating a tendency to reader older in 1994 compared to 1967-68.

f) Reader B had originally assigned ages to these otoliths in 1987. His 1994 and original readings showed 96% agreement (Table 8) and age compositions were similar (Fig. 6). The test of symmetry was not significant (χ^2 = 2.67, df = 2, $p \leq 0.30$).

g) Age readings in 1994 by Reader B for 1992 otoliths showed 90% agreement with his original 1992 readings (Table 9, Fig. 7). The test of symmetry was significant ($\chi^2 = 12.25$, df = 3, $p \leq 0.01$). Reader B tended to assign younger ages in 1994 compared to 1992.

Phase II

Within Reader Comparisons

a) When Reader A read the same otoliths about 5 months later, there was only about 79% agreement, although mean ages (Table 10) and age compositions (Fig. 8) were similar. The test of symmetry was not significant ($\chi^2 = 3.89$, df = 5, $p \leq 0.30$). This illustrates the fact that while overall agreement in ageing was not good, there was no systematic bias in the disagreements. As a result the test of symmetry was not significant and mean ages and age compositions were similar.

Reader B exhibited a higher agreement (94%) over the 5-month period. As a result, mean ages (Table 11) and age compositions (Fig. 9) were similar and the test of symmetry was not significant ($\chi^2 = 7.8$, df = 4, $p \leq 0.10$).

b) Reader B had originally assigned ages to the 1982 otoliths. The agreement between the 1994 and original readings was 83% (Table 12). The test of symmetry was significant ($\chi^2 = 29.1$, df = 6, $p \leq 0.001$). There was a tendency to read younger in 1994 with the greatest differences occurring at ages 2 and 6 (Table 12, Fig. 10).

c) When a similar comparison was made for Reader B using 1993 otoliths, there was 95% agreement (Table 13). The test of symmetry was not significant ($\chi^2 = 5.14$, df = 3, $p \leq 0.20$) and mean ages (Table 13) and age compositions (Fig. 11) were similar.

Between Reader Comparisons

d) There was 63% agreement between Reader A and Reader B's ageing of the 1982 otoliths (Table 14). The test of symmetry was significant ($\chi^2 = 89.5$, df = 9, $p \leq 0.001$). There was a tendency for Reader B to assign younger ages than Reader A (Table 14, Fig. 12).

e) When the ageings of otoliths from 1993 were compared, there was only 59% agreement (Table 15). The test of symmetry was significant (χ^2 = 90.6, df = 5, p $\leq$ 0.001). Reader B generally assigned younger ages than Reader A (Table 15, Fig. 13).

A summary of the overall results of the comparisons is given in Table 16. Several observations can be made.

1) Reader A and Reader B are interpreting the otoliths differently - all between reader comparisons indicated a significant difference using the test of symmetry. In all cases, there was a tendency for Reader A to assign older ages and Reader B to assign younger ages.

2) In the between-reader comparisons using individual years, the agreements going from best to worst were 1967-68, 1987, 1982, 1993, 1992. Thus, although the trend with years is not exact, the fact that the worst agreement occurred in the most recent years may support the observation that otoliths in recent years are more difficult to read. An explanation for this difficulty may be that environmental conditions have altered growth patterns - this might result in physical changes in the otolith making it difficult to read and it may affect interpretation relative to other years.

3) For both readers, there were no statistical differences in interpretation of otoliths over a short-time period of less than one year (5 months).

4) For Reader A, otoliths previously read by him were available for only one time period 1967-68. There was a significant difference in the readings with the more recent readings showing a tendency to assign older ages.

5) For Reader B, several years were examined, namely 1982, 1987, 1992, 1993. Significant differences occurred for otoliths from 1982 and 1992 but not for 1987 and 1993. This may indicate inconsistency in ageing over time but a more definite conclusion is not immediately obvious. Where differences did occur, the 1994 readings showed a tendency to assign younger ages.

6) Out of 13 comparisons that were made, nine showed significant differences using Bowker's test (Table 16). I did not conduct further tests on those comparisons that showed significant differences, but simply examined the age compositions and made a subjective determination on whether there appeared to be differences. The results are given below.

Comparison	Description	Differences in age compositions	Reference
Between A & B	all samples Phase I	Yes	Fig. 1
	1994 readings of 1967-68 otoliths	No	Fig. 2
	1994 readings of 1987 otoliths	No	Fig. 3
	1994 readings of 1992 otoliths	Yes	Fig. 4
Within readers	Reader A - 1967-68 otoliths - original ages compared to 1994 ages	No	Fig. 5
	Reader B - 1992 otoliths - original ages compared to 1994 ages	No	Fig. 7
	Reader B - 1982 otoliths - original ages compared to 1994 ages	No	Fig. 10
Between readers	1994 readings of 1982 otoliths	Yes	Fig. 12
	1994 readings of 1993 otoliths	Yes	Fig. 13

Thus in the between reader comparisons I concluded that we would have interpreted age compositions differently in four out of six cases where statistical differences in age readings were also shown to have occurred. When significant differences between ages occurred within ages by the same reader, I concluded that we would not likely have drawn different conclusions by examining age compositions alone.

Further Work

1) The analysis will be extended to examine if differences are related to sex of fish. Females appear to have a higher spawning survival and as a result, spawning checks may be deposited on the otolith and interpreted as annuli.

2) Resolve differences in readers. One possibility is to have otoliths read by Icelandic, Norwegian and/or Russian age readers.

3) Initiate a system that will maintain inter-annual consistency. Possibilities include reading a reference collection at the start of each annual age-reading session or have a subsample read by an independent reader.

4) Eventually all otolith images will be stored in an image analysis system. Each image will have the otolith with annuli flagged. This will allow future age readers to retrieve historical images and see what structures former readers interpreted as annuli. Otoliths will continue to be stored as they are at present.

References

Bowker, A. H. 1948. A test for symmetry in contingency tables. J. Am. Stat. Assoc. 43: 572-574.

Hoenig, J. M., M. J. Morgan, and C. A. Brown. 1995. Analyzing differences between age determination methods by tests of symmetry. Can. J. Fish. Aquat. Sci. 52 (in press)

Beamish, R. J., and G. A. McFarlane. 1983. The forgotten requirement for age validation in fisheries biology. Trans. Am. Fish. Soci. 112: 735-743.

Table 1. Details of samples used in first otolith reading (Phase I).

Order	Date collected	Sample no.	No. of otoliths
1	May 20, 1987	93	50
2	June 29, 1987	307	37
3	June 28, 1967 (otoliths 1-50)	10	50
4	June 28, 1967 (otoliths 51-100)	10	50
5	August 1, 1992	230	38
6	July 10, 1992	214	37
7	July 21, 1992	226	39
8	June 24, 1992	237	35
9	May 17, 1987	92	40
10	June 26, 1987	313	39
11	June 28, 1967 (otoliths 250-299)	10	43
12	May 21, 1987	94	37
13	July 3, 1992	236	38
14	June 19, 1968 (otoliths 1-50)	10	50
15	July 21, 1992	227	37
16	June 28, 1967 (otoliths 100-158)	10	50
17	July 3, 1987	305	31
TOTAL			701

Table 2. Details of samples used in second otolith reading (Phase II).

Order	Date collected	Sample no.	No. of otoliths
1	June 15, 1982	116	33
2	June 28, 1987 (otoliths 1-50)	10*	50
3	July 21, 1992	226*	39
4	June 29, 1993	275	34
5	July 2, 1993	304	39
6	July 30, 1993	318	29
7	August 1, 1993	315	35
8	June 14, 1982	35	39
9	June 24, 1992	237*	35
10	June 19, 1982	167	44
11	June 14, 1982	36	33
12	July 23, 1993	299	45
13	June 22, 1982	169	50
14	June 19, 1982	41	33
15	June 28, 1993	272	35
16	June 28, 1967 (otoliths 51-100)	10*	50
17	June 22, 1982	200	35
18	July 3, 1987	305*	31
19	June 26, 1987	313*	39
20	July 20, 1993	297	41
TOTAL			769

* Samples also used in first reading.

Table 3. Comparison of age readings of all samples from Phase I.

	Reader B							
	Age	2	3	4	5	6	N	
	2	<u>139</u>	5				144	
	3	29	<u>155</u>	2			186	
	4	2	87	<u>158</u>	1		248	
Reader A	5		7	52	<u>53</u>		112	Mean age = 3.51
	6			4	7		11	
	N	170	254	216	61		701	

Mean age = 3.24

72% agreement

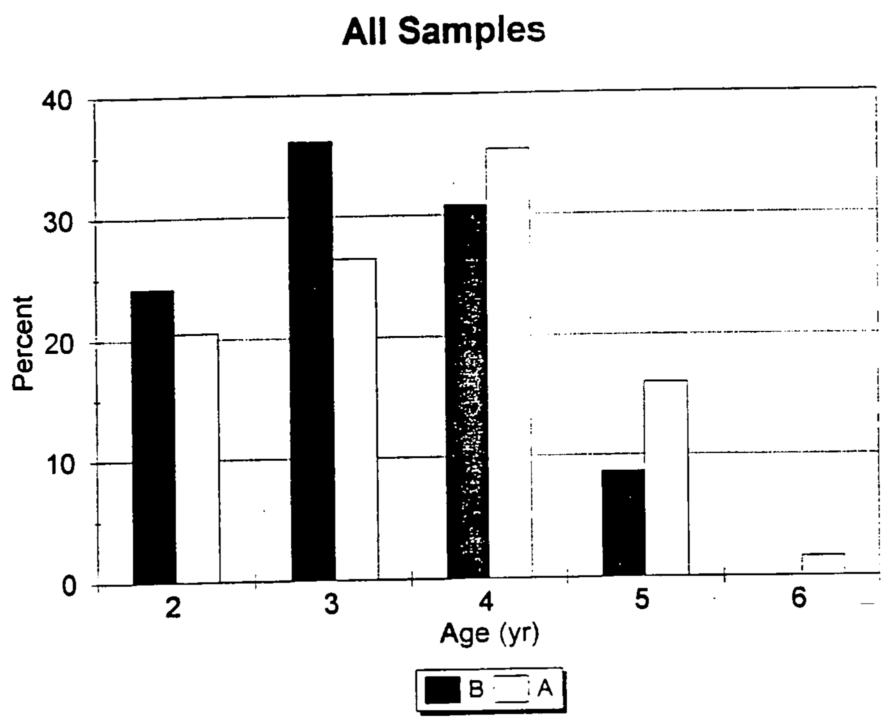

Fig. 1.

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Table 4. Comparison of Reader A and Reader B's 1994 readings of 1967-68 otoliths.

		Reader B						
	Age	2	3	4	5	6	N	
	2	6					6	
	3		68	2			70	
	4	1	12	90			103	
Reader A	5		2	18	39		59	Mean age = 3.95
	6			3	2		5	
	N	7	82	113	41		243	

Mean age = 3.77

84% agreement

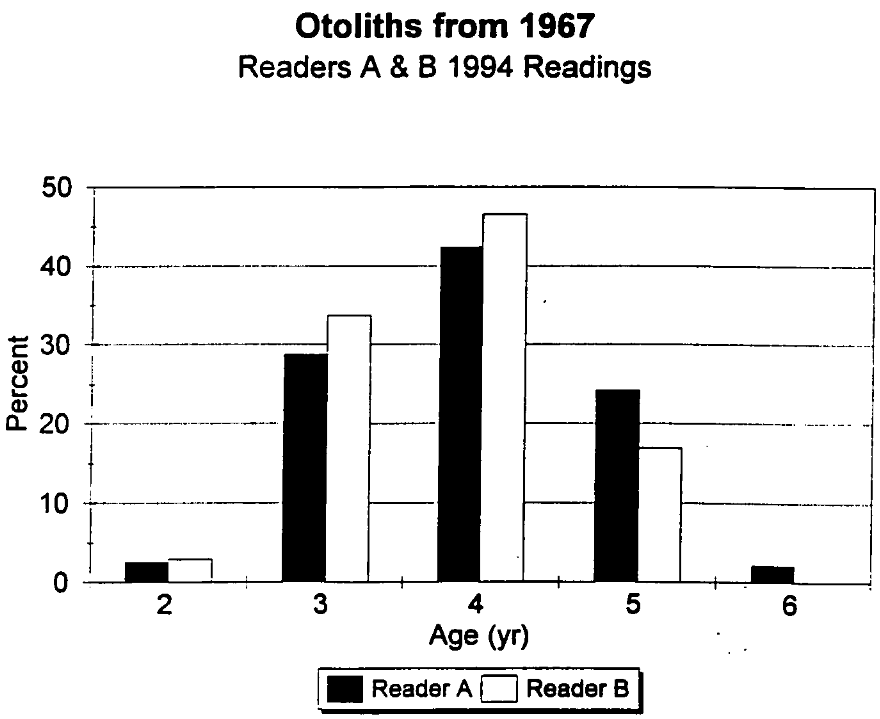

Fig. 2.

Table 5. Comparison of Reader A and Reader B's 1994 readings of 1987 otoliths.

		Reader B						
	Age	2	3	4	5	6	N	
	2	79	1				80	
	3	7	39				46	
	4	1	8	56	1		66	
Reader A	5		1	24	12		37	Mean age = 3.32
	6			1	4		5	
	N	87	49	81	17		234	

Mean age = 3.12

79% agreement

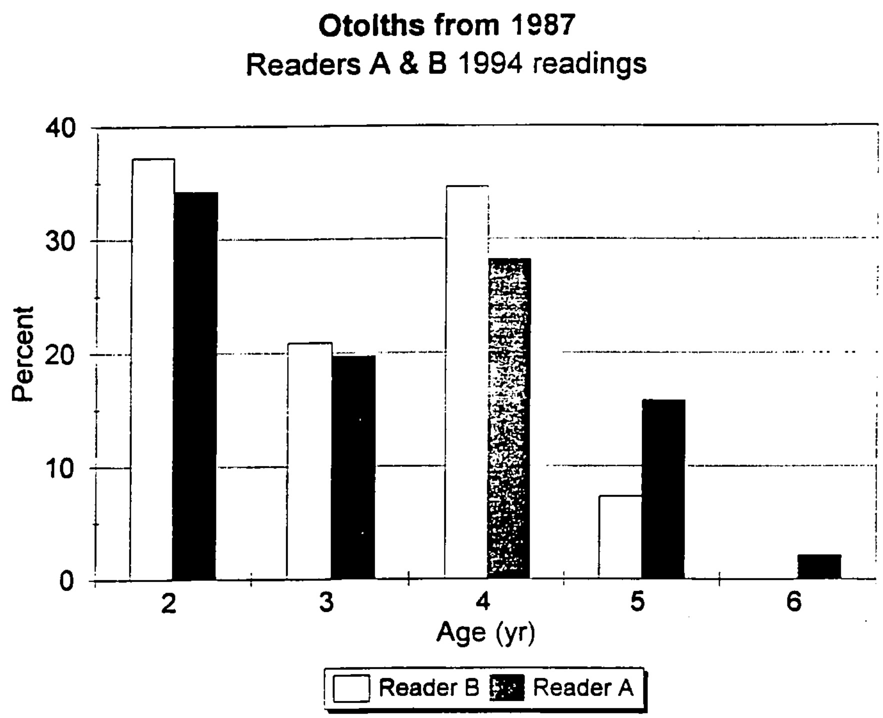

Fig. 3.

Table 6. Comparison of Reader A and Reader B's 1994 readings of 1992 otoliths.

		Reader B					
	Age	2	3	4	5	6	N
	2	<u>54</u>	4				58
	3	22	<u>48</u>				70
	4		67	<u>12</u>			79
Reader A	5		4	10	<u>2</u>		16
	6				1		1
	N	76	123	22	3		224

Mean age (Reader A) = 3.25

Mean age = 2.79

52% agreement

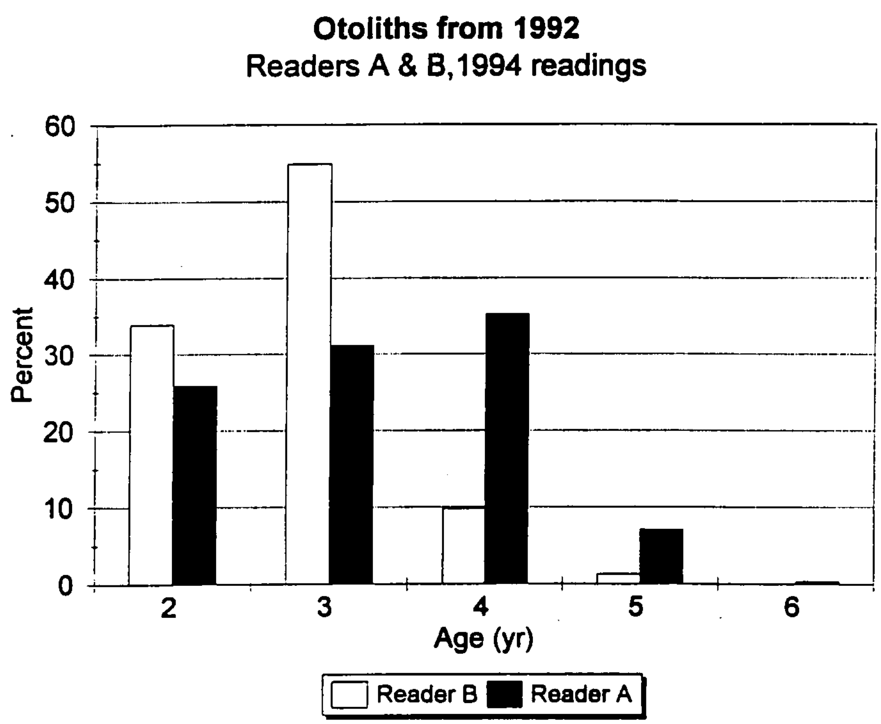

Fig. 4.

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Table 7. Comparison of Reader A's 1994 and 1967-68 readings of otoliths from 1967 and 1968.

		1994 Readings							
	Age	2	3	4	5	6	7	N	
Original readings	2	6						6	
	3		64	8				72	
	4		6	92	16	1		115	Mean age = 3.87
	5			3	40	3		46	
	6				3	_		3	
	7					1		1	
	N	6	70	103	59	5		243	

Mean age = 3.94

83% agreement

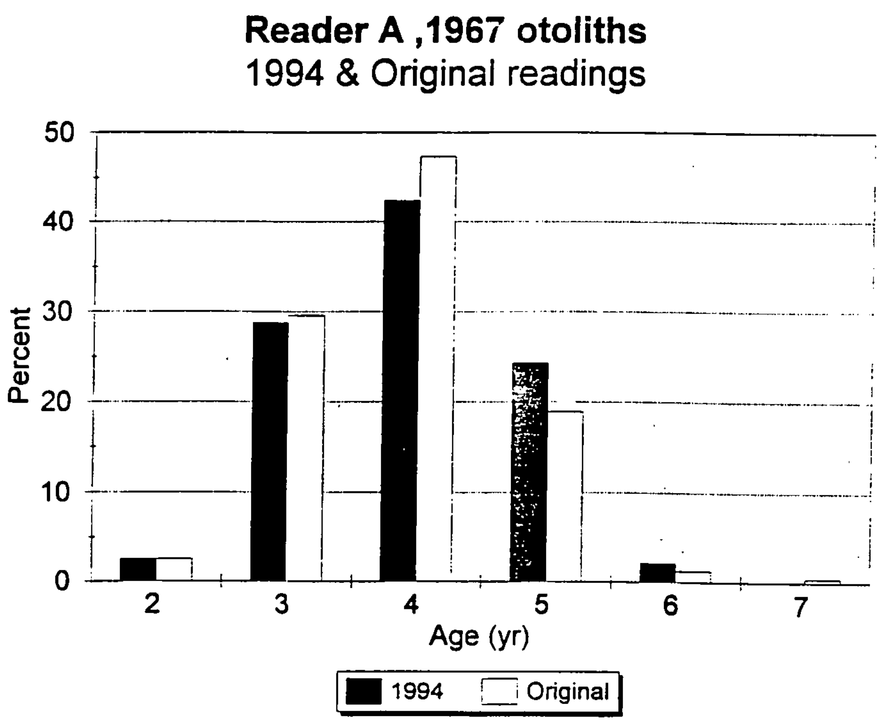

Fig. 5.

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Table 8. Comparison of Reader B's 1994 and 1987 readings of 1987 otoliths.

		1994 Readings						
	Age	2	3	4	5	6	N	
Original readings (1987)	2	85					85	
	3	2	49				51	
	4			77	2		79	Mean age = 3.14
	5			4	15		19	
	6							
	N	87	49	81	17		234	

Mean age = 3.12

97% agreement

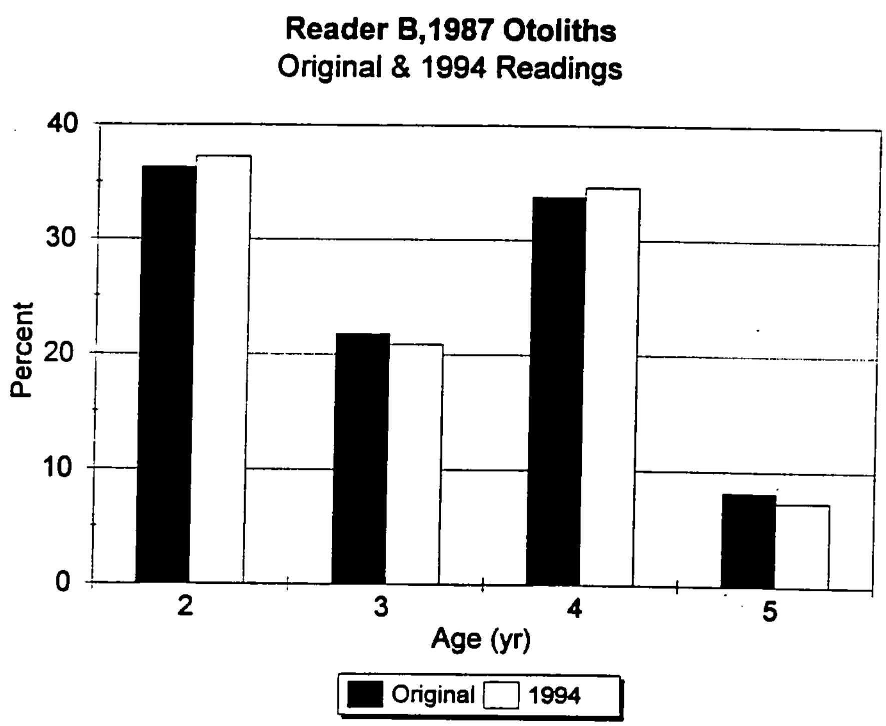

Fig. 6.

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Table 9. Comparison of Reader B's 1994 and 1992 readings of 1992 otoliths.

		1994 Readings						
	Age	2	3	4	5	6	N	
	2	<u>63</u>	3				66	
	3	13	<u>115</u>				128	
	4		5	<u>22</u>	1		28	
Original readings (1992)	5				<u>2</u>		2	Mean age = 2.85
	6							
	N	76	123	22	3		224	

Mean age = 2.79

90% agreement

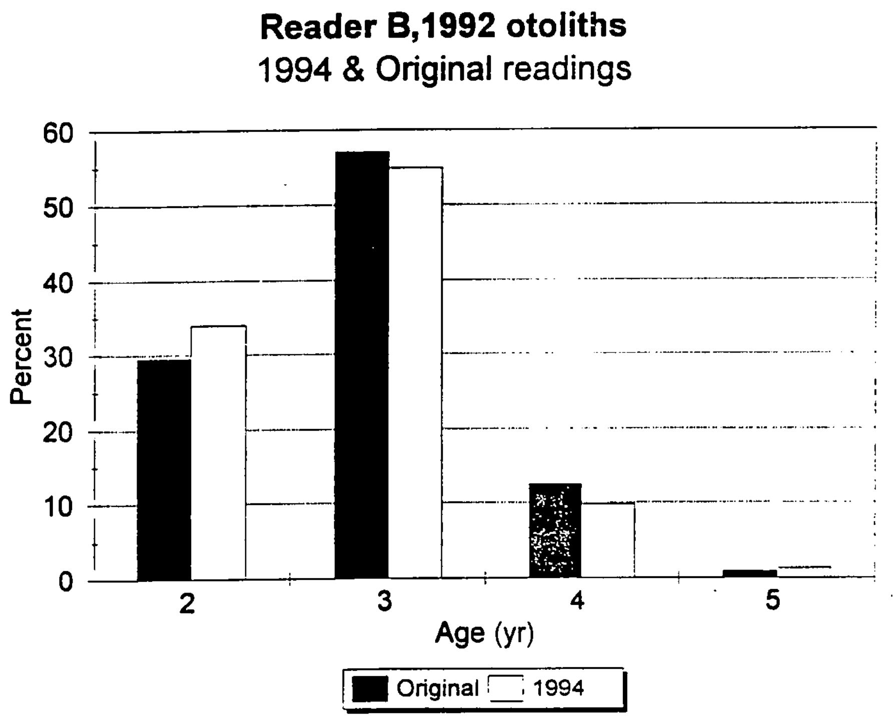

Fig. 7.

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Table 10. Comparison in reading the same set of otoliths by Reader A over a short-time period (about 5 months).

		First reading					
	Age	2	3	4	5	6	N
	2	30	4				34
	3	4	46	9			59
	4		7	71	14	1	93
Second reading	5			8	43	3	54
	6				1	3	4
	N	34	57	88	58	7	244

Second reading: Mean age = 3.73

First reading: Mean age = 3.78

79% agreement

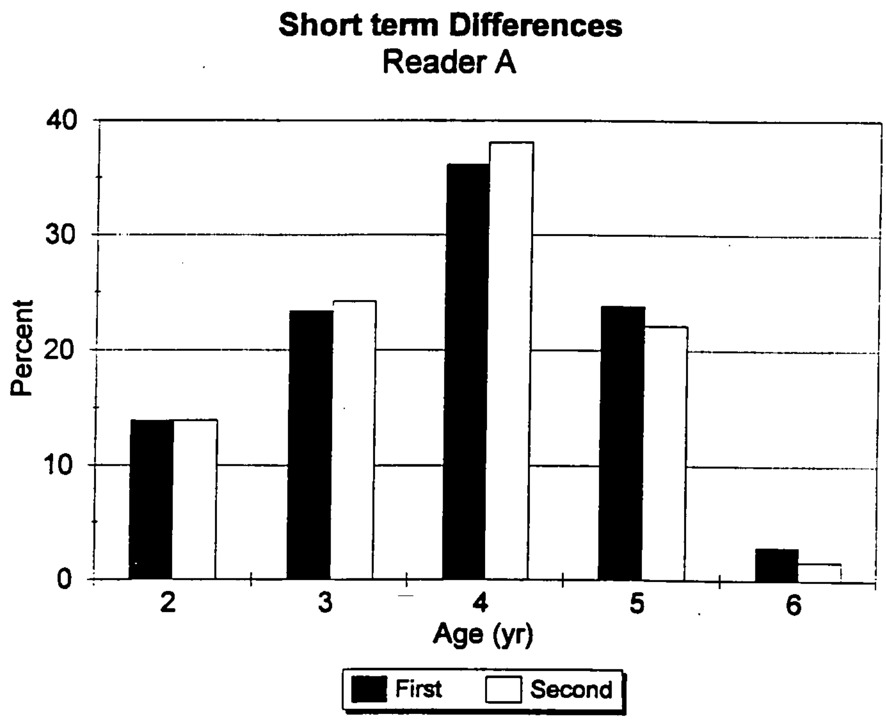

Fig. 8.

Table 11. Comparison in reading the same set of otoliths by Reader B over a short-time period (about 5 months).

		First reading					
	Age	2	3	4	5	N	
	2	34				34	
	3	5	81	1		87	
	4		4	73	3	80	
Second reading	5		1	3	39	43	Mean age = 3.54
	N	39	86	77	42	244	

Mean age = 3.50

94% agreement

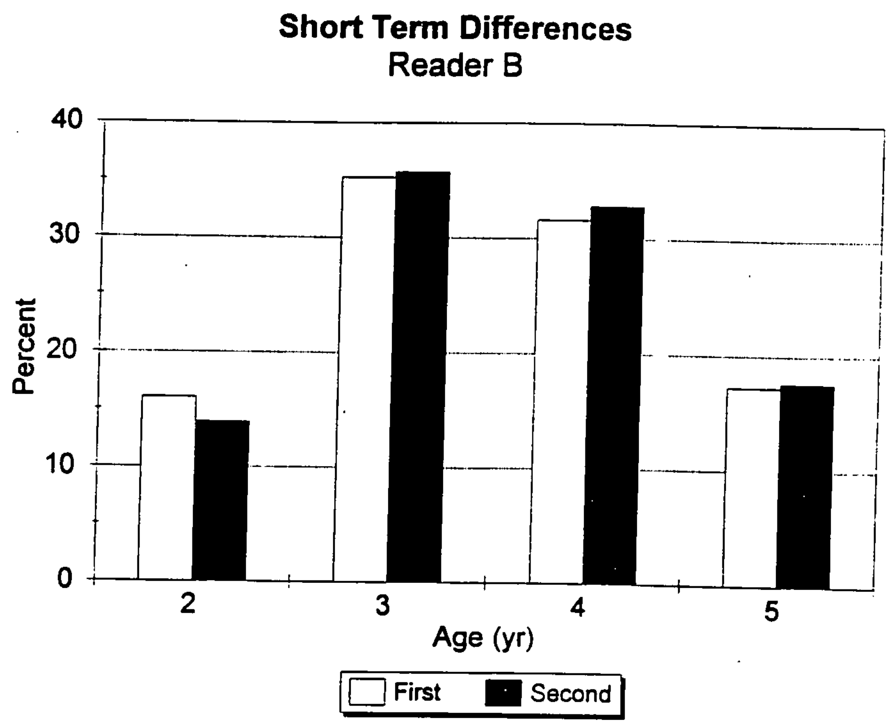

Fig. 9.

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Table 12 Comparison of Reader B's 1982 and 1994 readings of 1982 otoliths.

	Reader B 1982 Readings								
	Age	1	2	3	4	5	6	N	
	1	1						1	
	2		22	13				35	
	3		1	156	12	1		170	
	4			3	22	6	1	32	
Reader B 1994 readings	5					16	8	24	Mean age = 3.22
	6					1	4	5	
	N	1	23	172	34	24	13	267	

Mean age = 3.36

83% agreement

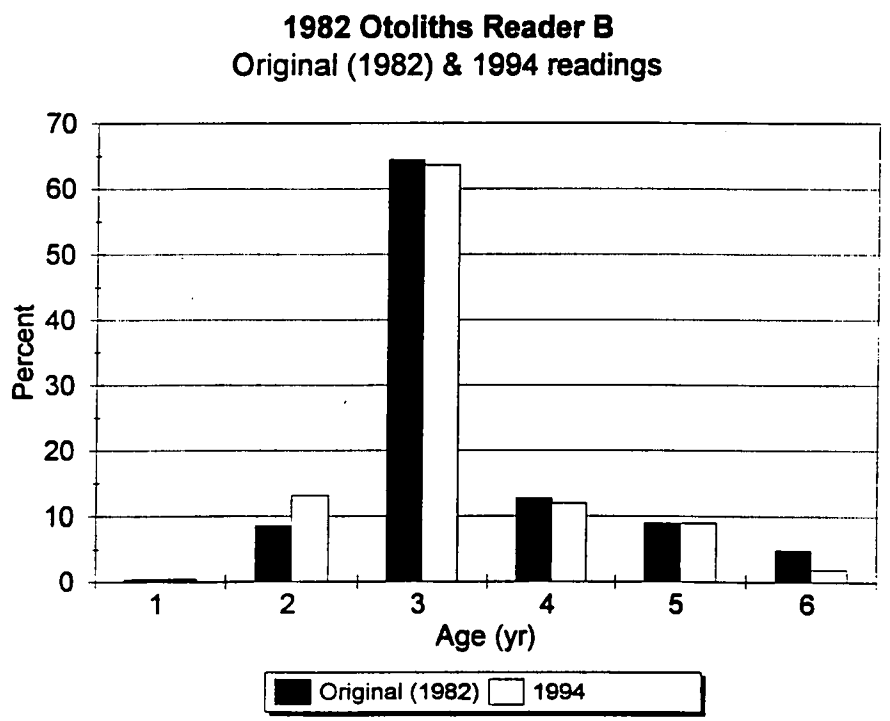

Fig. 10.

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Table 13. Comparison of Reader B's 1993 and 1994 readings of 1993 otoliths.

		Reader B 1993 Readings					
	Age	2	3	4	5	N	
Reader B 1994 readings	2	42	4			46	
	3	3	192	4		199	
	4			12		12	Mean age = 2.88
	5			1		1	
	N	45	196	17		258	

Mean age = 2.89

95% agreement

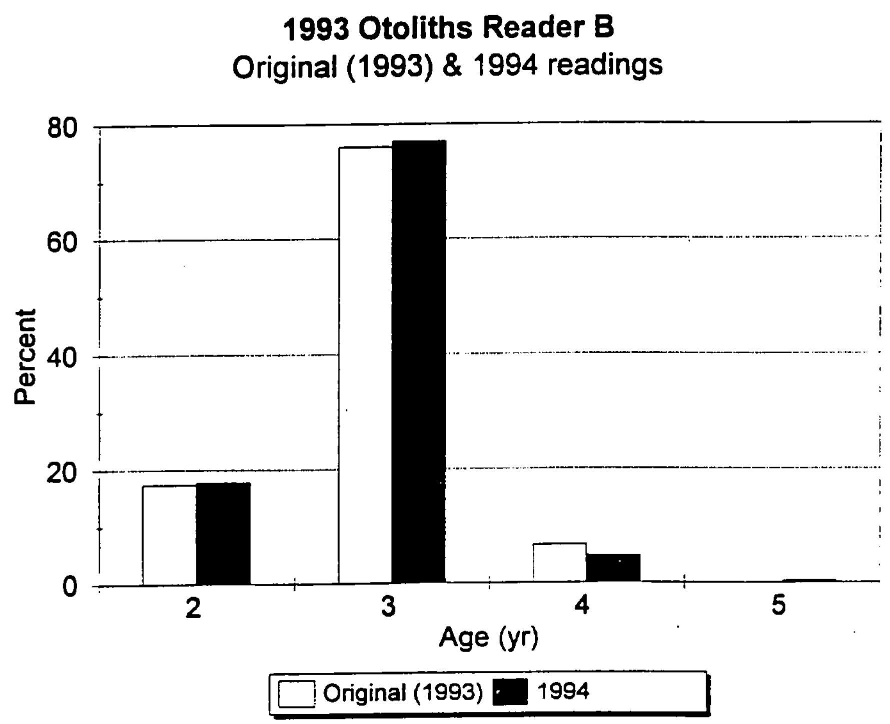

Fig. 11.

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Table 14. Comparison of Reader A and Reader B's 1994 readings of 1982 otoliths.

		Reader B							
	Age	1	2	3	4	5	6	7	N
Reader A	1	<u>1</u>							1
	2		<u>27</u>						27
	3		7	<u>109</u>	1				117
	4			55	<u>17</u>				72
	5			4	11	<u>10</u>	1		26
	6			1	2	14	<u>3</u>		20
	7				1		1		2
	N	1	34	169	32	24	5		

Mean age = 3.6 (Reader A)

Mean age = 3.22

63% agreement

1982 Otoliths
1994 Readings both Readers

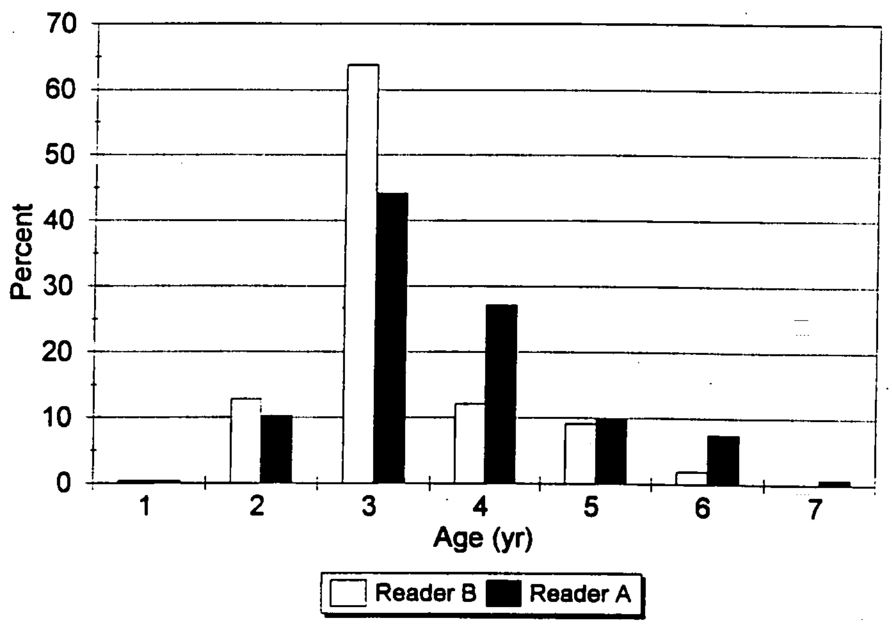

Fig. 12.

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Table 15. Comparison of Reader A and Reader B's 1994 readings of 1993 otoliths.

		Reader B						
	Age	2	3	4	5	6	N	
Reader A	2	32	8				40	
	3	14	105				119	
	4		81	7	1		89	Mean age = 3.27
	5		5	3	_		8	
	6			2			2	
	N	46	199	12	1		258	

Mean age = 2.88

59% agreement

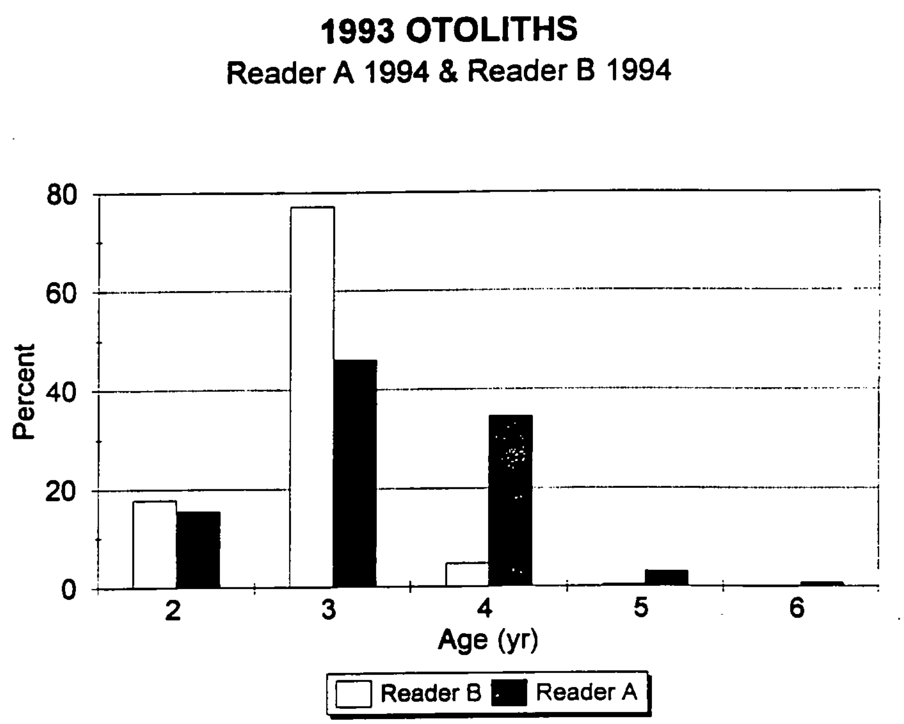

Fig. 13.

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Table 16. Summary of comparisons and results for Phases I and II of capelin otolith reading experiment.

Phase	Comparison	Description	N	% Agreement	Test of symmetry (χ^2)	Bias: Reader A	Bias: Reader B	Reference: Table	Reference: Figure
Phase I									
	Between Readers A&B	a) all samples	701	72	sig.	older	younger	3	1
		b) 1994 readings of 1967-68 otoliths	243	84	sig.	older	younger	4	2
		c) 1994 readings of 1987 otoliths	234	77	sig.	older	younger	5	3
		d) 1994 readings of 1992 otoliths	224	52	sig.	older	younger	6	4
	Within readers	e) Reader A - 1967-68 otoliths - original ages compared to 1994 ages	243	83	sig.	older in 1994	n/a	7	5
		f) Reader B - 1987 otoliths - original ages compared to 1994 ages	234	97	n/s	n/a	no bias	8	6
		g) Reader B - 1992 otoliths - original ages compared to 1994 ages	224	90	sig.	n/a	younger in 1994	9	7

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Table 16. Continued ...

Phase	Comparison	Description	N	% Agreement	Test of symmetry (χ^2)	Bias: Reader A	Bias: Reader B	Reference: Table	Reference: Figure
Phase II									
	Within readers A	a) Reader A - same otoliths as in Phase I, 5 months later	244	79	n/s	no bias	n/a	10	8
	B	Reader B - same otoliths as in Phase I, 5 months later	244	94	n/s	n/a	no bias	11	9
	B	b) Reader B - 1982 otoliths - original ages compared to 1994 ages	267	83	sig.	n/a	younger in 1994	12	10
	B	c) Reader B - 1993 otoliths - original compared to 1994 ages	258	95	n/s	n/a	no bias	13	11
	Between Readers A&B	d) 1994 readings of 1982 otoliths	265	63	sig.	older	younger	14	12
		e) 1994 readings of 1993 otoliths	258	59	sig.	older	younger	15	13

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Quantifying subjective capelin assessments using Bayesian inference

by

P.A. Shelton and J. Carscadden
Science Branch, Department of Fisheries and Oceans
P.O. Box 5667, St John's, Newfoundland
Canada A1C 5X1

INTRODUCTION

Stock assessment generally requires the current status of a fish stock to be inferred from available information. Various analytical assessment procedures have been developed to do this. Here "analytical procedures" are defined as all approaches which result in a numerical estimate of population size from a statistical sample of some quantity that is related to population size in a mathematically describable way. Desirable qualities of such procedures are that they be objective, rigorous, repeatable (give the same answer if applied a second time to exactly the same data) and explicit. Diagnostic tests may be included to judge the validity of an outcome. When there are insufficient data, data of poor quality, or a failure to pass the diagnostic tests, analytical procedures may be abandoned for subjective procedures. Here "subjective procedures" are defined as all approaches which result in a qualitative estimate of stock size from information which does not constitute a valid statistical sample of a quantity related to population size in a mathematically describable way. The subjectivity in such procedures replaces the mathematical description of the relationship between information and population size that is found in an analytical assessment. Unfortunately, such approaches typically lack rigour, are seldom explicitly described, and do not guarantee the same outcome if repeated on exactly the same data.

Many fish stock assessments in the Northwest Atlantic are pursued subjectively. A variety of information that may relate in some way to the status of a stock is reviewed by a working group and a conclusion is drawn regarding current stock status. There is no guarantee that such assessments are logical, rational and repeatable. One approach to provide rigour and repeatability to subjective approaches is to use Bayesian inference. In this paper this approach is described and then applied to quantify the assessment of three extant cohorts of the NAFO Div. 2J3KL capelin stock. Here "quantify" is defined as making explicit in mathematical terms the procedure used to arrive at an assessment of stock status.

DESCRIPTION OF THE APPROACH

It can easily be demonstrated that human reasoning may be flawed when it comes to drawing inferences from evidence, even in the simplest of cases (Plant and Stone 1991). Consider the case where the probability of having disease X is 1 in 10,000. A test is devised for detecting the disease. The test is not perfect so that 9 times out of 10 it correctly detects the disease when the disease is present, whereas 1 time out of 10 it indicates the person has the disease when in fact they do not (false positive). You take the test and the test is positive. What is the probability that you actually have the disease? Most people will incorrectly assign too high value to the probability that they have the disease, whereas the rational answer, under Bayes rule, is 0.0009.

Bayes rule is

$$P(H \mid E)=\frac{P(H)P(E \mid H)}{P(H)P(E \mid H)+P(\overline{H})P(E \mid \overline{H})} \tag{1}$$

where $P(H \mid E)$ is the posterior probability of the hypothesis (H) being true given the evidence (E). In this example the hypothesis is that you have disease X. The evidence is the positive test. P(H), the prior probability of the hypothesis is the probability that you have the disease before you take the test (1 in 10,000 = 0.0001). $P(E \mid H)$, the probability of the evidence given that the hypothesis is true is the probability of a positive test, given that you have disease X (9 times out of 10 = 0.9).

$P(\overline{H})$, the prior probability that the hypothesis is not true is the probability that you do not have the disease before you take the test (1 - P(H) = 0.9999). $P(E \mid \overline{H})$,the probability of the the evidence when the hypothesis is false is the probability of getting a positive test when you do not have disease X (1 time out of 10 = 0.1). Thus

$$P(H \mid E) = \frac{0.0001 \times 0.9}{0.0001 \times 0.9 + 0.9999 \times 0.1}$$

$$= 0.00089928$$

In other words, the positive test has changed the probability of having the disease from 1 in 10,000 before you took the test to about 1 in 1,000 after you took the test. Although in this example the probabilities provided for resolving the hypothesis using Bayes rule may have been empirically derived, the same rule can be applied to subjectively derived probabilities.

The inherent "strength" or "usefulness" of the evidence for resolving the hypothesis in the above application of Bayes rule is completely determined by the difference between the probability of a false positive ($P(E \mid \overline{H}) = 0.1$) and the probability of a true positive ($P(E \mid H) = 0.9$). In addition to the strength of the evidence, application of Bayes rule to assessment problems also requires uncertainty in the evidence to be accounted for. For example, the evidence from an acoustic survey may be that the strength of a cohort is strong, but how certain are we of that evidence? This certainty can be provided directly based on subjective judgment, or it can be derived by further application of Bayes rule (deepening of the inference web), in which the evidence is treated as an hypothesis to be resolved by the evaluation of subjective evidence relating to this hypothesis. In this initial application the certainty of the evidence (that the cohort is strong) must be supplied directly. Duda et al. (1976) provide the following solution for updating the probability of an hypothesis given uncertain evidence

$$P(H \mid E') = P(H \mid E)P(E \mid E') + P(H \mid \overline{E})P(\overline{E} \mid E') \qquad (2)$$

For most stock assessment problems it is likely that several independent pieces of evidence E_i relating to stock status will be available. In the disease example this would be equivalent to several independent tests for the same disease. Duda et al. (1976) provide a method for taking multiple sources of uncertain evidence into account, assuming that the different pieces of evidence are independent. Recall that under Bayes rule

$$P(H \mid E)=\frac{P(H)P(E \mid H)}{P(H)P(E \mid H)+P(\overline{H})P(E \mid \overline{H})}. \tag{3}$$

The complimentary form of (3) is

$$P(\overline{H} \mid E)=\frac{P(\overline{H})P(E \mid \overline{H})}{P(H)P(E \mid H)+P(\overline{H})P(E \mid \overline{H})}. \tag{4}$$

Dividing (3) by (4) gives

$$\frac{P(H \mid E)}{P(\overline{H} \mid E)}=\frac{P(H)P(E \mid H)}{P(\overline{H})P(E \mid \overline{H})}. \tag{5}$$

There are three terms in this equation:

(i) the prior odds

$$O(H)=\frac{P(H)}{P(\overline{H})}; \tag{6}$$

(ii) the posterior odds

$$O(H \mid E)=\frac{P(H \mid E)}{P(\overline{H} \mid E)}; \tag{7}$$

and (iii) the likelihood ratio

$$\lambda=\frac{P(E \mid H)}{P(E \mid \overline{H})}. \tag{8}$$

Note that

$$\lambda=\frac{O(H \mid E)}{O(H)}. \tag{9}$$

The equivalent form of (9) for the ith piece of <u>uncertain</u> evidence is

$$\lambda'_i = \frac{O(H \mid E'_i)}{O(H)} \quad (10)$$

$O(H \mid E'_i)$ is obtained from the updating equation (2). Multiple uncertain evidence is combined to obtain the posterior odds by multiplying the product of the likelihood ratios by the prior odds:

$$O(H \mid E'_i,\ldots,E'_n) = \left[\prod_{i=1}^{n} \lambda'_i\right] O(H) ,$$

from which

$$P(H \mid E'_i,\ldots,E_n) = \frac{O(H \mid E'_i,\ldots,E'_n)}{(O(H \mid E'_i,\ldots,E'_n) + 1)}$$ can be obtained, the probability of the hypothesis given multiple uncertain evidence.

APPLICATION TO THE DIV. 2J3KL CAPELIN STOCK ASSESSMENT

Assessments of the Div. 2J3K and Div. 3L substocks of capelin have in the past commonly been carried out by estimating population numbers at age in the current year from a hydroacoustic survey, and using these estimates to forecast next year's spawner biomass. The recommendation is typically a total allowable catch (TAC) that does not result in an exploitation rate that exceeds 10% of the projected spawner biomass. The performance of this procedure has been evaluated for the Div. 3L stock by Shelton et al. (1993) and found to be reasonably conservative despite all the uncertainties. High exploitation rates are thought to be potentially detrimental to cod stocks because capelin is a major forage species for cod. However, the small roe fishery on capelin is lucrative and it is undesirable to constrain this fishery below the market demand by imposing unnecessarily conservative TACs.

Mature capelin move to inshore areas in summer to spawn on beaches, during which time the trap and purse seine roe fishery is pursued. Supplementary information on stock status from inshore trap catch rates, inshore aerial surveys and spawning activity on beaches has not generally played an influential role in the assessment. However, in recent assessments the biomass of fish detected offshore by means of hydroacoustics has decreased substantially and application of the 10% exploitation rate would have severely limited fishing on capelin. In contrast, information on inshore catch rates, inshore aerial surveys and beach spawning activity do not appear to reflect the substantial decline observed in the hydroacoustic surveys (Anon. 1994a).

Faced with this dilemma the projection/10% exploitation rate procedure was not consistently applied to the Divs. 2J3K or Div. 3L capelin stocks in recent years. For example, with respect to the Div. 2J3K stock, in the 1991 assessment the acoustic estimate was judged invalid because of a very large decline from 1989 to 1990, the projection procedure was not carried out and the TAC recommendation was that the catch should not exceed that of the previous year (Anon 1991). The projection/10% exploitation rate procedure was carried out in 1993 but not in 1992. In both the 1992 and 1993 assessments the difference between the offshore acoustic survey and inshore information could not be reconciled, and it was recommended that the TAC be set to the lowest possible level (Anon 1992, 1993). In the 1994 assessment much more emphasis was given to the inshore information (Anon 1994a). It is of interest to note that the amount of disbelief in the acoustic estimate that could be tolerated before abandoning it was never quantified. In a further development, the substocks are now assessed as a single Div. 2J3KL stock.

As a consequence of discontinuing the projection procedure based on the offshore acoustic survey, inshore information has become influential in the assessment, as noted above, and scientists now struggle to resolve the multiple uncertain evidence regarding stock status from the inshore sources and from offshore sources. In addition to the acoustic survey, capelin bycatch and the partial fullness index of capelin (PFI) in cod stomachs in the fall groundfish survey provide two additional offshore indices.

In the most recent assessments the relative strengths of the different pieces of evidence have been evaluated largely on a qualitative basis and discussions have continued until a reasonable level of consensus has been reached regarding stock status. The recommendation regarding TAC (e.g. lowest possible catch, same catch as last year, average catch) based on the assessment is only qualitatively linked with recognised uncertainty in the conclusion regarding stock status. Such an approach is susceptible to irrational reasoning (i.e. inconsistent with the axioms of probability, see simple example given above). Further, there is no explicit trace of the procedure used to reach a conclusion regarding the status of the stock and should the assessment be repeated with exactly the same information there is no guarantee that the same conclusions will be drawn.

Application of the method of Duda et al. (1976) described above as a basis for providing scientific advice for 1995 was carried out by constructing a FRONT END spreadsheet to handle the required inputs and to present the results of the assessment, and an INFERENCE spreadsheet to handle the computations. The FRONT END constructed for the 1995 assessment is described below.

A SUBJECTIVE ASSESSMENT FOR 1995

In the FRONT END spreadsheet, (Table 1), the decision options, decision rules, prior feelings regarding cohort strengths and the information from each of the fall and summer indices are considered in turn. The FRONT END was constructed by a subgroup of the assessment participants. It is generally considered that the 1983 and 1986 cohorts were strong and that the 1981 and 1984 cohorts were weak. In order to determine the strength of an index, the past performance of the index with respect to correctly indicating that the 1983 and 1986 cohorts were strong and the 1981 and 1984 cohorts were weak was taken into account.

Decision options

The preliminary Management Plan for 1995 provides for the same TAC recommended to the Minister last year - 33,000 t. In keeping with the subjective nature of the assessment the "advice space" was discretized into 4 options: (i) Double the TAC (i.e. 66,000 t), (ii) Retain the MP TAC (i.e. 33,000 t), (iii) Halve the TAC (i.e. 15,000 t), or (iv) Set the TAC to zero. In order to decide on which option is appropriate, the anticipated status of the three cohorts likely to contribute to the fishery in 1995 are assessed - the 1991, 1992 and 1993 cohorts. The objective of the assessment is to infer for each cohort in turn the probability that it is strong from the available information. On the basis of this result a decision rule is triggered leading to one of the 4 advice options.

Decision rules

It was considered that 3 rules would be adequate. If it is quite certain (i.e. P=0.9) that either the 1991 or 1992 cohorts are strong, then the TAC could be doubled 66,000 t from the present MP level of 33,000 t. However, if there is a fairly substantial probability (P=0.7) that both cohorts are weak, then the TAC should be halved to 15,000 t. If it is more certain (P=0.9) that both cohorts are weak, then a zero TAC should be imposed. If none of the three rules are triggered, then the present MP TAC of 33,000 t is considered adequate and is retained.

A strong cohort is defined to be such that should a catch of double the TAC (66,000 t) come entirely from that cohort, the exploitation rate would not exceed the 10% level. The probability that the cohort is weak is given by

$$P(\text{weak}) = 1 - P(\text{strong}).$$

The strength of the 1993 cohort is not used in the TAC decision rules because it was considered that inferences regarding the strength of this cohort would be considered very preliminary and, because 2-year olds are a minor component of the fishery, the abundance of 2-year olds are not particularly relevant to the 1995 assessment. Nevertheless, an inference is drawn regarding the strength of the 1993 cohort because of the importance of this cohort to the 1996 assessment.

Prior probabilities regarding cohort strengths

The prior probability, before looking at the information contained in the indices, that the cohorts are strong were set equal at P=0.2. The reasoning behind this choice of prior probability was that strong year classes (as defined above) occur relatively infrequently - about 2 years in 10.

Indices of year-class strength

To aid in deciding on the strength of each index, Fig. 5 (Nakashima 1994) was used to evaluate whether strong or weak year-classes in the historical time-series were detected as such by the indices. Emphasis was on year-classes during the 1980s when there was some confidence in the relative strengths. The 1983 and 1986 year-classes were considered strong and 1981 and 1984 weak. Consideration was also given to general expectations for the index (eg. was it designed for capelin?) and length of the time-series (eg. short time-series might be given less weight since it was difficult to judge the usefulness of the series to discriminate between strong or weak year-classes). These indices are given alphabetical identifiers (e.g. Index F) which correspond to the identifiers used in the multiplicative analysis described in Chapter 15 of this report.

Index F - Groundfish RV trawl bycatch of 1-year-old capelin in 3L

- few data points for early years
- no evidence for strong year-classes
- weak year-classes were sampled but could not be compared to strong because strong year-classes were not sampled
- potentially an area where one-year-olds should occur in abundance
- based on frequency occurrence

Decision: no discriminating power to distinguish strong or weak year-classes, therefore the index is not used (setting all probabilities to 0.5 results in the index having no effect in the inference of year-class strength).

Index F - Groundfish RV trawl bycatch of 2-year-old capelin in 3L

- two strong year-classes appeared higher than others
- few data points but no strong evidence that a strong cohort is shown when it is actually weak

Decision: 0.7 probability that strong cohorts detected when they are strong
0.5 probability that weak cohorts are mistakenly registered as strong

Index in 1993 for 1991 cohort:

- nothing inherently wrong with survey
- index suggests an "average" cohort
- probability of 0.3 that cohort is strong

Index in 1994 for 1992 cohort

- only one sample from survey
- index appears very weak
- assigned probability of 0.5

Index F - Groundfish RV trawl bycatch of 3-year-old capelin in 3L

- detected strong 1986 year-class, other year-classes weaker

Decision: probability of detecting strong when strong is 0.6
probability of detecting weak when weak is 0.5

Index in 1994 for 1991 cohort
- no fish caught, evidence that cohort is strong is 0.

Index G - Groundfish RV trawl bycatch of 1-year-old capelin in 2J3K
- no detection ability for strong year-classes
- weak year-classes show as zeros
- some estimates of year-classes but sporadic

Decision: no certainty about ability to detect cohorts
- dropped from analysis

Index G - Groundfish RV trawl bycatch of 2-year-old capelin in 2J3K
- picked up 86 year-class in 1988, no samples for 1983 year-class
- weak 1961 year-class detected as weak
- no misleading information about strong year-classes
- many missing years

Decision: probability of detecting strong 0.6
probability of indicating strong when weak 0.5

Index in 1993 for 1991 cohort
- no known problems with survey, reasonable sample size
- the value appears valid and relatively strong
- assigned probability of 0.5

Index in 1994 for 1992 cohort

- good sample size, value indicates strong cohort
- assigned probability of 0.6

Index G - Groundfish RV trawl bycatch of 3-year-old capelin in 2J3K

- would expect these older fish in area
- no data for 83 or 86 year-classes
- 1984 appears weak

Decision: marginal information about this age group
probability of showing strong when strong .5
probability of showing strong when weak .4

Index in 1994 for 1991 cohort
- value is lowest in series
- probability of being strong 0.3

Index H - Canadian acoustic survey index in 3L

- data for only two years
- target strength values potentially inaccurate for these small fish
- would not be surprised to detect one-year-olds in this area

Decision: evidence too weak to accept index as reliable, mainly because of short data-series therefore not used in analysis for any age group

Index K - Canadian acoustic survey index for 1-year-olds in 2J3K

- did not detect strong year-classes
- indicated 1987 was strong
- one-year-olds in 3K some years, aerial coverage in this area variable early in survey

Decision: not a useful indicator, dropped from analysis

Index K - Canadian acoustic survey index for 2-year-olds in 2J3K

- picked up 83 and 86 year-classes as strong
- 81 and 84 year-classes were weak

Decision: reasonable expectations of picking up strong cohorts, probability is 0.7

not likely to assign strong year-class designation to a weak cohort, probability is .4

Index in 1993 for 1991 cohort

- no problem with survey, extensive coverage
- low value for cohort, low probability of strong cohort, probability is 0.2

Index in 1994 for 1992 cohort

- no problem with survey, extensive coverage
- low value for cohort, low probability of strong cohort, probability is 0.2

Index K - Canadian acoustic survey index for 3-year-olds in 2J3K

- 1986 year-class was strong but 1993 not
- 1981 year-class relatively weak and 1984 year-class weak
- 1982 and 1985 year-classes were found to be as strong as 1983 therefore some potential to be mislead

Decision: about equal probability of detecting strong year-classes when strong, probability is 0.5

- less probable to assign strong when weak, probability is 0.3

Index in 1994 for 1991 cohort

- no problem with survey, extensive coverage
- low value therefore low probability that cohort is strong, probability is

0.2

Index O - Campelen trawl for 1-year-olds

- occurs in area where one-year-olds expected
- short series, cannot evaluate
- similar gear and timing of 3L fall groundfish survey, although fewer sets therefore should not expect higher probability of detecting year-classes correctly

(Note: index based on numbers per tow rather than frequency occurrence as in other groundfish bycatch indices)

Decision: no predictive ability with existing data set (assigned same probabilities as 3L fall groundfish bycatch - 0.5 and 0.5 - and therefore index has no effect

Index O - Campelen trawl for 2-year-olds

- not enough data to evaluate index

Index O - Campelen trawl for 3-year-olds

- not enough data to evaluate index

Summer indices

Index A - aerial surveys of 1-year-old capelin in Trinity and Conception Bays

- not applicable for 1-year-olds

Index A - aerial surveys of 2-year-old capelin in Trinity and Conception Bays

- picked up good 83, 86 year-classes, poor 1984 year-class but assigned average strength to 81 year-class

Decision: reasonable probability of detecting strong year-classes, probability is 0.6

- some probability of saying weak year-class is strong, probability is 0.4

Index 1993 for 1991 cohort

- different source of age compositions compared to historical
- index shows above average
- probability that cohort is strong, probability is 0.4

Index in 1994 for 1992 cohort

- highest index on record
- different source of age compositions
- probability that cohort is strong is 0.6

Index A - aerial surveys of 3-year-old capelin in Trinity and Conception Bays

- 1986 year-class strong but 1983 year-class average
- weak 81 and 84 year-classes shown as weak
- some year-classes shown as strong as 83 therefore index may suggest strong when weak

Decision: probability is 0.6 that strong year-class will be detected
probability is 0.4 that weak year-class will be declared strong

Index in 1994 for 1991 cohort

- good survey in 1994
- very high value, even if assumed that aging might contribute, probability that cohort is strong is still high, probability is 0.7

Index R - the unadjusted egg deposition index for 2 and 3 year olds on selected beaches

- short time-series
- indirect measure of capelin abundance
- off-beach spawning may contribute substantial variability to unadjusted
- potential for off-beach spawning in 1994

Decision: no value to detect strong/weak cohorts in either time-series
without more validation

Index M - Purse seine catch rate for 2-year-olds
- intuitively given less value as indicator of stock status because of known problems with indices from mobile gear
- however, series generally agrees with traps
- detected 83 and 86 strong, 81 and 84 as weak
- no indication that weak year class would be called strong

Decision: potentially good indicator
probability is 0.7 of detecting strong year class
probability of 0.3 of misinterpreting weak year class

Index in 1993 for 1991 cohort
- appears to be average therefore probability is 0.6

Index in 1994 for 1992 cohort
- no fishery in 1994

Index M - Purse seine catch rate for 3-year-olds
-no fishery in 1994

Index T - Trap catch rate for 2-year-olds
- intuitively more reliable indicator of stock status than purse seine
- long series, picked up good and weak year-classes with no apparent misleading years

Decision: probability is 0.8 to detect strong year-classes
probability is 0.2 to be mislead regarding strong year-classes when actually weak

Index in 1993 for 1991 cohort

- very high index
- although aging differences may contribute to high value probability is 0.7 that cohort is strong

Index in 1994 for 1992 cohort

- no fishery in 1994.

Index T - Trap catch rate for 3-year-olds

- no fishery in 1994

Index C - Russian acoustic survey for 2-year-olds in 3L

- detected strong 83 and 86 year-classes
- 81 and 84 year-classes were weak

Decision: probability is 0.8 of detecting strong year-classes
probability is 0.4 of detecting strong cohort when actually weak

Index in 1993 for the 1991 cohort

- no evidence that the cohort is strong
- probability that the cohort is strong is 0.2

Index C - Russian acoustic survey for 3-year-olds

- no data available for 1994

Index L - Canadian acoustic survey for 1-year-olds in 3L

- no information on 1-year-olds

Index L - Canadian acoustic survey for fish age 2 and 3 3L

- no data after 1992, therefore, no information on year-classes of interest

Index N - Groundfish RV trawl bycatch of 2-year-olds in 3L

- 1983 and 1986 detected as strong, 1984 weak
- no indication of incorrectly providing evidence that year class is strong when it is in fact weak

Decision: probability is 0.7 of detecting strong year-classes
probability is 0.3 of misinterpreting weak year-classes

Index in 1993 for the 1991 cohort
- well below strongest but not weakest
- probability is 0.3 that cohort is strong

Index in 1994 for the 1992 cohort
- shows very high value
- small sample size
- some questions regarding % occurrence versus weight in tows
- probability is 0.6 that cohort is strong

Index N - Groundfish RV trawl bycatch of 3-year-olds in 3L
- 1983 year-class strong, no samples available to assess 1986 year-class
- 1984 year-class weak, no samples for 81 year-class
- no indication of misleading information

Decision: probability is 0.6 of detecting strong cohorts
probability is 0.4 of incorrectly concluding cohorts are strong when actually weak

Index in 1994 for 1991 cohort
- very low value, small sample size, low certainty that cohort is strong, probability is 0.2

OUTCOME

Based on the the FRONT END constructed as described above, the INFERENCE spreadsheet was used to calculate the posterior probabilities that the cohorts are strong given multiple sources of uncertain evidence. The outcome is that there is no updating of the prior probability for the 1993 cohort, given the evidence (i.e. the probability that the cohort is strong remains at 0.2 after taking into account the evidence). The probability that the 1992 cohort is strong is increased slightly from a prior probability of 0.2 to a posterior probability of 0.212. The information from the spring groundfish RV trawl bycatch (Index N) is influential in this increase. For the 1991 cohort, the posterior probability of it being a strong cohort is reduced from a prior probability of 0.2 to a posterior probability of 0.128 once the evidence is considered. The information from the fall Canadian acoustic survey is influential in this decrease (Index K). Based on these outcomes, and given the a priori decision rules, the FRONT END triggers the rule leading to the decision that the TAC should be halved from 33,000 t to 15,000 t. Note that this application was considered exploratory and included the input of only a subset of participants. The outcome was not considered further in the determination of stock status, which was based mainly on the results of the multiplicative analysis reported in Chapter 15.

DISCUSSION

The absence of adequate statistical samples may prevent a formal analytical approach to drawing inferences from evidence in some stock assessments. In such cases an approach based on subjective probabilities may be appropriate. However, human reasoning is not necessarily rational when combining probabilities. The method of Duda et al. (1976), described and applied above to the capelin assessment problem, provides a rational approach based on Bayes rule to the problem of drawing inferences from subjective probabilities. It differs from the more common use of Bayes rule in statistical inference in that not only are the priors based on subjective reasoning, so are the likelihoods. It shares the same objectives of composite models such as that of Methot (1989) in that it seeks to combine the information from several indices of stock abundance, but it differs in that the information is subjective. It also differs in that the aim is not to draw an inference regarding abundance in absolute terms. In the application to capelin, the status of the stock is discretized into two mutually exclusive hypotheses GOOD or BAD and the probability that the stock status is GOOD is inferred from the various sources of information. Traditional management rules such as F0.1 are not compatible with such an inference and examples of other rules are explored in the application.

Attempts have been made to incorporate subjectivity in other approaches. Varis et al. (1993) have applied belief functions (Pearl 1986) to the assessment of Baltic salmon. Belief functions allow the use of probability models that are less complete (require less information) than Bayesian models (Shafer 1987) but are less intuitive than Bayes rule. In the application to Baltic salmon subjectivity is used to combine regression and virtual population analysis models to estimate the parameters for the terminal population size, to produce forecasts and aid in determining the TAC. The melding of analytical approaches with subjective reasoning may have application to the capelin problem. For example, in the most recent assessment (Anon 1994a) regression analysis between catch rates of age y and age y+1 fish in the inshore fishery were carried out and results appear to have had a strong influence on the TAC recommendation in Anon (1994b). The Duda et al. (1976) approach would have to be modified if it were to incorporate both subjective reasoning and analytical results. Further, the present net could be "broadened" by adding additional pieces of evidence and "deepened" by considering j independent pieces of information relating to the uncertainty of the ith evidence (so that $P(E_i \mid E'_{i1}, E'_{i2}, \ldots E'_{ij})$ could be determined). However, the optimum complexity of an inference net for a particular stock assessment would have to be determined.

With regard to the application to the capelin assessment problem, not all the information requested by the procedure may seem intuitive to the user. Questions regarding the inherent strength and uncertainty of the evidence may be intuitive, but the questions aimed at determining the prior probability of the evidence may not seem easily separable from the reasoning relating to the strength and certainty of the evidence. What may be of particular interest in the present application was the degree to which the individual inputs to the inference procedure were scrutinised to evaluate their potential usefulness in making inferences about a particular cohort. The outcome in terms of an updated probability that the cohort is strong, is almost a trivial consequence of the decisions regarding the value of the inputs. In contrast, in an analytical procedure (multiplicative model) applied to the same information base at the same assessment meeting (see Chapter 15), most attention was given to interpreting the results.

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Table 1. Front end to the Bayesian decision support system. See text for explanations regarding contents. Note, xxx = data not available. Also, if all probabilities for a particular piece of evidence are set equal to 0.5 then that piece of evidence has no effect on the inference.

Front end to Bayesian decision support system	**Prob**
Decision rules	
How certain do you want to be that either the 1991 cohort or the 1992 is STRONG before doubling the TAC?	0.9
How certain do you want to be that both the 1991 and 1992 cohorts are WEAK before halving the TAC?	0.7
How certain do you want to be that both the 1991 and 1992 cohorts are WEAK before advising zero TAC?	0.9
Prior feelings regarding cohort strengths	
Before looking at any evidence considered below, what do you think the probability is that the 1991 cohort is strong?	0.2
Before looking at any evidence considered below, what do you think the probability is that the 1992 cohort is strong?	0.2
Before looking at any evidence considered below, what do you think the probability is that the 1993 cohort is strong?	0.2
FALL INDICES	
Fall index 1 for 1-year olds (F)	
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is STRONG?	0.5
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is WEAK?	0.5
Fall index 1 in 1992 for the 1991 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.5
Fall index 1 in 1993 for the 1992 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.5
Fall index 1 in 1994 for the 1993 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.5
Fall index 1 for 2-year olds (F)	
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is STRONG?	0.7
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is WEAK?	0.5
Fall index 1 in 1993 for the 1991 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.3
Fall index 1 in 1994 for the 1992 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.5
Fall index 1 for 3-year olds (F)	
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is STRONG?	0.6
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is WEAK?	0.5
Fall index 1 in 1994 for the 1991 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0
Fall index 2 for 1-year olds (G)	
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is STRONG?	0.5
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is WEAK?	0.5
Fall index 2 in 1992 for the 1991 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.5
Fall index 2 in 1993 for the 1992 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.5
Fall index 2 in 1994 for the 1993 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.5
Fall index 2 for 2-year olds (G)	
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is STRONG?	0.6
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is WEAK?	0.5
Fall index 2 in 1993 for the 1991 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.5
Fall index 2 in 1994 for the 1992 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.6
Fall index 2 for 3-year olds (G)	
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is STRONG?	0.5
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is WEAK?	0.4
Fall index 2 in 1994 for the 1991 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.3
Fall index 3 for 1-year olds (H)	
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is STRONG?	0.5
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is WEAK?	0.5
Fall index 3 in 1992 for the 1991 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.5
Fall index 3 in 1993 for the 1992 cohort	

What is the certainty that the evidence is that the cohort is STRONG?	0.5
Fall index 3 in 1994 for the 1993 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.5
Fall index 3 for 2-year olds (H)	
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is STRONG?	0.5
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is WEAK?	0.5
Fall index 3 in 1993 for the 1991 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.5
Fall index 3 in 1994 for the 1992 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.5
Fall index 3 for 3-year olds (H)	
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is STRONG?	0.5
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is WEAK?	0.5
Fall index 3 in 1994 for the 1991 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.5
Fall index 4 for 1-year olds (K)	
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is STRONG?	0.5
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is WEAK?	0.5
Fall index 4 in 1992 for the 1991 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.5
Fall index 4 in 1993 for the 1992 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.5
Fall index 4 in 1994 for the 1993 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.5
Fall index 4 for 2-year olds (K)	
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is STRONG?	0.7
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is WEAK?	0.4
Fall index 4 in 1993 for the 1991 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.2
Fall index 4 in 1994 for the 1992 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.2
Fall index 4 for 3-year olds (K)	
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is STRONG?	0.5
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is WEAK?	0.3
Fall index 4 in 1994 for the 1991 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.2
Fall index 5 for 1-year olds (O)	
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is STRONG?	0.5
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is WEAK?	0.5
Fall index 5 in 1992 for the 1991 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.5
Fall index 5 in 1993 for the 1992 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.5
Fall index 5 in 1994 for the 1993 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.5
Fall index 5 for 2-year olds (0)	
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is STRONG?	0.5
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is WEAK?	0.5
Fall index 5 in 1993 for the 1991 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.5
Fall index 5 in 1994 for the 1992 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.5
Fall index 5 for 3-year olds (0)	
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is STRONG?	0.5
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is WEAK?	0.5
Fall index 5 in 1994 for the 1991 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.5

Table 1. Continued ...

SUMMER INDICES	
Summer index 1 for 2-year olds (A)	
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is STRONG?	0.6
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is WEAK?	0.4
Summer index 1 in 1993 for the 1991 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.4
Summer index 1 in 1994 for the 1992 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.6
Summer index 1 for 3-year olds (A)	
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is STRONG?	0.6
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is WEAK?	0.4
Summer index 1 in 1994 for the 1991 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.7
Summer index 2 for 2-year olds (R)	
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is STRONG?	0.5
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is WEAK?	0.5
Summer index 2 in 1993 for the 1991 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.5
Summer index 2 in 1994 for the 1992 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.5
Summer index 2 for 3-year olds (R)	
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is STRONG?	0.5
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is WEAK?	0.5
Summer index 2 in 1994 for the 1991 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.5
Summer index 3 for for 2-year olds (M)	
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is STRONG?	0.7
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is WEAK?	0.3
Summer index 3 in 1993 for the 1991 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.6
Summer index 3 in 1994 for the 1992 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	xxx
Summer index 3 for 3-year olds (M)	
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is STRONG?	0.5
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is WEAK?	0.5
Summer index 3 in 1994 for the 1991 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.5
Summer index 4 for for 2-year olds (T)	
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is STRONG?	0.8
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is WEAK?	0.2
Summer index 4 in 1993 for the 1991 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.7
Summer index 4 in 1994 for the 1992 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	xxx
Summer index 4 for 3-year olds (T)	
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is STRONG?	0.5
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is WEAK?	0.5
Summer index 4 in 1994 for the 1991 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.5
Summer index 5 for for 2-year olds (C)	
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is STRONG?	0.8
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is WEAK?	0.4
Summer index 5 in 1993 for the 1991 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.2
Summer index 5 in 1994 for the 1992 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	xxx
Summer index 5 for 3-year olds (C)	
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is STRONG?	0.5

If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is WEAK?	0.5
Summer index 5 in 1994 for the 1991 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.5
Summer index 6 for for 2-year olds (L)	
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is STRONG?	0.5
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is WEAK?	0.5
Summer index 6 in 1993 for the 1991 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.5
Summer index 6 in 1994 for the 1992 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.5
Summer index 6 for 3-year olds (L)	
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is STRONG?	0.5
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is WEAK?	0.5
Summer index 6 in 1994 for the 1991 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.5
Summer index 7 for for 2-year olds (N)	
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is STRONG?	0.7
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is WEAK?	0.3
Summer index 7 in 1993 for the 1991 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.3
Summer index 7 in 1994 for the 1992 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.6
Summer index 7 for 3-year olds (N)	
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is STRONG?	0.6
If there were no uncertainty in the evidence, what is the prob of it indicating a STRONG cohort when the cohort is WEAK?	0.4
Summer index 7 in 1994 for the 1991 cohort	
What is the certainty that the evidence is that the cohort is STRONG?	0.2
Posterior probabilities that a cohort is strong	
Given all the observations on the indices, the probability that the 1991 cohort is STRONG is:	0.128
Given all the observations on the indices, the probability that the 1992 cohort is STRONG is:	0.212
Given all the observations on the indices, the probability that the 1993 cohort is STRONG is:	0.200
TAC decision:	
Double the TAC?	FALSE
Halve the TAC?	TRUE
Set TAC to Zero?	FALSE
Retain the MP TAC?	FALSE

A Multiplicative Approach to Capelin Abundance Indices

by

G. H. Winters
Science Branch
Department of Fisheries and Oceans
P. O. Box 5667
St. John's, NF A1C 5X1

Introduction

Shepherd and Nicholson (1991) and Sinclair and Chouinard (1991) describe the use of multiplicative models for analyzing fish catch-at-age from research vessel abundance indices. Multiplicative models also provide an objective method by which annual abundance indices from a variety of sampling techniques can be statistically integrated into a standardized time series. Gaps in the individual indices can be accounted for, providing there is sufficient overlap in the data for intercalibration of the different indices.

There are a variety of potential abundance indices of capelin in NAFO 2J3KL (Table 1). These indices represent a wide range of sampling techniques and cover a period (1970's to the period) during which the environment and ecosystem in 2J3K have undergone extensive changes. In this paper we will describe the application of a simple multiplicative model to these indices as a first attempt at reconstructing an objective index of capelin abundance during the past 20 years.

Methods and Materials

a. Abundance Indices of Capelin Abundance

There are a variety of indices and potential indicators of capelin stock status (Table 1) whose verification and validation remain an ongoing process as it does for most wild populations in which controlled experiments are not feasible. In the past assessments, the 3L acoustic survey, trap catch rates and the aerial survey estimates have come closest to general acceptance because of their correlated nature. Since the indices represent a wide variety of sampling techniques, it is instructive to provide a brief description of each index.

1) 3L Spring Acoustic Survey

This began in 1982 and terminated in 1992 in favour of a combined 2J3KL fall survey. The survey has been conducted in May month with the exception of 1982-84 when the survey was done in April. In theory, this survey should be ideally suited to capelin abundance mensuration; 3L is relatively shallow, all age-groups are present (certainly in normal years) and in a relatively small area thus providing high-density acoustic probabilities. The area surveyed generally covers the area to the west of 49°30′ longitude and to the south of 49° latitude. Excluded from survey coverage are the coastal bays, the extreme northern portion of 3L and the nose of the Grand Banks. In severe years a portion of the 3L capelin biomass may be occluded by ice cover or it may be distributed elsewhere outside the survey area (Carscadden 1994). Shackell et al. (1993) considered that the 3L survey data were representative of stock abundance up to 1991 when the acoustic biomass was very low and the proportion of mature fish changed dramatically from previous years. Subsequent analyses by Shackell et al. (1994) associated this distribution change with interannual changes in water temperature.

2) Trap Catch Rates

Capelin traps passively intercept adult capelin as they migrate into shallow water (15-30 m) for spawning. For the capelin fishery, a voluntary research logbook system was instituted in 1981 covering approximately 100-200 fishers located in each of the bays along eastern Newfoundland (Nakashima 1994). The research logbook data have been reanalyzed by Winters (1994) in terms of the most appropriate expression of density and spawning biomass proxy. Mean seasonal fish density was estimated as catch per trap haul. Such a seasonal density estimate is of limited value if the duration of the spawning runs varies from year to year, as indeed they do. In order to take this into account, Winters (1994) integrated daily densities across the spawning season and concluded, based on comparisons with other indices that the integrated trap index was a better measure of spawning biomass than the mean density index alone.

Since traps are a passive gear, density-dependent changes in the area occupied by the stock (i.e. catchability changes) is unlikely to affect catch rates, if such catch rates are monitored throughout the historical distribution area. For most years nearly all of the coastal bays are sampled and there is good coherence in both catch rates and age compositions for Div. 3L and 3K (Nakashima 1994, Winters 1994). Potential biases could be introduced by inconsistent reporting of catch or effort levels, annual changes in shallow water migration patterns and saturation effects in years (areas) of high abundance.

3) Aerial Surveys of Spawning Runs

This index began in 1982 using aerial photography capable of detecting fish schools at maximum depths of 25-30 m. Since 1990 schools have been measured from digital data collected by the Compact Airborne Spectrographic Imager (CASI) (Nakashima 1994). The depth restraints of CASI are the same as for aerial photography but greater flexibility is obtained from the ability to survey on overcast days. In each year standard transects are flown in Conception Bay and Trinity Bay. For each transect flown, the mean surface area of capelin schools, the total number of schools, and the total surface area of all schools are estimated.

The traditional method for interpretation of this index was to sum the highest total school surface area observed on each of the three major transects (Nakashima 1994).

This index assumes that interannual changes in the aerial index of spawning schools in Conception Bay-Trinity Bay adequately represents trends in Div. 3K (high coherence of trap catch rates in 3K and 3L indicates that this is not an unreasonable assumption for most years). Biases could be introduced since only school area and not school density are measured. Also since the survey is generally timed to measure abundance only during the initial part of the spawning runs, years in which spawning runs are late (eg. 1991) sometimes receive often receive less sampling coverage than normal years.

4) Groundfish Bycatch Rates

Bycatch statistics of capelin in bottom trawl surveys in 2J3K (fall), 3L (fall) and 3L (spring) are available from Lilly (1994). Bycatch levels are available as either percentage of sets containing capelin (i.e. probability of capture) or as actual catch/set. Catch-per-set, however, can be heavily influenced by single large catches so that in many years single stratum may contain a high proportion (60-70%) of the total catch. Winters (1994) chose the bycatch success rate as a more appropriate indicator of general abundance trends. This was based on the observation that for most pelagic species (see Winters and Wheeler 1985 and references therein) the habitat (range) occupied is a direct function of stock biomass levels. A similar phenomenon has been documented for groundfish species as well (see Rose and Leggett 1991 and references therein).

Bycatch success rates measures only presence or absence and therefore are a coarse index of overall abundance changes. They should be, however, suitable for pelagic species whose populations are more dynamic. From a theoretical viewpoint, the relationship between bycatch success and capelin biomass levels is likely to be asymptotic. That is, as habitats become increasingly occupied, local increases in density will not be linearly reflected in by-catch success rates (small and large by-catches are treated equivalently). For these analyses the bycatch index is provided for 2J3K (mainly maturing fish), 3L (fall) (mainly immature fish), and 3L (spring) (a mixture of both).

5) PFI Index (Partial Fullness Index)

Lilly and Davis (1993) provide data on capelin PFI levels for cod sampled in 2J3K and 3L (fall). Analyses of PFI data are restricted to the size range of cod (36-71 cm) which prey most frequently on capelin. Fahrig et al. (1993) compared PFI values with localized acoustic estimates of capelin in the 3L acoustic survey and concluded that cod stomachs can be viewed as a sampling tool of capelin abundance. In addition, they showed that PFI levels of capelin were statistically independent of cod abundance as measured by trawl catches.

6) 2J3K Acoustic Survey

The Canadian survey usually takes place in October and is designed to provide a measure of the abundance of mature fish which will spawn inshore the following summer. These surveys began in 1977 with the Dowd System (Dowd 1974) which was replaced in the early 1980's by a customized HYDAS system built in-house. The area covered has gradually increased with time to include extensions to the east and south. Excluded from the survey area are the coastal bays, extreme northern portion of 2J and the deeper areas to the east of 52° longitude in 2J and 51° longitude in 3K. This survey has had little success in predicting inshore abundance, as measured by the various inshore indices (traps, purse seiners, and aerial surveys). Winters (1995) has analyzed interannual variations in capelin biomass estimated by the Canadian 2J3KL survey since 1981 and concluded that the acoustic estimates were largely driven by periodic shifts in capelin abundance from Div. 2J to the deeper waters to the south and east in Div. 3K.

The USSR acoustic surveys in 2J3K started in the early 1970's and ended in 1992. These surveys cover approximately the same longitudinal areas as Canada but do not extend as far west (towards the coast) or east as the Canadian survey. The area covered is therefore somewhat smaller and the methodology has changed over the years from the photogrammetric method to conventional acoustic systems. This survey usually occurs in mid November.

7) Purse Seine Catch Rates

Catch and effort statistics of the purse seine fleet are captured from the same research logbook program as capelin traps (Nakashima 1994). Fishing days for purse seines are defined as those days when the vessel was out searching for capelin. CPUE data are expressed as catch/day and catch/set. These indices shown similar trends and each is consistent with the trends exhibited by the trap and aerial indices. Purse seine CPUE's however have considerable potential for bias because of the fishing behaviour associated with purse seine in conjunction with the interaction between stock range and the catchability component (Winters and Wheeler 1985).

8) USSR Catch Rates

Catch rates are available from the USSR commercial fleet (>200° t GRT) for both 3L (1972-78) and 3K (1973-91). These are available from the FCR Observer Program since 1980 and are available from Soviet sources for years prior to then. Catch rates are expressed as tons per hour trawled.

b. Model Formulation

(i) Year Effect

In this case abundance is expressed as a multiplicative function of year and survey effects as follows:

$$C_{tj} = \mu \; A_t \; \bar{B}_j \; \epsilon$$

when C_{tj} = abundance of survey j in year t

μ = mean abundance over all years

A_t = year effect

B_j = survey effect

ϵ = random normal error

The additive model becomes (by log transformation)

$$\ln C_{tj} = \log \mu + \log A_t + \log B_j + \epsilon$$

Statistical analyses was performed using the general liner models procedure (PROC GLM) of SAS (Anon. 1985).

Interaction terms have not been included but crossover effects will instead be shown by plotting the various permutations of the available indices. These permutations follow from natural associations of the sampling data relating to methodology, population structure sampled and/or geographical area/season. They are as follows (Run #).

Run #	Category
1.	All indices (see Table 1).
2.	All indices excluding 2J3K acoustics.
3.	Inshore indices only (trap, aerial, purse seines = mature adults)
4.	Offshore indices only (bycatch, CPUE, PFI, 3L acoustics = all age groups
5.	Offshore, excluding acoustics (CPUE, bycatch, PFI) = all age groups
6.	Acoustics only (USSR + Canada) = all age groups
7.	Bycatch only (2J3K, 3L fall, 3L spring) = all age groups
8.	PFI only (2J3K, 3L fall) = all age groups
9.	Immature indices (3L acoustics, 3L bycatch (spring), 3L bycatch (fall), 3L PFI (fall)
10.	Mature index (inshore indices, 2J3K bycatch, 2J3K PFI and CPUE)
11.	Offshore mature index (2J3K PFI, 2J3K bycatch, CPUE)
12.	All indices excluding acoustics

Unless specifically stated, the following data were excluded (a) 3L acoustics 1991-92 (see Shackell et al. 1994) excluded from all runs except run #6; (b) USSR 3L acoustics for 1983, 1986 (June surveys); (c) 2J3K acoustics excluded from all runs except run #1 and run #6); (d) the integrated aerial and BSN trap indices have been excluded in favour of the integrated trap index and conventional aerial (BSN aerial).

(ii) Cohort Effect

In this model catch-at-age is expressed as a multiplicative function of yearclass size (Cohort) and survey-specific survival at age (Myers et al. 1993). Let the number of fish of age i in year t estimated by survey j be R_{tij}. If the catchability of survey j at age i = q_j and the survival of fish of age i = P_i then

$$R_{tij} = q_j * P_i * cohort_{t-i} * \epsilon_{tij}$$

where

ϵ_{tij} = error term with constant variance. The additive model is described as follows:

$$\text{Log } R_{tij} = \log q_j + \log P_i + \log \text{Cohort}_{t-i} + \epsilon_{tij}$$

From the data available it is not possible to estimate q_j and P_i separately and therefore only the sum of these two parameters are estimated for each survey and age. Since the same gear is used for each survey, it is assumed that age-specific annual changes in the product of these two variables reflects survival changes.

The multiplicative model for extracting the yearclass effect is more attractive than the year effect model because yearclasses are integrated across years and surveys and hence have more information content than annual abundance indices.

For these analyses we have chosen the following selected indices. They are (a) integrated trap catch-at-age (Winters 1994), (b) aerial survey index decomposed by the 3L commercial age compositions (NCSP ages are used for 1991-94), (c) the purse seine index (Nakashima 1994), (d) the 2J3K fall bycatch index, (e) the 3L fall by-catch index, (f) the 2J3KL USSR FCR catch rate series (1980-91) and (g) 3L acoustics (USSR and Canada and 2J3KL acoustic (USRR and Canada).

The multiplicative model has been applied to the following groups:

1) inshore only
2) offshore only (non-acoustic)
3) acoustic only

Results

All main effects were significant for all combinations of the various indices and the models explained a high proportion of the total variance.

Figure 1 illustrates the impact of including the Canadian 2J3K acoustic estimates into the multiplicative model. Divergence occurs after 1990, consistent with analyses by Winters (1995) that the recent 2J3K acoustic estimates are responding mainly to annual distribution changes rather than to annual changes in abundance.

Figure 2a (upper panel) shows the least squares means estimates of the immature index versus the mature index. The two series are significantly correlated when lagged one year (Fig. 2b, lower panel).

Figure 3a (upper panel) shows a similar time series of least squares means for inshore, bycatch and PFI methods. The increase in the bycatch index is clearly less than that by either the inshore or the PFI offshore index, reflecting perhaps the limitation on upper bycatch rates (presence or absence) because a certain proportion of the available habitat will always be unsuitable. Nevertheless both the PFI and bycatch indices are significantly correlated with the inshore index (Fig. 3, middle and lower panels, unlagged).

Figure 4 (upper panel) shows a comparison of the offshore immature index and the inshore (i.e. mature) index. The trends in the two time series are very similar and the statistical fit is highly significant (Fig. 4 (lower panel), lagged one year).

Figure 5 (lower panel) shows a similar comparison of the offshore mature index with the inshore index (mature fish). Again, the trends are very similar and the relationship is statistically significant (Fig. 5 (lower panel), lagged one year).

Figure 6 (upper panel) shows the offshore index (maturing and immatures) including 3L acoustics compared with the inshore index (mature fish). The two time series show the same overall trend and the relationship is statistically significant (Fig. 6 (lower panel), lagged one year).

Figure 7 (upper panel) shows the offshore index excluding acoustics in relation to the inshore index. The relationship is highly significant (Fig. 7, lower panel) but indicates (in comparison with Fig. 6, lower panel) that the addition of the acoustic data (3L Canada, 3L USSR) does not improve the relationship.

Finally, in Figure 8 the multiplicative indices containing no acoustic data (inshore, offshore) are plotted against the multiplicative least squares means estimates of all acoustic data. This plot shows the incompatible and divergent nature of the acoustic index versus the other offshore and inshore indices since 1990. The combination of these indices into a multiplicative composite is clearly inappropriate since 1990.

The above analyses can be summarized as follows: the offshore annual indices excluding acoustics continue to be a good predictor of inshore annual abundance during the spawning season, whether the prediction is lagged one year (in the case of the offshore mature index) or two years (in the case of the immature index). The acoustic index has been a good predictor of inshore abundance (both current year and projected one year) up to 1990 but has been inconsistent with the inshore indices since then.

Results of the cohort multiplicative model runs for the inshore indices, offshore indices, and acoustic indices are shown in Figures 9 and 10 respectively. Year-class strengths estimated from the non-acoustic offshore indices (Fig. 9, top panel) show good coherence with the year-class strengths estimated from the inshore indices (Fig. 20, lower panel). Differences are however evident for the most recent year-classes (1990, 1991, and 1992) with the inshore data indicating that these are the strongest on record. In the offshore areas the 1990 and 1992 year-classes are also above average whereas the 1991 year-class is about average. The 1992 year-class from the inshore index is considerably stronger than all other year-classes but it relies heavily on a single estimate from the 1994 aerial survey.

Year-class strength estimated from the acoustic surveys (Fig. 10) are in good agreement with the inshore indices up to the 1987 year-class but diverge in the most recent year-classes to the weakest on record. This discrepancy is likely associated with distributional changes observed in the recent cold period both in 3L (Carscadden 1994, Shackle et al. 1994) and 2J3K (Winters 1995, Lilly and Davis 1994).

The log ratios of the offshore to inshore cohort estimates provide an index of year-class survival from the late fall period (as measured in the offshore indices) to the beginning of beach-spawning (as measured by the inshore indices). This pre-spawning survival index is plotted in Figure 11 (top panel) along with an arbitrary cod predation index (sum of minimum trawlable cod biomass for each year-class at ages 2 to 4). The relationship is statistically significant (Fig. 11, lower panel) and could indicate that recent reductions in cod abundance have had differential effects on the survival of capelin in inshore versus offshore areas, i.e. the relatively higher year-class strength from inshore indices in recent years may reflect increased survival relative to the fall offshore where cod predation rates on capelin are likely much lower than during the inshore spawning migrations. Alternatively, the offshore/inshore difference may reflect the fact that bycatch success (presence or absence) in the groundfish bottom-trawl survey likely underestimate local densities when habitats become increasingly occupied. Likewise, systematic underaging of older age-groups in the inshore indices could also account for some of the observed differences.

The combined (offshore plus inshore) multiplicative estimates of standardized year-class strength are shown (±2 SE) in Figure 12. The composite index shows that the year-classes contributing to the 1995 inshore fishery (1990, 1991, 1992) are all above average. This multiplicative model was rerun to include the USSR 2J3K acoustic estimates (billions of fish at age) in order to provide a calibration framework for an analytical projection of absolute abundance levels to 1995 (Table 2a). The USSR 2J3K acoustic survey provides conservative estimates of year-class strength relative to the Canadian and USSR spring acoustic survey in 3L. Table 2b provides a similar projection to illustrate the influences of excluding the estimate of the 1992 year-class (at age 2) in the 1994 aerial survey from the multiplicative model. Table 2c is the same as Table 2b except that the more conservative survival estimates of Shackell et al. (1994) are used as a basis for projection.

In summary, the multiplicative cohort model can provide an objective analytical framework for estimating standardized year-class strengths from a wide variety of abundance estimates. It provides for estimates of statistical uncertainty, for gaps in the sampling data and new indices can be added as they become available. Model output is easily replicated from one year to the next and projections can be made either on a relative or absolute basis from the age-specific estimates of survival routinely estimated as part of the model formulation.

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Table 1. Tabular summary of capelin abundance indices. Note that all fall indices have been advanced to the next year for direct comparison with spring-summer indices.

Year	2J3K byc. (%)	3L fall byc. (%)	3L spr. byc. (%)	Integ. trap	3L acous (Can.)	2J3K fall PFI	3L fall PFI	3L USSR CPUE	2J3K USSR CPUE	3L acous USSR	Purse seine CPUE	BSN aerial	Can. 2J3K acous
1973								2.27					
1974								3.42	2.81				
1975								3.40	3.29				
1976								3.88	4.56				
1977								3.68	6.47				
1978			8					3.31	5.27	230			
1979	1		30						4.14	483			
1980	35		17						2.29	-			
1981	18		35	75		0.11			1.34	530	5.0		
1982	26	14	43	70	455	0.77	0.16		4.57	610	8.4		1494
1983	34	29	-	64	84	0.26	0.15		3.68	(346)*	9.5	220	-
1984	25	31	-	60	353	0.38	0.21		3.19	2280	7.4	348	94
1985	26	-	43	89	3426	0.63	-		5.31	2200	9.3	173	826
1986	44	34	80	148	3697	0.91	0.64		4.24	(1492)*	11.5	308	1035
1987	26	27	28	155	2576	1.19	0.60		6.97	2161	11.1	260	431
1988	35	27	70	121	4551	1.00	0.56		6.05	3951	10.3	716	112
1989	37	46	75	148	3829	1.69	0.56		7.70	2458	10.6	402	1804
1990	49	40	64	167	6958	1.79	0.70		5.97	3752	11.8	538	1794
1991	35	21	48	153	116	1.95	1.12		6.12		11.7	358	96
1992	43	23	52	132	217	0.72	1.15		1.27		13.5	548	55
1993	53	52	46	146	-	1.50	1.26				9.4	335	34
1994	47	53	48	-	-	1.03	1.29					675	18
1995	47	39	-	-	-								10

* June survey

Table 2. Multiplicative year-class estimates, standardized to the Div. 2J3K Russian acoustic survey and projected to 1995. (A) Using Russian 2J3K SAGE (survival) estimates (age 2-3 = 0.79, Age 3-4 = 0.30, Age 4-5 = (0.30); (B) Second multiplicative run using same survival estimates, W_1 and % mature as in Table 1; (C) Capelin projection using estimates of survival and proportions mature from Shackell et al., mean weights-at-age as in Table 1, population sizes at age 2 from Table 2.

A.

Age	W_1	% Mature[2]	Population size (bill.) in years				1995 Projected mature population	1995 mature Biomass (mill. tons)
			1992	1993	1994	1995		
2	.15	.05	160	128	245	(128)*	6	.09
3	.22	.47		126	101	193	91	2.0
4	.27	.87			38	31	27	.73
5	.31	.93				11	10	.31

Mature Biomass 3.13
95% Confidence limits (1.35-8.03)

1 - 1991-93 3KL mean
2 - conventional parameter values
* - assumed equal to 1991 year-class

B.

Age	W_1	% Mature	Population size (bill.) in years				1995 Projected mature population	1995 mature Biomass (mill. tons)
			1992	1993	1994	1995		
2	.15	.05	162	119	126	(128)	6	.1
3	.22	.47		128	94	100	47	1.0
4	.27	.87			38	28	24	0.7
5	.31	.93				12	11	0.3

Mature biomass 2.1
95% Confidence limits (0.8-6.0)

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Table 2. Continued ...

C.

Age	W_1	% Mature	Population size (bill.) in years 1992	1993	1994	1995	1995 Projected mature population	1995 mature Biomass (mill. tons)
2	.15	.028	162	119	126	(128)	4	.1
3	.22	.585		64	47	50	29	.6
4	.27	.955			13	9	9	.2
5	.31	.969				2	2	.1
								Mature biomass 1.0
								95% Confidence limits (0.3-3.1)

Survival estimates

	2	3	4	5
Immature	0.40	.28	.28	.28
Mature	0.14	.14	.15	.09
Mature				

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From Shackell, N. L., P. A. Shelton, J. M. Hoenig, and J. E. Carscadden. 1994. Age- and sex-specific survival of northern Grand Bank capelin (Mallotus villosus). Can. J. Fish. Aquat. Sci. 51: 642-649.

Proportions Mature

These were provided by sex. For use in projection, unweighted averages were used.

	Age			
	2	3	4	5
Male	1.2	42.7	94.5	99.3
Female	4.4	74.2	96.4	94.4
Combined	2.8	57.5	95.5	96.9

Survival Estimate

Survival estimates were calculated by Shackell et al. by age, sex and maturity. Sexes were combined, unweighted. For some ages and sexes, one point in the data series was influential in the calculation, so two values were given, with and without the influential data point. When the influential data points were dropped, standard errors were smaller and the amount of variance explained increased (p. 646, Shackell et al.). Since the fit was better in these cases, the data without the influential data points were used in the projections. Values in parentheses include all values. Underlined values were not available but were set the same as adjacent values.

	Age			
	2	3	4	5
Immature	0.40	0.28 (0.24)	0.28	0.28
Mature	0.14	0.14 (0.31)	0.15 (0.28)	0.09

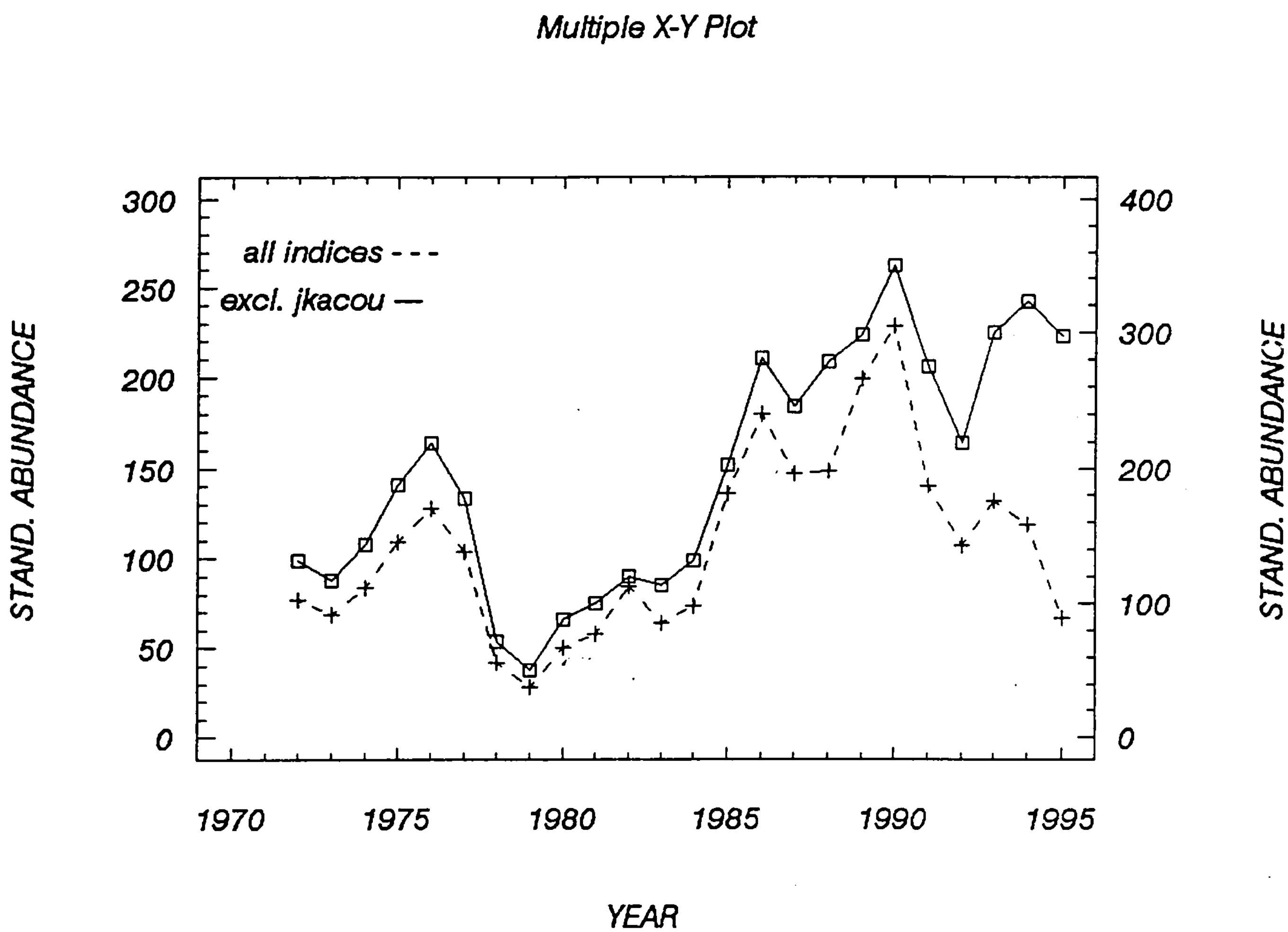
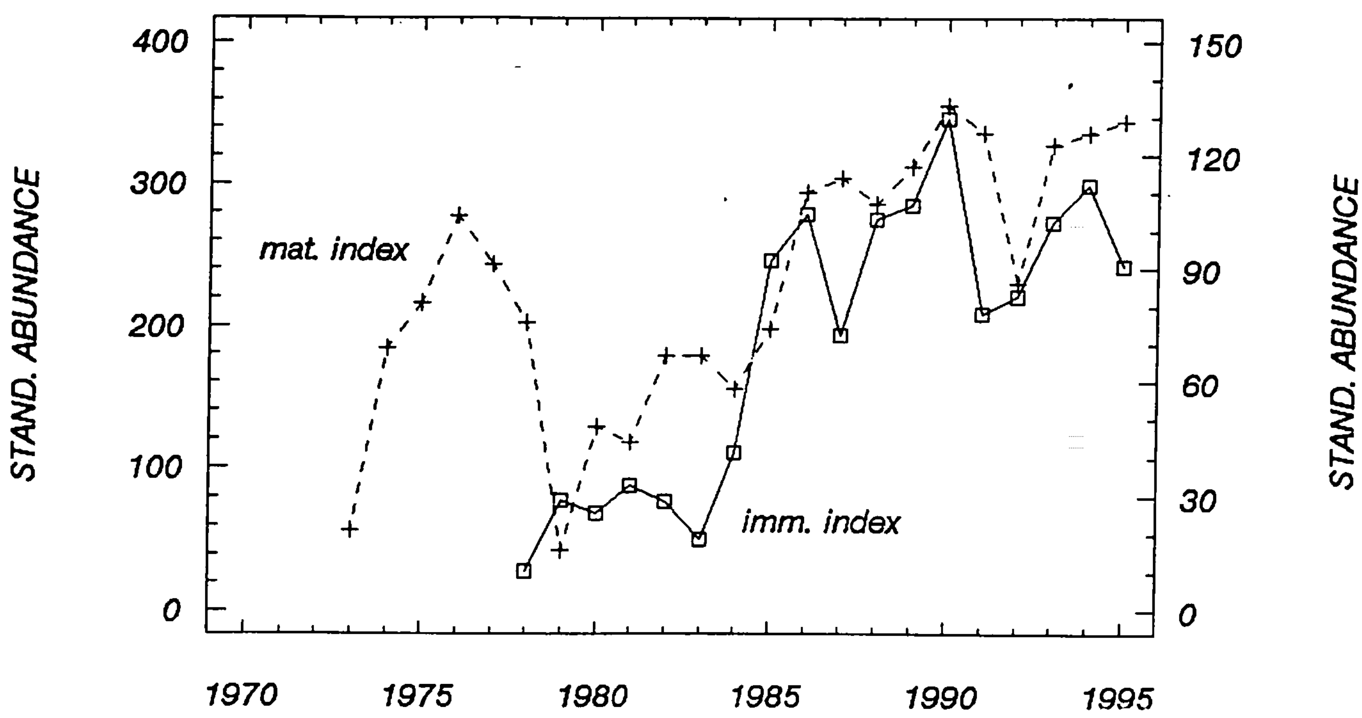


Fig. 1. Standardized abundance estimates for all abundance indices (see Table 1 and exemptions) compared with the same index with the Canadian 2J3K acoustic survey excluded.



IMMATURE INDEX VS MATURE INDEX

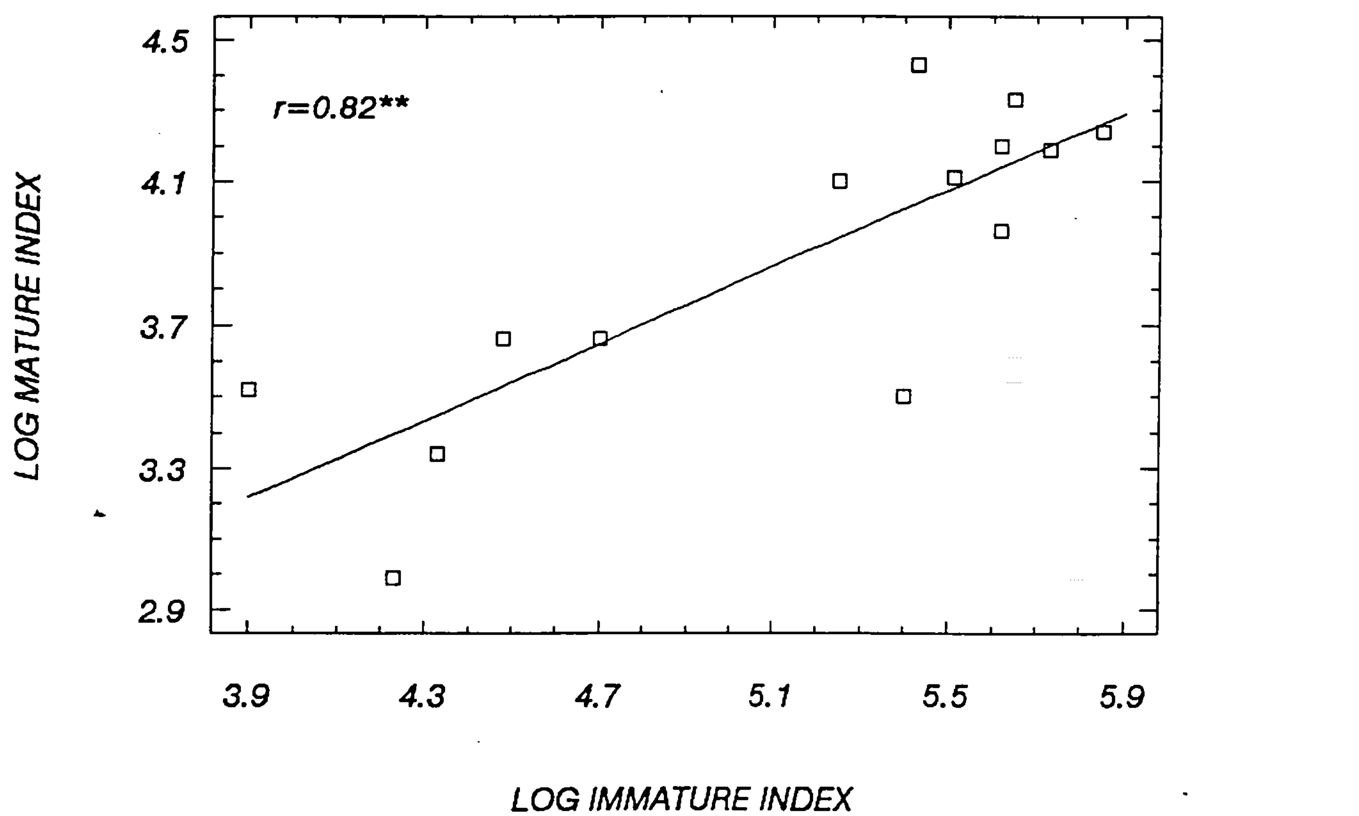


Fig. 2. Plot of the mature index versus the immature index (upper panel). The lower panel shows the statistical fit (lagged one year).

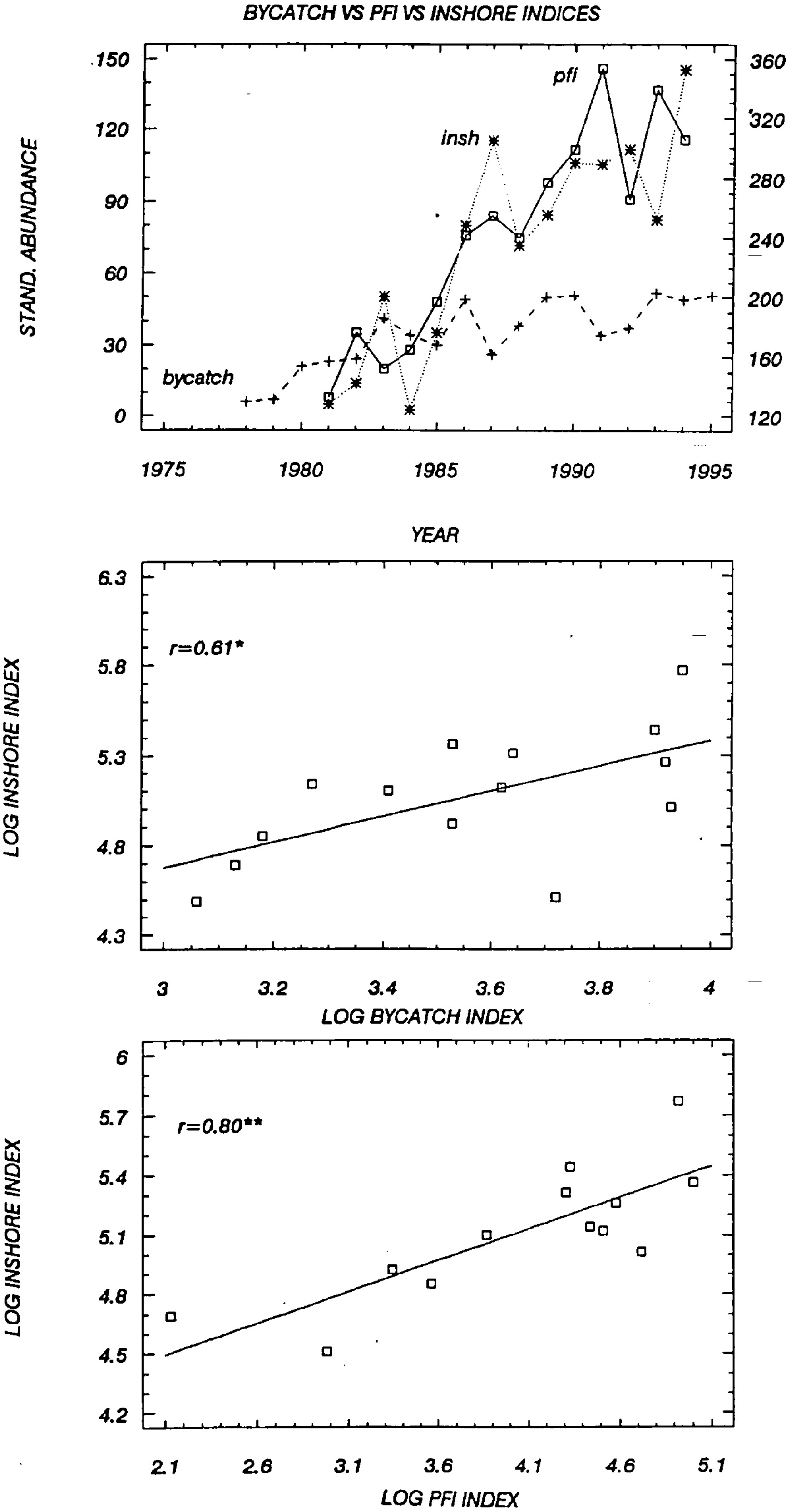


Fig. 3. The multiplicative bycatch index plotted against the inshore and PFI index (upper panel). The middle panel and lower panel displays the statistical fits of the bycatch and PFI to the inshore index (unlagged).

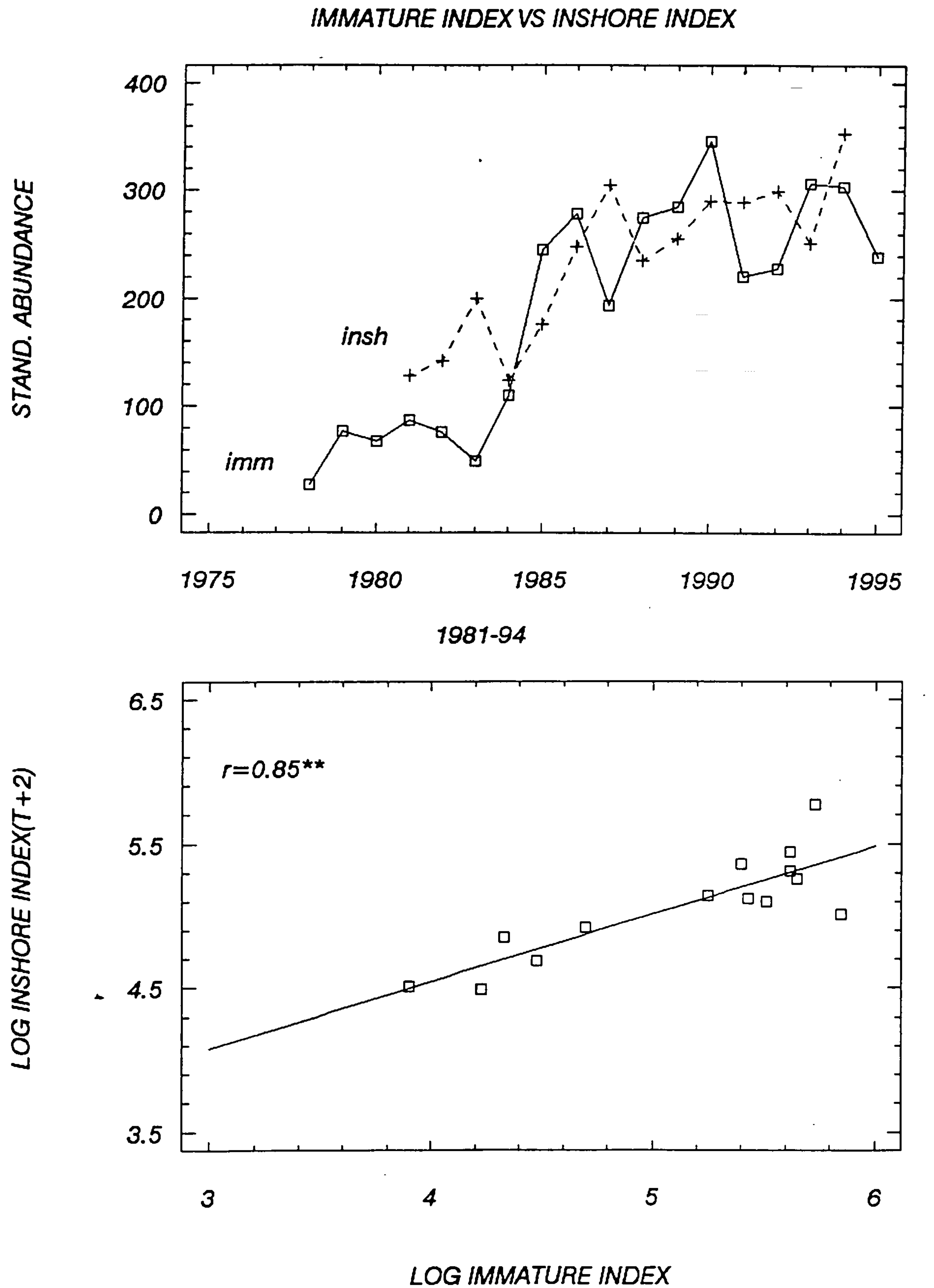


Fig. 4. The multiplicative immature (offshore) index versus the inshore index (upper panel) and the statistical fit of the two indices (lagged one year) (lower panel).

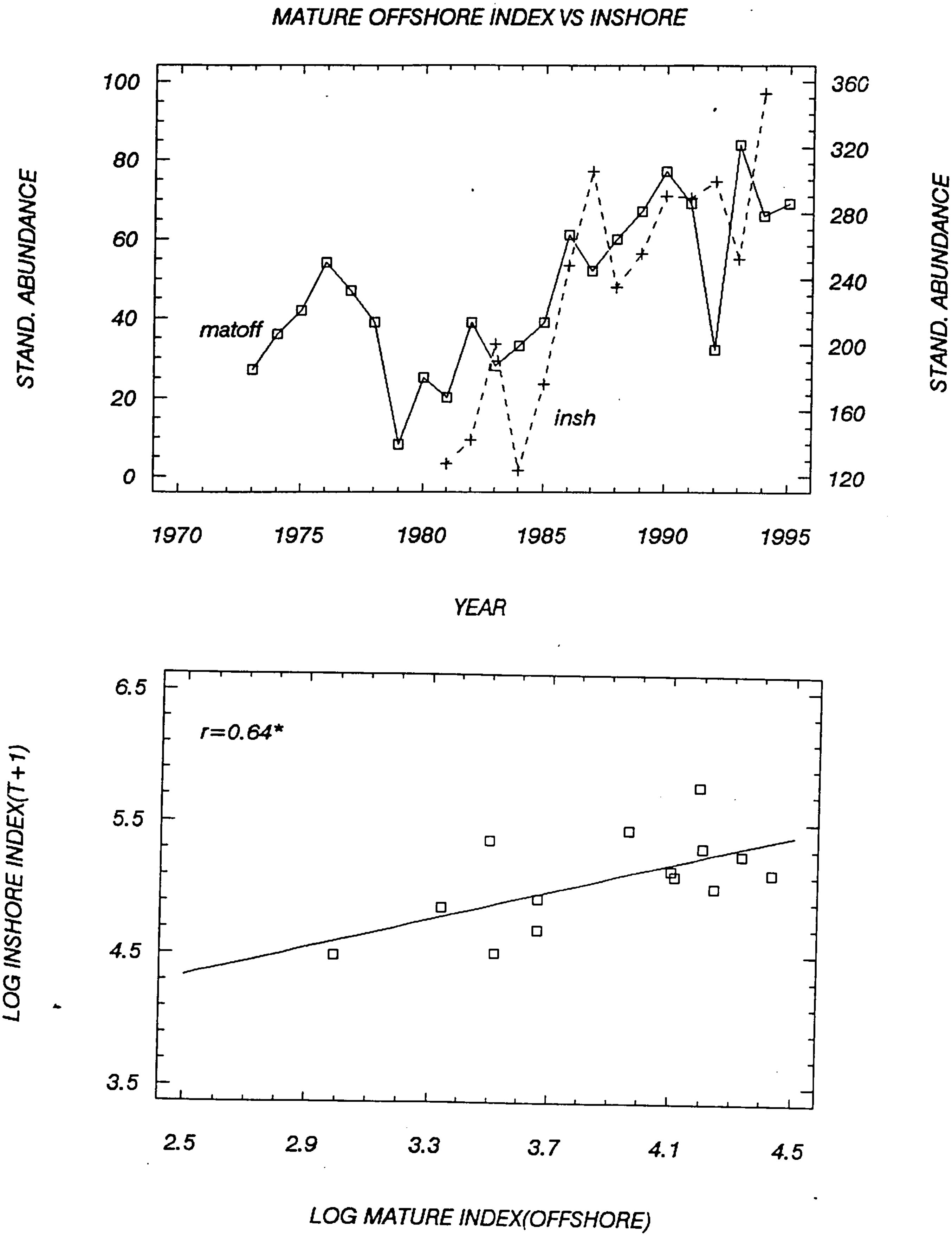
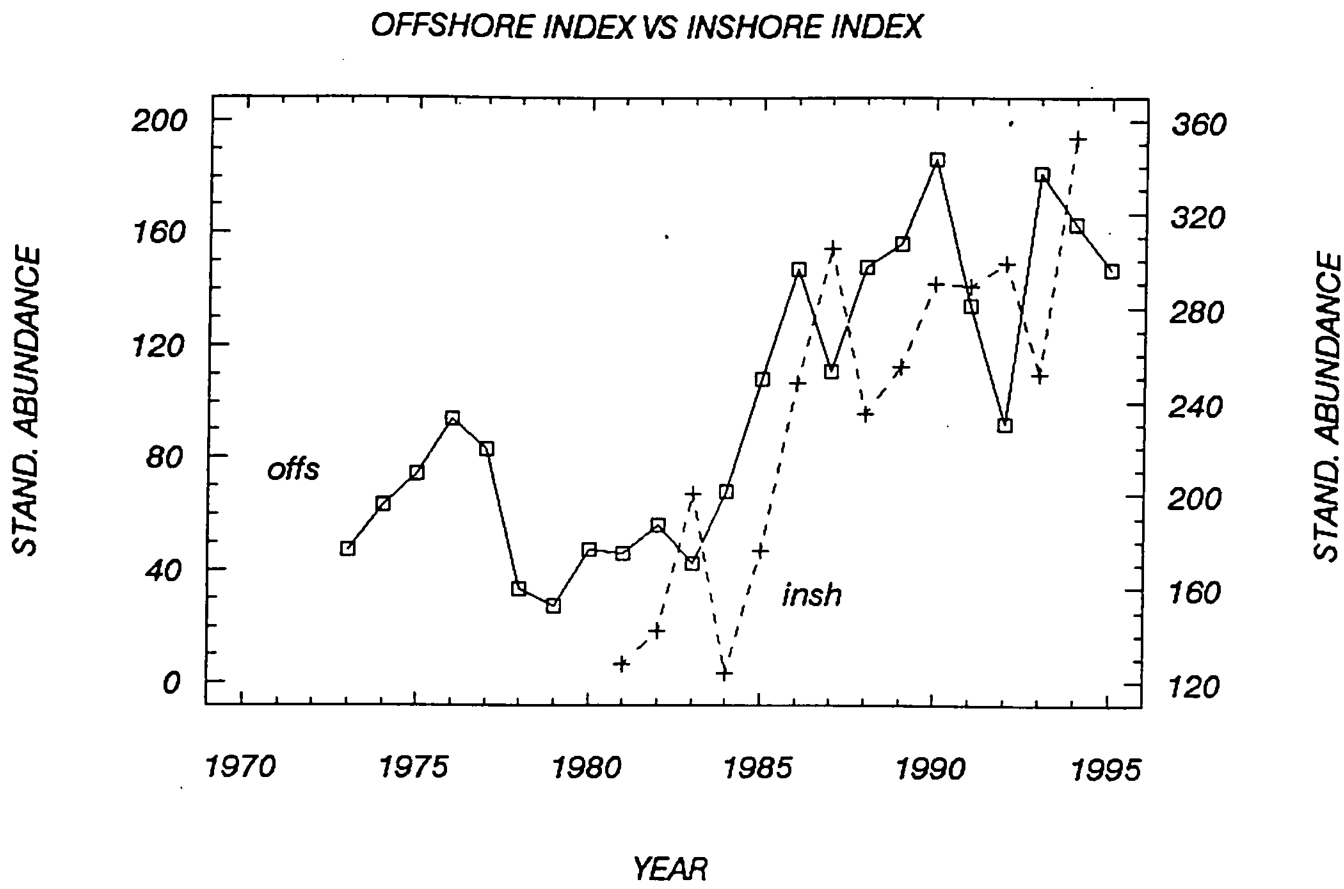


Fig. 5. The multiplicative offshore mature index versus the inshore index (upper panel) and their statistical fit (lower panel) lagged one year.



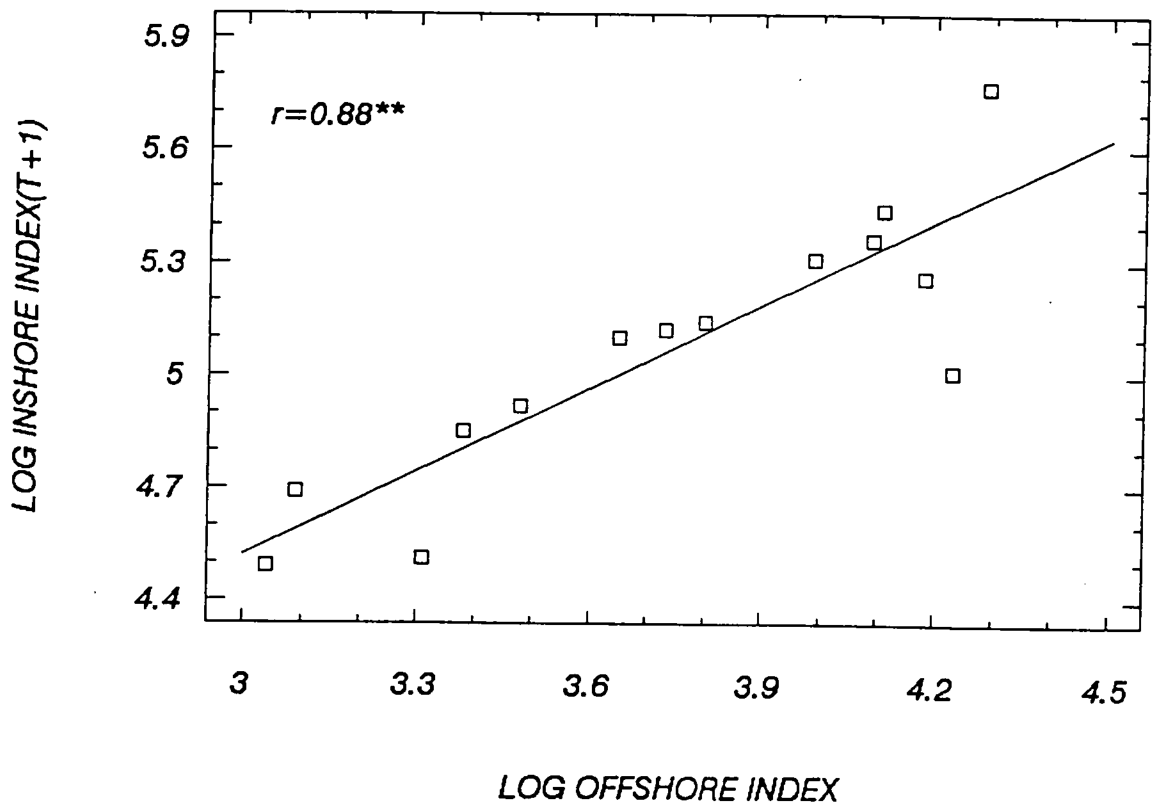


Fig. 6. Plot of the offshore index (including Canadian and USSR 3L acoustics) versus the inshore index (upper panel). The lower panel shows the statistical fit of the two indices.

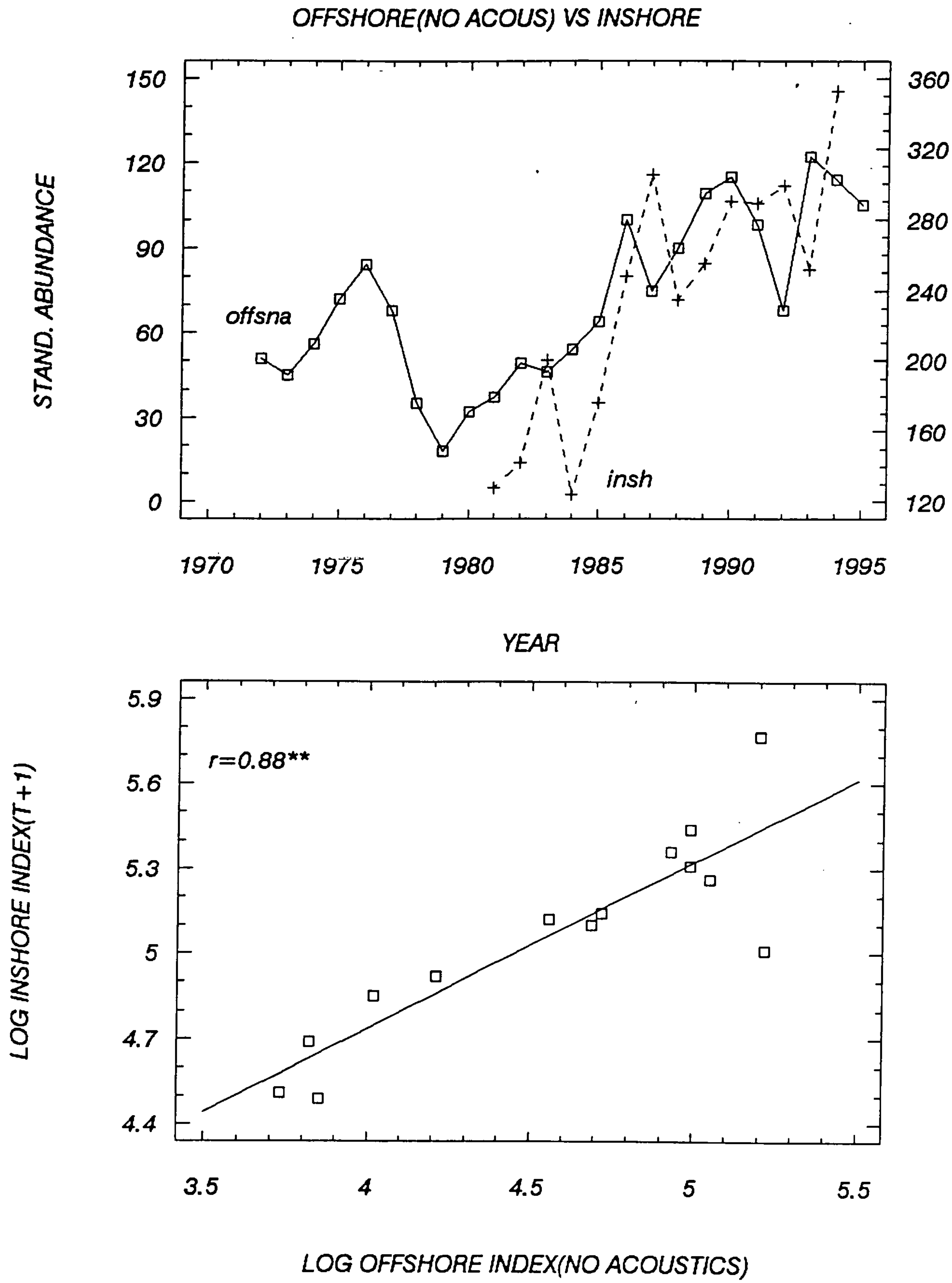


Fig. 7. Plot of the offshore index (without acoustics) versus the inshore index (upper panel). The lower panel shows the statistical fit of the two indices.

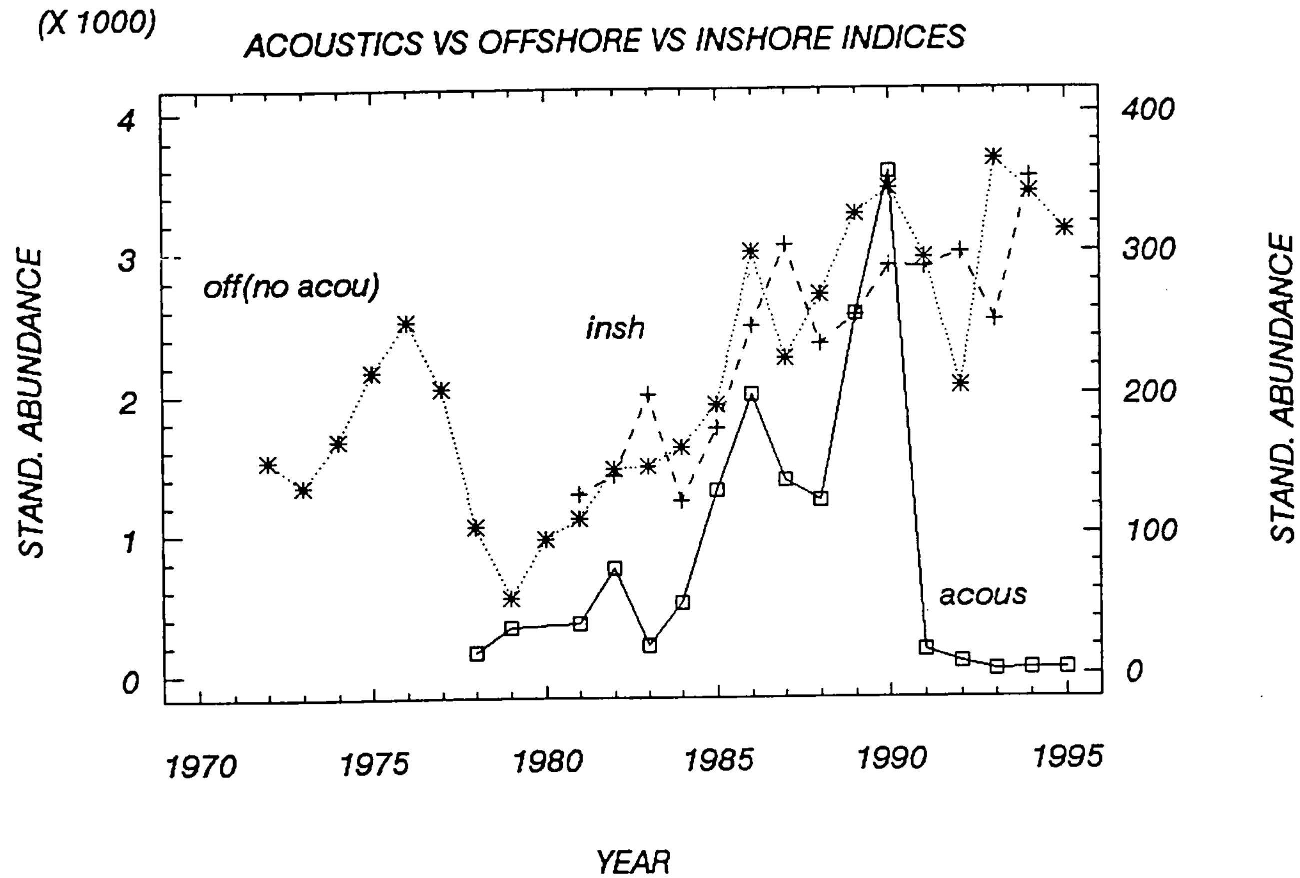


Fig. 8. Plot of the multiplicative acoustic index versus the inshore and offshore index excluding acoustics.

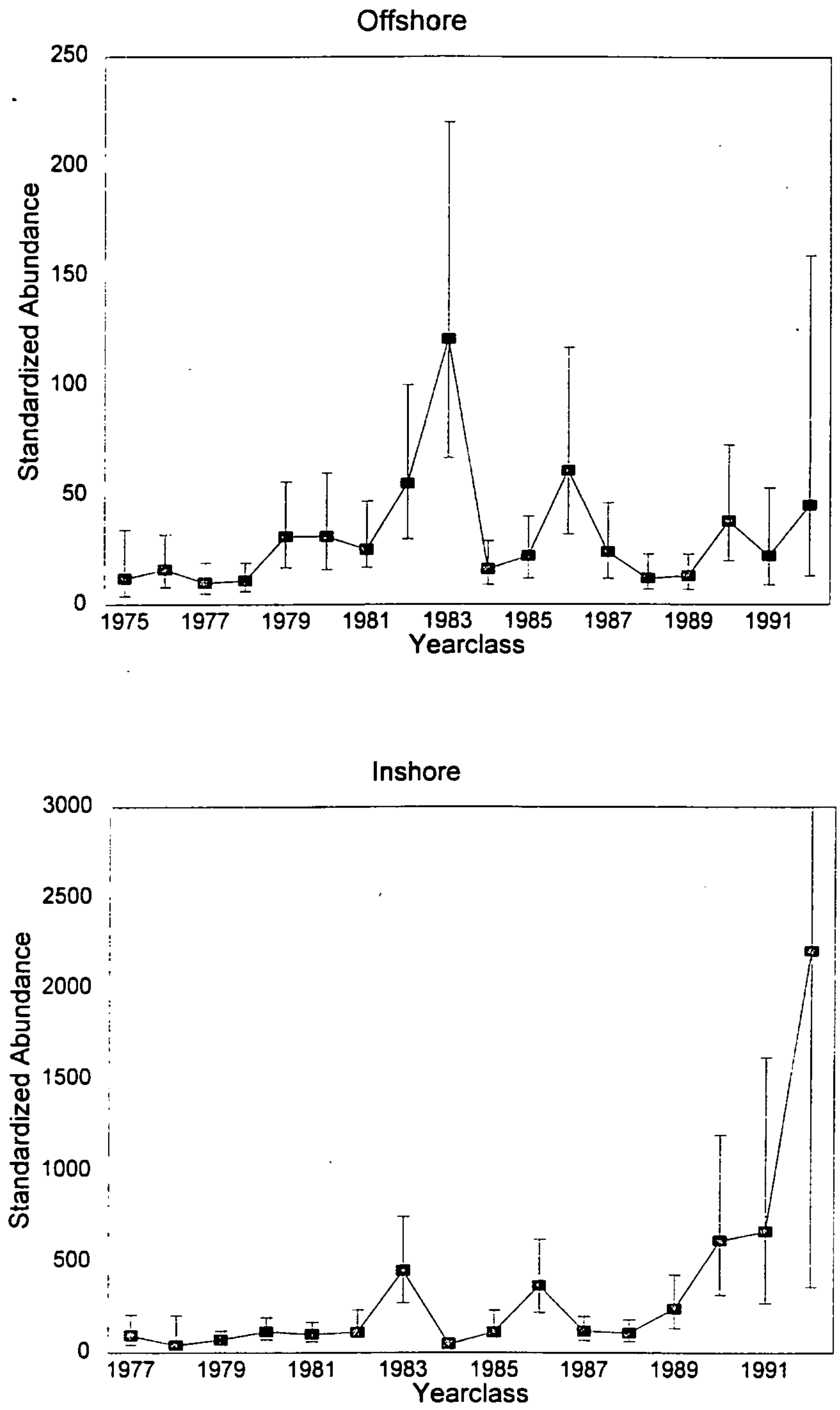


Fig. 9. Plot of multiplicative cohort estimates for the offshore (non-acoustic) indices (top panel) and the inshore indices (lower panel).

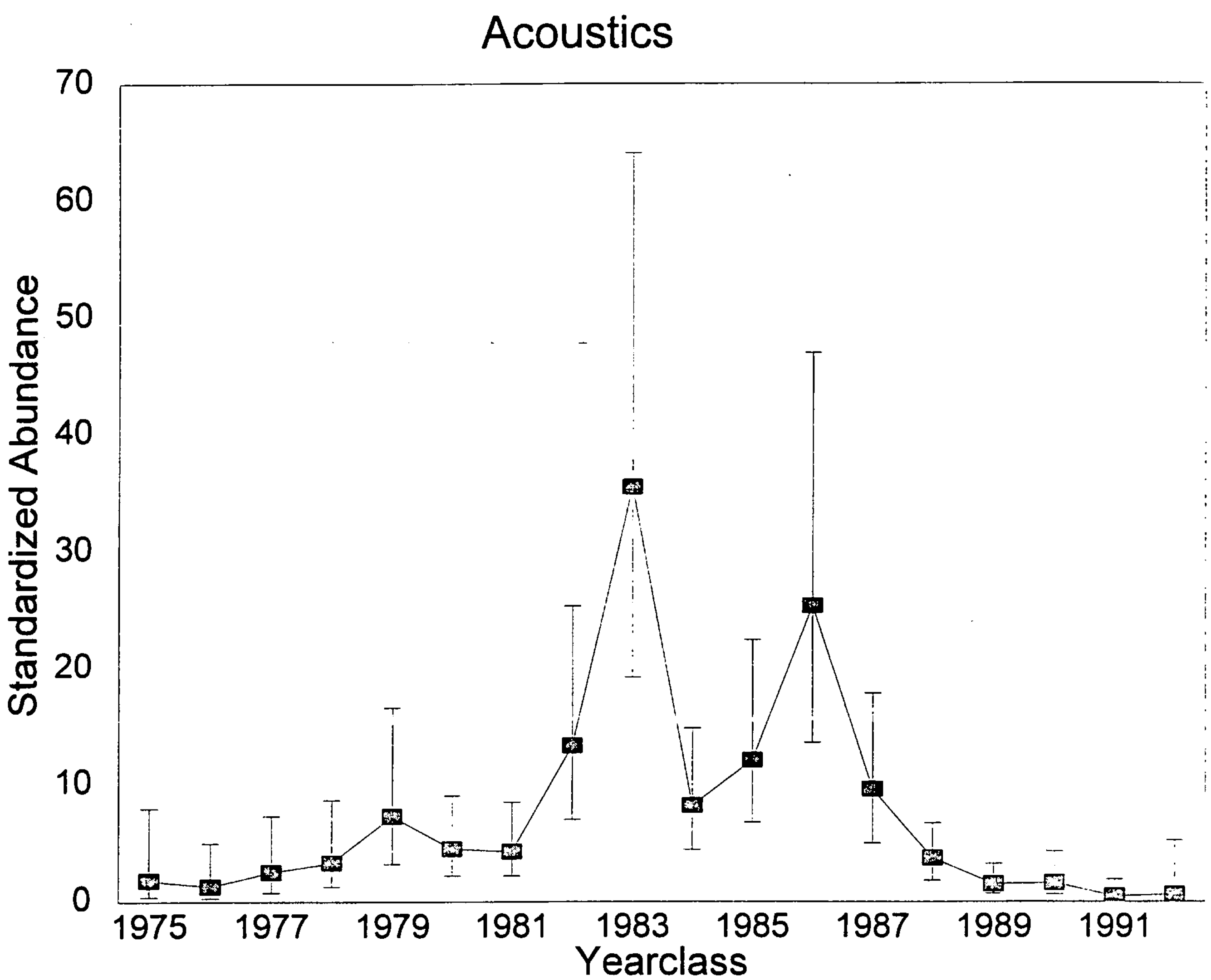


Fig. 10. Plot of the multiplicative cohort estimates for the acoustic indices.

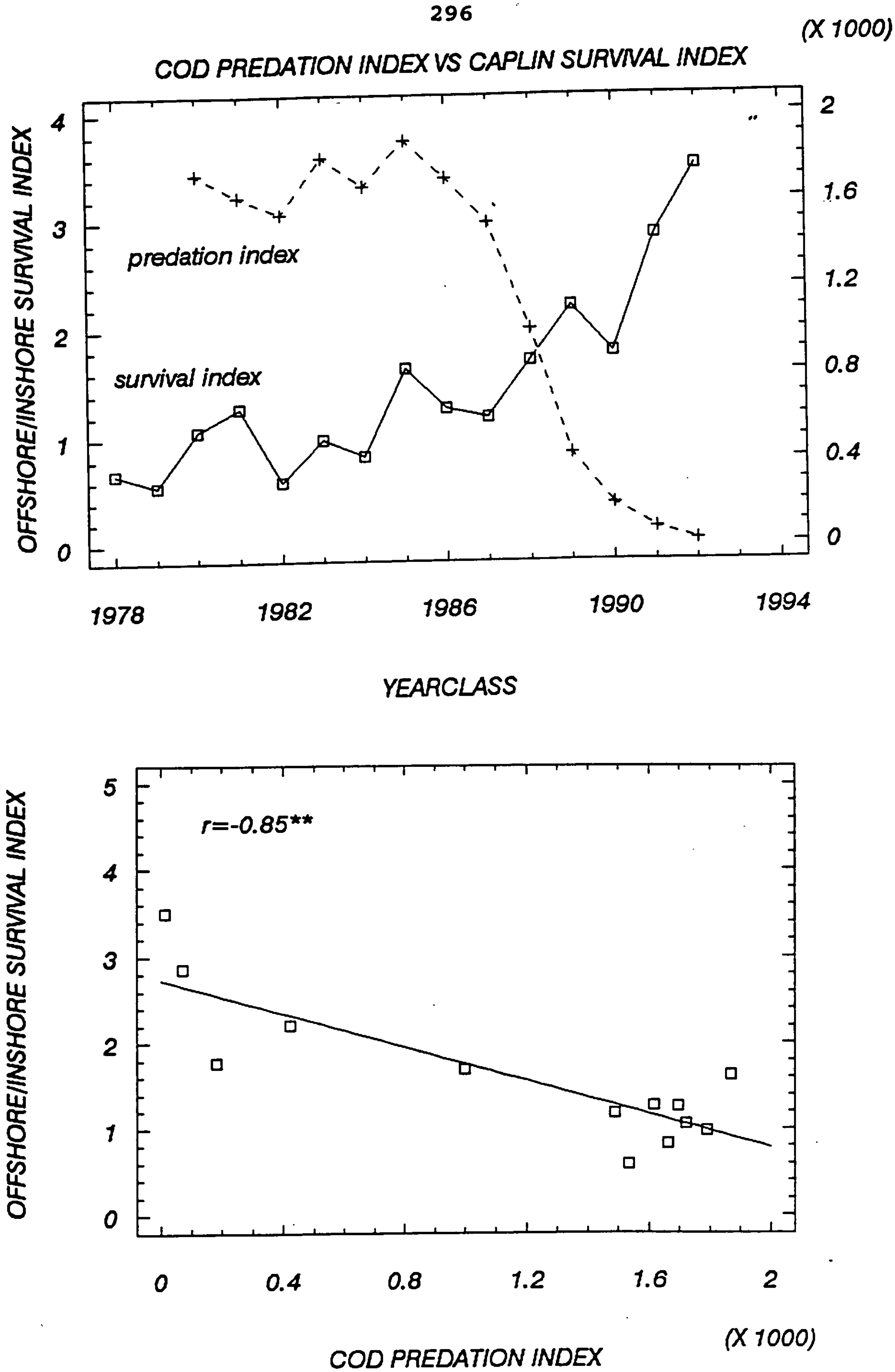


Fig. 11. Plot of the offshore/inshore relative survival index and the cod predation index (top panel) and their statistical association (lower panel).

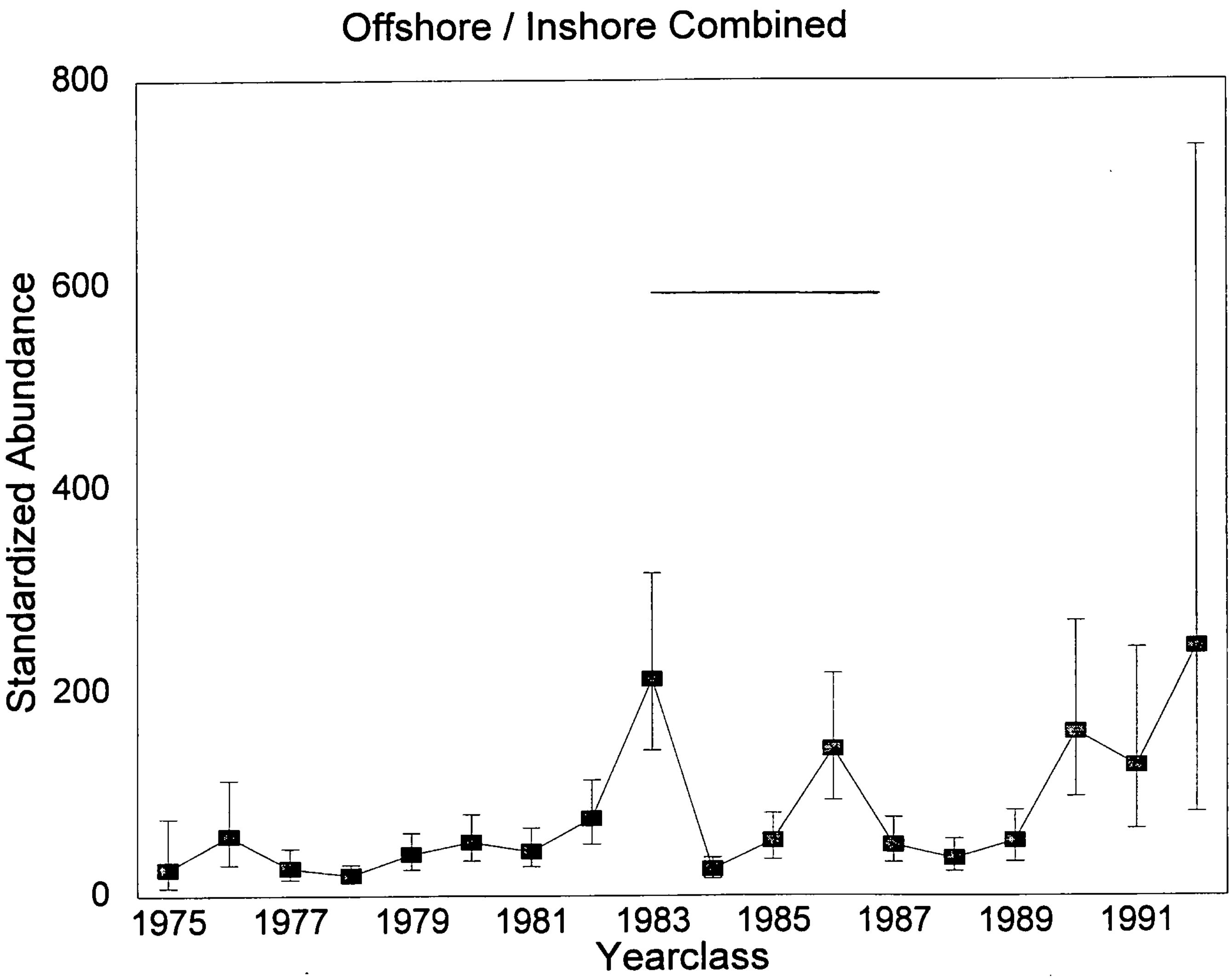


Fig. 12. Standardized estimates of cohort strengths estimated by the multiplicative model for all offshore and inshore indices combined (including acoustics).

Assessment of

Capelin in SA2 + Div. 3KL

Meeting Report

March 1995

Science Branch
Department of Fisheries and Oceans
P. O. Box 5667
St. John's, NF A1C 5X1

Capelin in SA2 + Div. 3KL

Introduction

A capelin assessment committee met several times during March 1995 at NAFC, St. John's to assess the capelin stock in SA2 + Div. 3KL. A list of attendees is given in Appendix 1. The committee noted that the 1994 capelin management plan, attached as Appendix 2, had been maintained for 1995, pending final scientific advice. Under this plan, the major items to be addressed in this assessment were the TAC of 33,000 t and the criteria of 50 count/kg as a requirement to open the fishery.

Stock Structure

Until 1994, capelin in SA2 + Div. 3KL had been managed as separate SA2 + Div. 3K and Div. 3L stocks. Assessments for SA2 + Div. 3K had been considered by CAFSAC but Div. 3L assessments were conducted under the auspices of NAFO. Evidence of movement of these stocks prior to and during the spawning season derived from tagging studies and similarities in age structure and year-class strength in these areas, led us to combine these into one stock complex.

Catch Trends

SA2 + Div. 3K

The capelin fishery in NAFO SA2 + Div. 3K was, until 1972, limited to inshore catches during the spawning season. In 1972, substantial catches were taken offshore by vessels from several countries. Catches peaked in 1976 at 212,000 t before declining in the late 1970's to 11,000 t in 1979 (Fig. 1).

Offshore catches during the 1980's were restricted by quota and ranged between 5,000 to 31,000 t. The offshore fishery was generally conducted during August-December with peak catches occurring in September-November. The offshore fishery was closed beginning in 1992.

During the 1980'S, an inshore directed roe fishery during June and July has occurred, primarily in Div. 3L. Beginning in 1988, landings increased because of an increased share of the market for Canadian capelin with the closure of the Barents Sea capelin fishery. TACs generally reflected market demand and the increase of the TACs during the late 1980's can be attributed to the larger market share. These did, however, remain below the 10% of total spawning biomass that had been set as the biological criteria for setting the TAC.

The 1994 preliminary inshore catch was 67 t, well below the TAC of 11,400 t and the 1993 catch of 13,000 t. The 1994 fishery did not open in most management areas because the capelin were too small to meet the market size criteria of 50 count/kg, defined in the Management Plan. In 1994, capelin continued a trend that began in 1991 of spawning late although the 1994 spawning was somewhat earlier than in 1993.

The offshore fishery first came under quota regulation in 1974 and the inshore fishery in 1982.

Div. 3L

Catches in NAFO Div. 3L were less than 4,000 t prior to 1970, increased to a peak of 58,000 t in 1974, and declined to 12,000 t in 1979 (Fig. 1). During the 1980's an inshore roe fishery employing purse seines, capelin traps and beach seines occurred during June and July. This fishery has been later since 1991 due to the late arrival of capelin. In recent years, TACs have reflected market demand. In years when biological data were adequate to advise a specific TAC, the actual TACs have been less than advised on a biological basis.

The 1994 preliminary catch of 871 t was well below the 1993 catch and the 1994 TAC of 21,730 t. Most (82%) of the catch came from the Southern Shore, an area that usually accounts for only a small proportion of the Div. 3L catch (no more than 7% between 1990-93). The low catches in 1994 occurred because capelin did not exceed the size criteria necessary to open or keep open the fishery.

Catches and TACs (tons x 10-3) since 1988 are shown below.

	1988	1989	1990	1991	1992	1993	1994
SA2 + Div. 3K							
Offshore							
Advised TAC	a	b	107	57	-	-	-
TAC	17	20	71	57	0	0	0
Nominal catch	17	22	57	0.5	0	0	0
Inshore							
Advised TAC	a	b	107	f	d	d	a
TAC	21.5	24.1	29	29	17	11.4	11.5
Nominal catch	27	28	33	20	18c	13c	<.1c
Div. 3L							
Advised TAC	90	335	350	e	e	d	a
TAC	45	46	56	56	19.3	21	21
Nominal catch	53	52	48	22	3c	23c	1c
SA2 + Div. 3KL							
Total nominal catch	97	102	138	42.5	21	36	1

a data not adequate to advise a TAC
b total inshore and offshore catches could be 200,000-250,000 t without exceeding 10% target exploitation rate
c provisional
d lowest possible level
e STACFIS concluded that a catch of 50,000 t as in recent years would not exceed a 10% exploitation rate
f catch should not exceed that of previous year

Information from Participants in the Fishery (Chapter 1)

During 1994-95, a questionnaire was designed to quantitatively evaluate biological and fishery-related information obtained from capelin fishers. This survey was undertaken because of concerns about the utility of qualitative information coming from comments in some research logbooks or made directly to research personnel. The survey was being conducted through telephone interviews and was still ongoing at the time of the assessment meeting. From a survey population of 2717 fishers licensed to fish capelin using traps and beach seines in Div. 3Ps, 3L and 3K in 1994, approximately 450 were chosen at random for the interviews. This sample size is large enough to calculate statistical confidence limits on the final results. However at the time of the meeting, responses were available from only about 50% (204) of the interviews.

On a scale of one to ten, with one being the lowest, 46% of respondents rated the 1994 abundance of capelin as one and 87% rated the abundance as five and lower. Eighteen percent thought the 1994 capelin abundance was about the same as 1993 while 66% thought the 1994 abundance was lower than 1993. Ninety-three percent thought the abundance was lower than when they started fishing while 3% thought it was the same.

Regarding the number of beaches in their area on which capelin normally spawn, 2% of fishers said none, 45% reported one to five beaches, 34% reported six to ten beaches, and 17% reported more than ten beaches (4% did not know). In comparison, 33% reported no beaches with spawn in 1994, 50% with spawning on one to five beaches, 5% with spawning on six to ten beaches, and 3% with spawning on more than ten beaches (10% did not know). Fifty-nine percent of fishers reported spawning on more beaches in 1993 compared to 1994, 37% reported spawning on the same number of beaches in both years and 3% said fewer beaches had capelin spawning in 1993 than in 1994.

On a scale of one to ten with one being lowest, 24% ranked the intensity of spawning as one with 85% ranking the intensity of spawning five or lower. Sixty-two percent ranked the intensity of capelin spawning lower than 1993, 28% ranked it higher and 7% ranked it the same.

Forty-nine percent of respondents reported spawning in deeper water in 1994, 17% did not observe it and 34% did not know. Of the fishers who reported spawning in deeper water, 57% attributed it to water temperatures, 8% to predation, 1% to weather, 2% to low abundance, 5% to unsuitable beaches, 2% to offshore capelin only and 25% did not offer a reason. When asked how often since they had started fishing had they observed capelin spawning off beaches in deeper water, 10% reported every year, 18% reported most years, 23% reported sometimes, 24% reported it as rare, and 24% reported never.

Fishers were given the opportunity to comment at the end of the telephone interview. Forty percent had no comment. Thirty-one percent mentioned fishery closure, 7% mentioned seals eat capelin and the seal hunt should be increased, 5% mentioned quota management and more monitoring, 3% mentioned keeping the capelin fishery open, 3% mentioned small capelin, 2% mentioned a negative effect of trawlers or purse seiners on capelin, 1% mentioned water temperatures and 2% commented on the questionnaire. These comments should not be viewed as comparable to questionnaire questions and therefore should be treated with caution. For example, although there were a large number of comments on fishery closure it was not always known whether it was a comment about the fishery in general or specific to a particular year (eg. 1994, given the problems in that year). These comments represent fishers' concerns and provide guidance to the surveyors on formulating additional questions for future surveys.

<u>Age-compositions and Mean Lengths in the Commercial Fishery</u> (Chapter 2)

The 1994 fishery was small, sporadic, and centred mainly on the Southern Shore. The few commercial samples collected were from this area and were collected over a very short time period. As a result, the committee concluded that it would be inappropriate to compare 1994 data to previous years, even though it might adequately represent the 1994 fishery.

In 1994, the fishery did not open in most areas or closed prematurely because females were too small to meet the 50 count/kg criteria. In the few instances when the fishery did open, small females were the predominant reason for discarding. Based on these observations, it appears that capelin were small in 1994.

The observations on smaller mean lengths in 1994 continued a trend that had been observed in recent years. In Div. 3K, the 1993 mean lengths in the commercial fishery were smaller than in previous years and continued a trend that began in 1987. In Div. 3L, 1993 mean lengths from the commercial fishery increased but were still lower than lengths of capelin landed during the 1980's.

Normally, three- and four-year-olds dominate the commercial fishery. However, in 1991, 1992 and 1993 a higher than normal proportion of two-year-olds had occurred. In 1993, age-compositions of the commercial fishery and beach-collected research samples differed although the reasons for the differences could not be identified.

<u>Inshore Commercial Catch Rates</u> (Chapter 2)

Because the 1994 fishery was small and sporadic, very few research logbooks were completed. As a result, the committee concluded that the catch rates would not be indicative of stock status.

Trap catch rates have been viewed as more reliable indicators of stock status than purse seine catch rates in past assessments, although the historical trends in the series are similar. In recent years, trap and purse seine catch rates have not declined to the extent that would have been predicted from acoustic estimates.

Aerial Surveys (Chapter 3)

The 1994 aerial survey provided frequent coverage of transects in both Trinity and Conception Bays because of excellent weather conditions. During last year's assessment, a new index was derived to supposedly correct for multimodal spawning which would result in underestimates of inshore abundance. This index was derived by summing total surface area (m^2) along each transect by year, dividing the total area by the survey time (hr) and multiplying by the duration of the fishing season. However, the derivation of this estimate suffered from two problems: the time used in the calculation included transit time as well as actual survey time, and multiple counting of schools occurred using this method. For these reasons and because the fishery was inactive in 1994, this index was not recalculated. As a result, the original index, the sum of the peak estimate of school surface area along each transect, was again used. The 1994 estimate was approximately double the 1993 index and the second highest in the series (about 94% of the highest, 1987). The 1994 index was heavily influenced by the high estimate in Trinity Bay. The Trinity Bay portion of the index was the highest in the Trinity Bay series and about four times higher than the 1988-93 average. The Conception Bay estimate was about the lowest in the series, comparable to estimates during the early 1980's and about one-half the 1988-93 average.

Offshore Acoustic Survey (Chapter 4)

An acoustic survey for capelin in Div. 2J3KL was conducted from 12 September to 29 October 1994. This is the second year of a fall survey to cover the area from 46°N to 55°N and out to the 500 m depth contour. The total biomass estimate was 102,700 t which is an increase from the 1993 estimate of 45,600 t. The Div. 2J3K component has shown a decline from 32,900 t in 1992 to 17,900 t in 1993 to 10,300 t in 1994. The Div. 3L portion increased from 27,600 t in 1993 to 92,400 t in 1994, largely as a result of increases in one- and two-year-olds. The biomass of one-year-olds in Div. 3L increased from 24,000 t in 1993 to 82,000 t in 1994 while the biomass of two-year-olds increased from 2,900 t to 9,600 t. There were no capelin detected in Div. 2J. This is the fifth consecutive year of low biomass estimates in Div. 2J3K in the fall. There have been few or no capelin in Div. 2J for the last four years. The average biomass estimate in Div. 2J3K, 1990-94, is about 5% of the average biomass estimated during 1981-89 (no estimate for 1982). During the 1994 survey, ages 2 and 1 accounted for 56% and 33% of the total numbers in Div. 3K while in Div. 3L, age 1 accounted for 97% of the numbers estimated. The distribution of capelin in bottom trawl catches during the stratified groundfish survey immediately following the acoustic survey generally agreed with the distribution of capelin in the acoustic survey. Few capelin were found in the groundfish survey outside the area covered by the acoustic survey. (Details follow in the section describing bycatches in bottom trawl surveys in Div. 2J3KLNO).

Egg Deposition Studies (Chapter 5)

Six beaches along the northeast coast in Div. 3KL have been surveyed since 1991 and indices of egg deposition have been developed from these studies. On one beach (Chapel Cove, Conception Bay), egg deposition was the second highest in the series but on the remaining five beaches, egg deposition was the lowest observed. On one beach (Cape Freels), no egg deposition occurred. When the results for all beaches were combined, the egg deposition index was the lowest in the series, about 15% of the next highest (1992) and about 8% of the highest (1993).

Overall larval production was the lowest in the four years of the study, about one-quarter of next highest (1991) and about one-sixth the highest (1992).

Age-compositions derived from samples of spawning runs were dominated by three-year-olds (52%) and four-year-olds (29%). Two-year-olds accounted for 12%, more than double the proportions observed during 1991-93. This proportion of two-year-olds is comparable to those observed in 1985 and 1988 when the strong 1983 and 1986 year-classes appeared in the mature population (and assuming that age-reading was comparable in the early to mid 1980's - see section on comparison of capelin ageing).

The peak beach spawning in 1994 was again delayed although it was not as late as 1991-93. The duration of beach spawning was also shorter on four of the six beaches. Only one beach (Hampden) supported a protracted spawning period.

The question of the relative amount of off-beach spawning came under scrutiny. Previous studies have shown that smaller fish and lower offshore temperatures during the maturation period resulted in later spawning. Both factors existed in 1994 and spawning was later. Furthermore, the weather conditions that developed in late June and persisted throughout the summer, were conducive to rapid warming of water temperatures near the beaches. The incidence of winds that would provide favourable capelin spawning temperatures was lower in 1994. This combination of factors provided the basis for a hypothesis that there was a higher than usual occurrence of off-beach spawning in 1994. This hypothesis was supported by three observations.

1) Apparently heavy concentrations of capelin eggs in deeper water adjacent to spawning beaches were observed in aerial photographs. Such concentrations had not been previously observed except in 1988.

2) In the questionnaire survey, 49% of the fishers reported off-beach spawning during 1994. Of this group, 24% reported that they had never observed it before and an additional 24% reported it as rare.

3) Beach spawning duration was shorter in 1994. Spawning tended to be earlier and occurred over a shorter time period at beaches where water temperatures were warm. Conversely, the spawning duration was extended where water temperatures were cooler.

If off-beach spawning was common in 1994 relative to previous years, the result might be an underestimate of the egg deposition index for 1994. An off-beach spawning index was calculated using observed spawning dates of capelin and numbers of days each year when water temperatures near the beach fell in the preferred spawning temperatures of 5-10°C. In the time period for which data were available (1990-94) there was good agreement between the egg deposition index and the number of days available for spawning. The Committee agreed that the results from this analysis offered support for the hypothesis that off-beach spawning was more extensive in 1994, however, the proposal to use the off-beach index to correct the egg deposition index was not supported because of lack of validation through subtidal sampling.

Capelin Predators (Chapter 6)

Since 1991, Atlantic puffins, black-legged kittiwakes, herring gulls, great black-backed gulls and common murres have bred later than usual on Great and Gull Islands in Witless Bay. Kittiwakes and gulls have experienced severe breeding failure. Kittiwake breeding failure was much more severe in 1991-93 than 1990 and 1994 and all years in the 1990's show lower breeding success than 1969-70. It was hypothesized that 1990 was a transition year from typical to atypical conditions. Puffins and common murres have experienced normal breeding success during the 1991-94 period. The failure of only surface-feeding piscivores suggests that forage fish were not as abundant at the surface. Preliminary data indicate that there has been a decline in mean size of individual capelin in the puffin diet but the overall food mass has not changed in recent years. More recent detailed feeding data for puffins suggest that while capelin are important components of the puffin diet, other foods are also taken without noticeable detrimental affects to the puffins.

Harp seal feeding data have, in the past, been described using prevalence of prey items. Now feeding data are available from 1982, 1986 and 1990-93, nearshore and offshore, using reconstructed wet weights derived from measurements of otoliths and squid beaks in the stomachs (Lawson and Stenson, in press). The most comprehensive data came from NE Newfoundland. In 1982, capelin were predominant (81% by weight) in the diet but in 1986 and 1990-93, they accounted for no more than 8% by weight. On the other hand, Arctic cod increased from 3% by weight in 1982 to 53-86% by weight in 1986, 1990-93. It is not known whether this change reflects a change in prey distribution, prey abundance or both although since 1985 Arctic cod have been caught in greater quantities during bottom trawl surveys. Arctic cod was the major prey consumed in both summer and winter but herring, capelin and squid gained importance during the summer.

Capelin occur frequently in the stomachs of cod caught in the offshore environment of Div. 2J3KL during the autumn and these occurrences have been used to describe distribution patterns of capelin. During the period 1980-88, the average quantity of capelin in cod stomachs, expressed as a stomach fullness index, was moderate to high in two broad regions: (1) northern and western Div. 2J3K (Hamilton Bank, western Belle Isle Bank, and the inner shelf off northeastern Newfoundland) and (2) northern Div. 3L (northern and northeastern slopes of Grand Bank). In many years, such as 1984 and 1985, the capelin in Div. 2J3K were primarily on Hamilton Bank and along the coastal shelf off southern Labrador and northeastern Newfoundland, whereas in some other years, notably 1986 and 1987, they were more aggregated on the central Northeast Newfoundland Shelf. During the early 1990's, the capelin in Div. 2J3K experienced a pronounced shift from the northwest to the southeast. The apparent distinction between a Div. 2J3K group and a Div. 3L group became less clear in 1990 and disappeared in 1991 and 1992.

Catches of cod during autumn 1993 were very small with the exception of a few moderate catches near the shelf break just south of the Div. 3K/3L boundary. Capelin were found in greatest quantities in the stomachs of those cod caught in southeastern Div. 3K and in northern Div. 3L. The northern limit of moderately large partial fullness index values (middle of Funk Island Bank) was further south than in any previous year. The use of stomach content data as indices of capelin abundance is limited by the change of survey design in 1991 and the reduction in cod distribution which has been progressively more dramatic since 1989. An adjustment for survey design is possible but it is unlikely that a correction can be derived for the absence of the sampler (cod). It was recognized that turbot might be a better sampler and that existing data should be analyzed to evaluate the potential.

<u>Bycatches in Other Surveys</u>

<u>Bottom Trawl Surveys in Div. 2J3KLNO</u> (Chapters 7, 8)

Capelin are frequently caught during bottom trawl surveys directed towards groundfish off southern Labrador and Newfoundland. The distribution and magnitude of capelin catches from the surveys in Div. 2J and 3K during the autumns of 1978-93 have been compared with geographic coverage by acoustic surveys for capelin to help evaluate acoustic survey coverage. As a result of these comparisons, acoustic surveys were expanded temporally and spatially during the late 1980's and early 1990's. During the autumn 1994 random-stratified bottom trawl survey, very few capelin were caught on Hamilton and Belle Isle Banks and near the coast off southern Labrador and northeast Newfoundland. Largest catches were on the eastern flank of Funk Island Deep, on western Funk Island Bank, and south of Funk Island Bank. In general, the distribution in 1994 was similar to that observed in 1991-93. All of the large catches in Div. 2J and 3K occurred within the area covered by the acoustic survey, although several near the southern border of Div. 3K were very close to the boundary of the survey.

During autumn 1994 in Div. 3L, capelin were caught in northern and northeastern Div. 3L and in the Avalon Channel in western Div. 3L. There were no catches on the plateau of Grand Bank. There were also no catches at the extreme northeast of Div. 3L, where catches had been taken in 1992 and 1993.

The Committee also examined frequency of occurrence of capelin in bottom trawls and minimum biomass estimates of capelin from the same data as potential indices of abundance. In this assessment, frequency of occurrence was adjusted to take into account the high proportion of sets allocated to certain strata in each year beginning in 1991. The new adjusted estimates of frequency of occurrence were very similar to the original estimates. In Div. 2J3K, capelin were recorded at 46% of the 237 fishing stations (<750 m depth) which is the third highest frequency of occurrence (1978-94). In Div. 3L, capelin were recorded at 42% of the 200 stations which is the third highest frequency of occurrence (1985-94). The minimum trawlable biomass estimates for fall in Div. 2J3KL show highest estimates during 1979-81 and generally variable and lower estimates after that. The 1994 value is slightly lower than the 1979-94 mean but slightly higher than the 1982-94 mean (excluding the initial three years with highest estimates). Estimates of minimum trawlable biomass in Div. 2J have been very low since 1990 consistent with the observations from the acoustic surveys of extremely low numbers (1990) or none at all (1991-94) in Div. 2J.

Unlike the surveys in Div. 2J3KL in the fall, the spring 3L bottom trawl surveys had not been examined to compare capelin bycatch distribution and abundance to that observed in acoustic surveys. Data were available for 1971-94. Long-term distribution patterns from the entire series indicated that capelin were distributed on the eastern, northern and northwestern slopes of Grand Bank and towards the shelf break along the southwestern and southeastern parts of the bank. Largest catches tended to occur in the eastern Avalon Channel and on the adjacent northwestern slope of Grand Bank and in the Avalon Channel south of the Avalon Peninsula. Catches tended to be small in the deeper water of the Northeast Newfoundland Shelf north of Grand Bank. Only in a few years were moderate to large catches obtained on the plateau of Grand Bank. The distribution of capelin in any particular year may be compromised somewhat by the seasonal timing of the survey and the pattern of surveying, but the general distribution of capelin in western Div. 3L during April-June is in agreement with previously described migration of maturing capelin from northern Div. 3L to southwestern Div. 3L and northwestern Div. 3O. The moderate and large catches obtained on northeastern Grand Bank in some years, notably 1982 and 1985-90, occurred outside the area covered by the acoustic surveys in those years. Acoustic surveys were extended to the east in 1991 and 1992 but failed to detect sizeable concentrations of capelin. Bottom trawl catches of capelin on eastern Grand Bank were generally small in those years.

The frequency of occurrence of capelin during the surveys in Div. 3L ranged from 8% in 1978 to 80% in 1986. During the period 1991-94, the frequency of occurrence was consistent at an intermediate level (48-52%). Minimum trawlable biomass estimates have been very variable with highest values since 1980 in 1986, 1987, and 1990. Estimates have been low during 1991-94.

The bycatch indices of % frequency of occurrence and minimum trawlable biomass were considered for inclusion in later analysis. Neither are designed to measure abundance of pelagic species. Large catches, which might occasionally be expected for pelagic species, will heavily influence the biomass estimates. On the other hand, frequency of occurrence may better describe general abundance trends because for pelagic species the range of a species may be a direct function of stock biomass levels. Frequency of occurrence data were used in the subsequent multiplicative analysis although it was noted that during the 1990's in Div. 3L spring surveys the bycatch success rate has remained relatively constant while size of the catches has been small.

Other Surveys (Chapters 9, 10)

Bycatch data were available from juvenile cod surveys in inshore and offshore areas of NAFO Div. 3KL conducted during winter (December 1992, December 1993-January 1994, December 1994-January 1995). A Campelen 1800 shrimp trawl was towed on bottom at predetermined stations on line transects from the large northeast Newfoundland bays to the edge of the Continental Shelf. Capelin were widely distributed during the surveys and frequency of occurrence was 89%, 82% and 92% for 1992, 1993-94 and 1994-95, respectively. The mean catch rates (numbers per 30 min tow) of capelin decreased from 373 in 1992 to 83 in 1993-94 but increased to 652 in the 1994-95 survey. Catch rates (numbers) were highest offshore in Div. 3K in all years and in Div. 3L in 1992 and 1994.

Over 85% of the capelin caught were one- and two-year-olds with about 55% one-year-olds.

Using similar survey areas in Div. 3K, estimates of capelin abundance from the acoustic survey, from the groundfish random-stratified survey and from the juvenile cod survey were calculated. The acoustic survey estimate was about 10,000 t (September-October), a minimum trawlable biomass from the random-stratified survey (November-December) was about 2,000 t and, a minimum trawlable biomass estimate from the juvenile cod survey (December 1994-January 1995) was about 22,000 t (using arithmetic mean of catch rate in the calculation) or about 3000 t (using geometric mean of catch rates).

Capelin have also been frequent bycatches in pelagic 0-group cod surveys conducted in Div. 3KLNO during autumn 1991-94. These surveys were about the same time during 1991-93 but about 40 days earlier during 1994. Different sampling gears resulted in catches of 0-group and one-year-old capelin. In 1991-93, 0-group capelin occurred in both inshore and offshore samples but in 1994, most capelin were taken only inshore. The length distribution data also showed fewer larger fish in 1994. Both the distribution and length data reflect the much earlier sampling in 1994. One-year-old capelin were widely distributed over the northern Grand Banks during 1993 and 1994, reinforcing the general observation that this is an important nursery area. Although detailed comparisons of distribution of this age-group with that observed during the acoustic survey could not be made at the meeting because of differences in data presentation, the general predominance of one-year-old capelin in Div. 3L occurred in both surveys. The Committee noted that the 0-group survey would likely be discontinued and therefore did not represent the beginning of a time-series of 0-group estimates. However, the biological data would be very valuable when linked with the detailed capelin early life history data collected on the beaches as part of NCSP.

Other Studies

Capelin Distribution (Chapter 11)

Since 1981 systematic hydroacoustic surveys of capelin abundance have been conducted during October by Canada in NAFO Div. 2J3K. The biomass estimates from these surveys have shown large interannual variations which have not been reflected in subsequent inshore indices of mature fish which they were designed to measure. In particular, low biomass levels were observed offshore in 1983, 1986, 1987, and from 1990 onwards. Previous authors had reported that up to 1992, anomalously low acoustic estimates had been consistently associated with shifts in capelin distribution to the south and east towards the outer portions of the acoustic survey blocks. As a result of these observations, the acoustic survey had been expanded both temporally and spatially until in 1993 and 1994, this survey had covered the area from 55°N to 46°N and from the headlands out to the 500 m contour. In the analysis reviewed by the Committee, groundfish bycatch data and cod feeding data (partial fullness indices) were primary data sources to describe statistical associations between capelin distribution patterns and interannual variability in the Div. 2J3K capelin acoustic biomass estimates. Central to the analysis was a conceptual model of capelin distribution and migration in Div. 2J3KL. This model indicated that Div. 3L was an important nursery area for juvenile capelin. During late summer/early fall maturing capelin would begin a northward migration towards an autumn feeding area in Div. 2J. Later in the fall, these capelin would migrate southwards to southern Div. 3K and northern Div. 3L where they would overwinter. In the spring, these maturing capelin would begin a feeding/spawning migration which would take most to southwestern Div. 3L/northern Div. 3O. They would continue their spawning migration northward through the Avalon Channel and into east and northeast coast bays.

Because the capelin are migrating extensively during the autumn period and the timing of the migration is changeable depending on the hydrographic conditions (which may be a proxy for other factors, eg. food), then timing of the survey is critical. This was illustrated by a comparison of autumn Canadian and Russian acoustic surveys (Russian surveys are later) and spring Div. 3L surveys. This comparison suggested that differences in timing of only a month can have large and systematic effects on biomass estimates.

Bycatch rates in the groundfish surveys show a general southeastward shift in distribution during the 1990's which has been associated with a shift of bycatches into deeper water (300-350 m compared to 200-250 m in earlier years). There was also an association between acoustic estimates and mean depth with lower acoustic estimates in years when mean bycatch depths exceeded 300 m.

Furthermore, a statistical relationship was established that showed that high biomass levels were reported from the acoustic survey when the centroid of capelin distribution (described by frequency occurrence in groundfish surveys) was located in the north (in 2J) and inshore (western 3K). When the centroid was located to the south and east (in the deeper eastern areas of 2J and 3K) the available biomass (as inferred from bycatch rates) was largely undetected, presumably because the major concentrations of capelin were to the east of the survey transects. The author noted that the acoustic abundance estimates contain an abundance component and a distribution component and the statistical relationships were used to remove the distributional component.

As a result of the statistical analyses, modifications to the conceptual distribution model were hypothesized. In cold years, capelin would penetrate less extensively into 2J and the southern migration would begin earlier and be deflected more to the east. Thus, capelin would be unavailable to the October acoustic survey. By November, the capelin would begin their cross-shelf migration and be available to the groundfish survey. By January, demersal juvenile cod surveys suggest the capelin are widely distributed across the northeast Newfoundland shelf and into coastal bays.

The Committee noted that the statistical relationships agreed with the earlier interpretation of capelin distributions from bycatches in the groundfish surveys and which resulted in expansions in the acoustic survey coverages. Unfortunately, it did not provide a mechanism to explain why in 1993 and 1994 the acoustic surveys did not result in higher biomass estimates because they would have covered the migration routes hypothesized in the conceptual model. However, the analyses and concepts could prove very useful in developing hypotheses that might be tested during the modified 1995 acoustic survey (see research recommendations).

Mean Lengths Offshore and Inshore (Chapter 12)

Sizes of female capelin have become important in the market since the late 1980's with the Japanese market demanding larger capelin. During the 1990's, capelin have been smaller-at-age and there have been relatively more two-year-olds in the population resulting in problems in the industry. The small size of capelin has been a concern to management because a market for predominantly large females when only small capelin occur provides a framework for extensive dumping. Consequently, provision was included in the 1994 management plan that prevented opening or allowed early closure of the fishery until a specific size was reached (50 count/kg).

The Committee examined the results from a comparison of mean lengths from fall acoustic surveys and inshore mean lengths to determine whether the mean lengths from the acoustic surveys could be used to predict mean lengths in the following year. Mean lengths at age for both sexes from the acoustic surveys were calculated from survey strata which contained high proportions of maturing fish. The relationships were positive but stronger for females. Since females are targeted by the market, females became the focus of the analysis. The relationships were statistically significant for all ages tested except age 2 fall-age 3 spring. There was a positive and significant relationship between the residuals from the acoustic length-inshore length relationship and 0-20 m temperatures during the growing period (February-June), suggesting slower growth in colder years. Mean length of age 2 females in the 1994 acoustic survey (age 3 in 1995) were the smallest in the series and for age 3 females (age 4 in 1995) the mean length was below average. Thus, even if temperatures during the February-June 1995 period are average, female capelin at ages 3 and 4 in 1995 will likely be smaller than capelin seen during the 1980's.

Comparison of Capelin Ageing (Chapter 13)

Age-composition of capelin collected during different studies and aged by different readers have been different since 1991, even though both age-compositions were assumed to be indicative of the same population. A formal ageing comparison experiment was conducted to determine whether different ageing protocols were contributing to the differences.

Between reader comparisons indicated that the two readers were interpreting ages differently. Otoliths from several years were used and this comparison showed that the agreements were better in earlier years. This confirmed the general observations of the readers that otoliths in recent years have been more difficult to read. Anomalous environmental conditions may be affecting growth which may be manifested in physical changes in the otoliths. The biases between readers were consistent for all comparisons with the reader who regularly ages commercial samples assigning younger ages. This meant that age-compositions from the commercial samples in the capelin database would tend to show more younger ages than otoliths collected from capelin spawning on beaches.

Both readers exhibited significant differences in age interpretation over time. For the reader who has had the responsibility of reading capelin otoliths during the 1980's and 1990's, differences over time were not consistent, that is, otoliths from some years were read the same as original readings while some were not. However, in all cases, most recent readings resulted in generally younger ages. Thus, given this tendency to read younger in some cases and the difficulty in reading otoliths during the last few years, the Committee noted that the proportions of younger ages in the commercial samples (eg. age 2) should be viewed as upper estimates and the proportion of older ages as lower estimates. However, the Committee also noted that even otoliths collected from the capelin on spawning beaches and read by the other reader, who tended to assign older ages, had resulted in relatively high proportions of two-year-olds especially in 1994.

Bayesian Analysis (Chapter 14)

The Committee evaluated a new approach to weighting and combining different indices of abundance of capelin. This approach was presented as an alternative to the approach used in the most recent assessments, when some of the indicators of capelin stock status diverged. In these assessments, the different pieces of evidence were, to a large extent, evaluated on a qualitative basis and discussions continued until a reasonable level of consensus had been reached regarding stock status. The recommendations regarding TAC based on these assessments were only qualitatively linked with recognized uncertainty in the conclusions regarding stock status. Since there was no explicit trace of the procedure used to reach a conclusion regarding the status of the stock, there was no guarantee that the same conclusion would be drawn if the assessment were repeated with the same information.

In the new approach, indices and individual cohorts would be evaluated. These evaluations would involve defining how good each index was at measuring the strength of specific age-groups and then particular cohorts (in this case, 1990-92) would be evaluated as to their relative strengths. The evaluations would be considered subjective in nature but probabilities would be assigned that would describe the usefulness of the index and the strengths of the target year-classes. All of the probabilities would then be combined mathematically using Bayes rule. Each year-class would then have a final calculated probability that described its strength. These probabilities could then be compared to predetermined values which would automatically trigger a decision (eg. maintain TAC, reduce TAC, etc.).

This approach was tested with a small working group and found to be a useful framework to discuss individual indices and year-class strengths. It was agreed that the method would be considered experimental but could be useful in the final assessment only if an assessment could not be finalized using the multiplicative model.

<u>Assessment of Stock Status</u> (Chapter 15)

The Committee used a multiplicative model to statistically integrate a variety of indices into a standardized timeseries. Some initial decisions whether to include or exclude potential indices in the final model were necessary. These decisions were based on knowledge of each index and required a judgement regarding the potential value of the index. Each index and each cohort was given equal weight in the multiplicative model.

<u>Multiplicative Model</u>

Sixteen potential indices were identified for possible inclusion in the multiplicative model. Six were from inshore sources and ten were from offshore. Each index was broken down into age-classes (Appendix 3). The indices were highly variable in terms of historical length and availability of sampling data. Notes on origins of the data, possible deficiencies in each index, and reasons for retaining or not using the indices are given in Appendix 3.

Several indices were retained for inclusion in the model but not all were included in a single model formulation because the strengths of individual year-classes diverged in recent years. The following formulations of the multiplicative model were run with the noted data series from Appendix 3 (alphabetic codes as in computer database).

1) Acoustic formulation (Fig. 2) included:
   a) Russian 3L spring acoustic index (C)
   b) Canadian 3L spring acoustic index (L)
   c) Russian 2J3K fall acoustic index (B)
   d) Canadian 3L fall acoustic index (H)
   e) Canadian 2J3K fall acoustic index (K)

2) Inshore formulation (Fig. 3) included:
   a) Aerial survey index (A)
   b) Purse seine catch rate index (M)
   c) Trap catch rate index (T)

3) Offshore formulation (Fig. 4) included:
   a) Groundfish 3L fall bycatch (F)
   b) Groundfish 2J3K fall bycatch (G)
   c) Russian 2J3K fall commercial catch rate index (J)

4) The relative strengths of the 1990-92 year-classes were very different in formulation 1) above compared to formulation 2) and 3) above. The strengths of these year-classes in the last two formulations showed them to be relatively strong compared to earlier year-classes. As in last year's assessments, less weight was placed on the results from the acoustic survey. Thus this final formulation (Fig. 5) was developed to provide a possible representation of actual stock abundance by including a data series of absolute estimates for calibration. Data from formulations 2) and 3) were combined with the data from the Russian 2J3K fall acoustic index (B). The latter data were used as a source of absolute abundance to scale the year-class strengths. The trends in this acoustic series closely matched the Russian fall midwater catch rate series.

In all versions of the model, the historical perspective of year-class strengths, 1977-88, were similar. The 1983 and 1986 year-classes were more abundant than all other year-classes, with the 1983 year-class being the strongest. The 1984 year-class was weak.

The first run of the model using only acoustic indices showed all recent year-classes, 1987-92, to be low in abundance.

The second formulation using inshore indices showed the 1990 and 1991 year-classes stronger than the 1983 and 1986 year-classes. The 1992 year-class appeared as the strongest on record; this estimate resulted from only one data source, the aerial survey (no data for 1994 purse seine and trap catch rates).

The third formulation showed the 1990 year-class to be equal in abundance to the strong 1986 year-class. The 1991 year-class was the weakest of the three with the 1992 year-class almost as strong as the 1990 year-class.

In the final formulation, using seven indices including the fall Russian acoustic survey for calibration, the 1990-92 year-classes are strong. The 1990 and 1991 year-classes are approximately equal to the 1986 year-class and the 1992 year-class is about equal to the 1983 year-class. Confidence intervals are particularly large around the 1992 year-class, reflecting the statistical uncertainty in this estimate.

Three projections were made using different estimates of year-class abundance from the calibrated multiplicative model, survival at age and maturity at age. One projection used year-class abundance and survival from the multiplicative model and maturity for Div. 3L capelin from past assessments. A second projection used year-class abundance from the multiplicative model as in the first projection except the age 2 for the 1992 year-class from the aerial survey index was excluded. This run of the model was used to illustrate the effect of the estimate of the 1992 year-class from the aerial survey on the projection. Estimates of survival and maturity were the same as in the first projection. In the final projection, estimates of year-class abundance were the same as the second projection, but estimates of survival and maturity were from Shackell et al. (1994). The estimates of mature biomass in 1995 from these projections ranged from approximately 1 to 3 million tons. The 95% confidence limits on the lowest projected biomass of 1.0 million tons were 0.3 to 3.1 million tons and on the highest projected biomass of 3 million tons, the 95% confidence limits were 1.4 to 8.0 million tons.

Stock Status in 1994

Stock status has been difficult to determine in recent years because of the divergence between inshore indices and the offshore acoustic surveys. This continued to be the situation in this assessment with the added uncertainty regarding the appropriate interpretation of the 1994 inshore indices. Egg deposition in 1994 varied from low to average on monitored beaches. Although the aerial survey index for 1994 was high, it was largely a result of the presence of large schools only in Trinity Bay and not in Conception Bay. Capelin arrived late inshore again in 1994 and acceptable inshore catch rates were unavailable because the fishery opened only sporadically.

The 1991 and 1990 year-classes contributed (about 80% combined according to beach sampling) to the spawning population in 1994. These year-classes were estimated to be average and strong, respectively, in the multiplicative analysis suggesting a higher than average spawning stock abundance in 1994.

The results of the multiplicative model formulations rely in some cases on indices which have not been collected specifically to monitor capelin abundance nor have they been validated as reliable indicators of capelin abundance. In addition, the formulation of the multiplicative model combining different kinds of indices is not known to have been attempted in other fish stock assessments.

Prognosis for 1995

The 1994 acoustic survey estimate was again low, even though this was the second year of such an extensive synoptic survey. These acoustic surveys have been designed to provide a recruitment index and therefore, were expected to provide a basis for prediction of the spawning biomass inshore the following year. In recent years, these expectations have not been met. Consistently low biomasses have been estimated offshore but there have been no decreases in catch rates or aerial survey indices inshore of the magnitude that would be expected from the low acoustic indices. Thus, similar to last year, the acoustic survey is not being relied upon although there continued to be concern about the trends in this survey. The reasons for these low biomass estimates in the acoustic survey as well as the concerns regarding the indices and the multiplicative model noted above require further research. Despite the concerns about the indices and the model, the Committee noted that the projected biomass in 1995 would support a catch of 33,000 t as outlined in the Management Plan without exceeding the conservation level of 10% of the spawning stock biomass.

Capelin captured in the 1994 acoustic survey were relatively small and based on historical trends in sizes in the acoustic survey and sizes inshore the following year, capelin in the 1995 spawning stock likely will be small. Even if spring water temperatures were average or above normal, growth would have to be exceptional for capelin to reach sizes attained in the late 1980's. The overall average size in the spawning stock will be dependent on the relative proportions of the year-classes present. Since the 1992 year-class is expected to be stronger than the 1991 and the latter should already be reduced by spawning mortality, the 1992 year-class would be expected to dominate. This will likely contribute to an overall smaller mean size. Although the abundance of the 1993 year-class could not be quantified, it dominated in some surveys and appeared widespread in the offshore. If it is a strong year-class, it could also appear in the 1995 spawning population and contribute to a small overall mean size.

Research Recommendations

1) The lack of correspondence between abundance in the offshore acoustic surveys and other indices in recent years has resulted in the suggestion that the acoustic surveys have not been detecting capelin. This has occurred in both the Canadian and Russian acoustic surveys. Acoustics is a widely accepted method of assessing the abundance of pelagic, schooling species. Acoustic surveys have been used successfully to assess capelin in the Northwest Atlantic in the past and they continue to be the sole method of assessing recruiting year-classes of capelin in Iceland and the Barents Sea. However, given the recent problems and the fact that it is likely that multispecies surveys will soon dominate survey activity in the Region, the Committee recommended that high priority be given to testing the most likely hypotheses raised to explain the recent low biomass estimates. These include capelin too dispersed to be detected by the acoustic system especially near the depth limits of the system, capelin in the "acoustic dead zone" near bottom and capelin occurring outside the survey area. It may not be possible to test all possible hypotheses but those considered most likely and most tractable should be given highest priority. This testing should be done during the shiptime allocated for the autumn capelin acoustic survey.

2) Different indices were combined, unweighted, in the multiplicative cohort model. The Committee recommends that the question of appropriate methods of weighting different indices in this model be referred to the SSS Committee.

3) If the 1995 capelin fishery does not open or operates at a reduced level, commercial catch rate data will not be available nor will commercial sampling data. The Committee therefore recommends the following:
   a) the aerial survey be conducted in 1995;
   b) the egg deposition studies be continued (former NCSP project) see below;
   c) capelin should be sampled on spawning beaches to provide age composition data;

   Items a) and b) require immediate allocation of funds and extensive planning and represent continuation of valuable time series of data. Item c) should be planned as a contingency in the event a fishery does not develop. Funding of b) above would guarantee the collection of adult capelin on spawning beaches.

5) The aerial survey index using school areas assumes all capelin schools encountered are of uniform density. The Committee recommends for 1996 that an inshore acoustic program be developed in coordination with the aerial survey to investigate the relationship between school area, colour as viewed by the imaging spectrometer and acoustic density for prespawning schools.

6) Greenland halibut are known to be important predators of capelin. There is an extensive database on Greenland halibut food and feeding and the Committee recommends that this database be analyzed to augment our knowledge of predator-prey relationships and distribution patterns of capelin from predator stomachs.

References

Lawson, J. W., and G. B. Stenson. (in press) Historic variation in the diet of harp seals (Phoca groenlandica) in the Northwest Atlantic. Proc. of the International Symposium on the Biology of Marine Mammals in the Northwest Atlantic. Tromso, Nov. 29-Dec. 1, 1994.

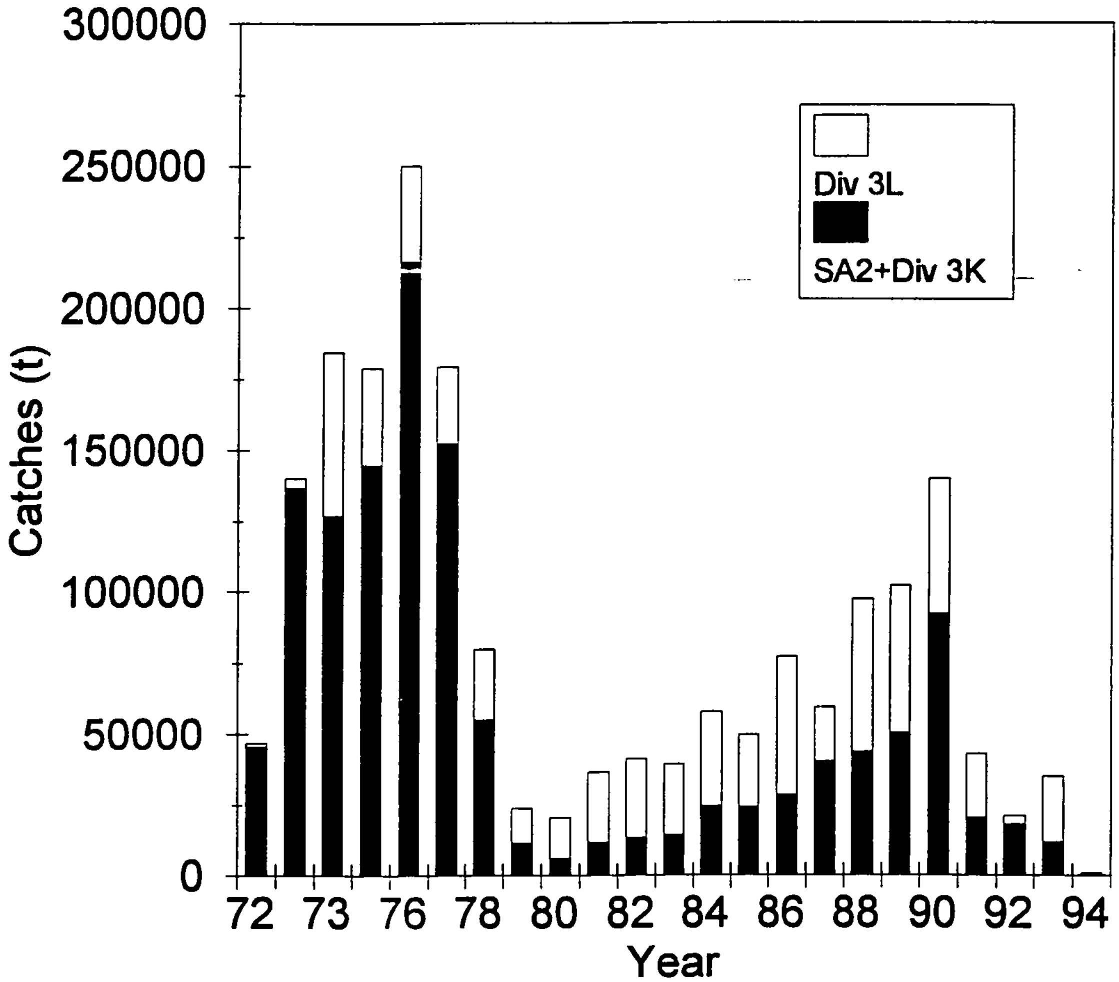


Fig. 1. Catches of capelin in SA2 + Div. 3K and Div. 3L, 1972-94.

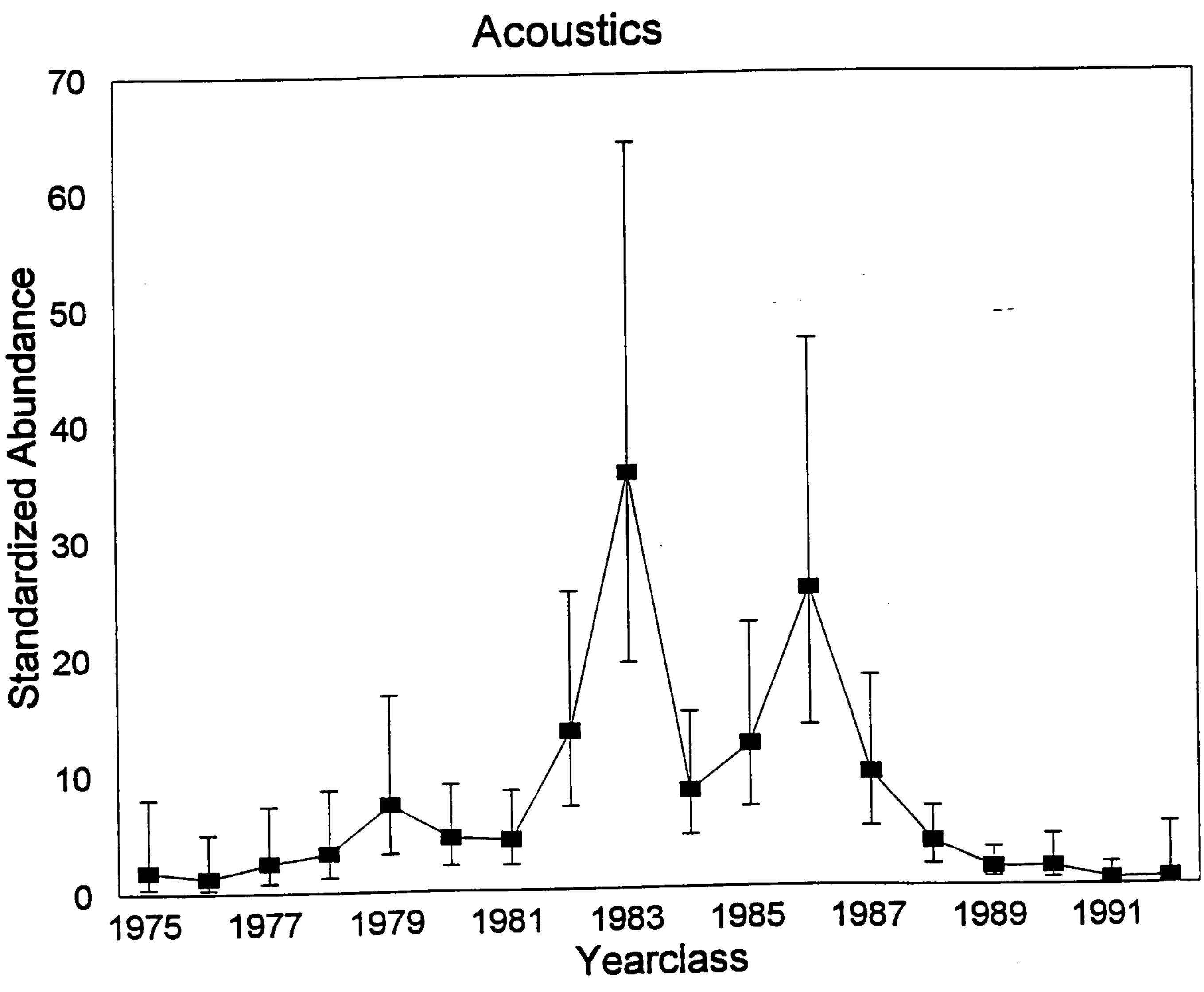


Fig. 2. Standardized abundance and 95% confidence intervals of capelin year-classes from multiplicative model using acoustics data as input.

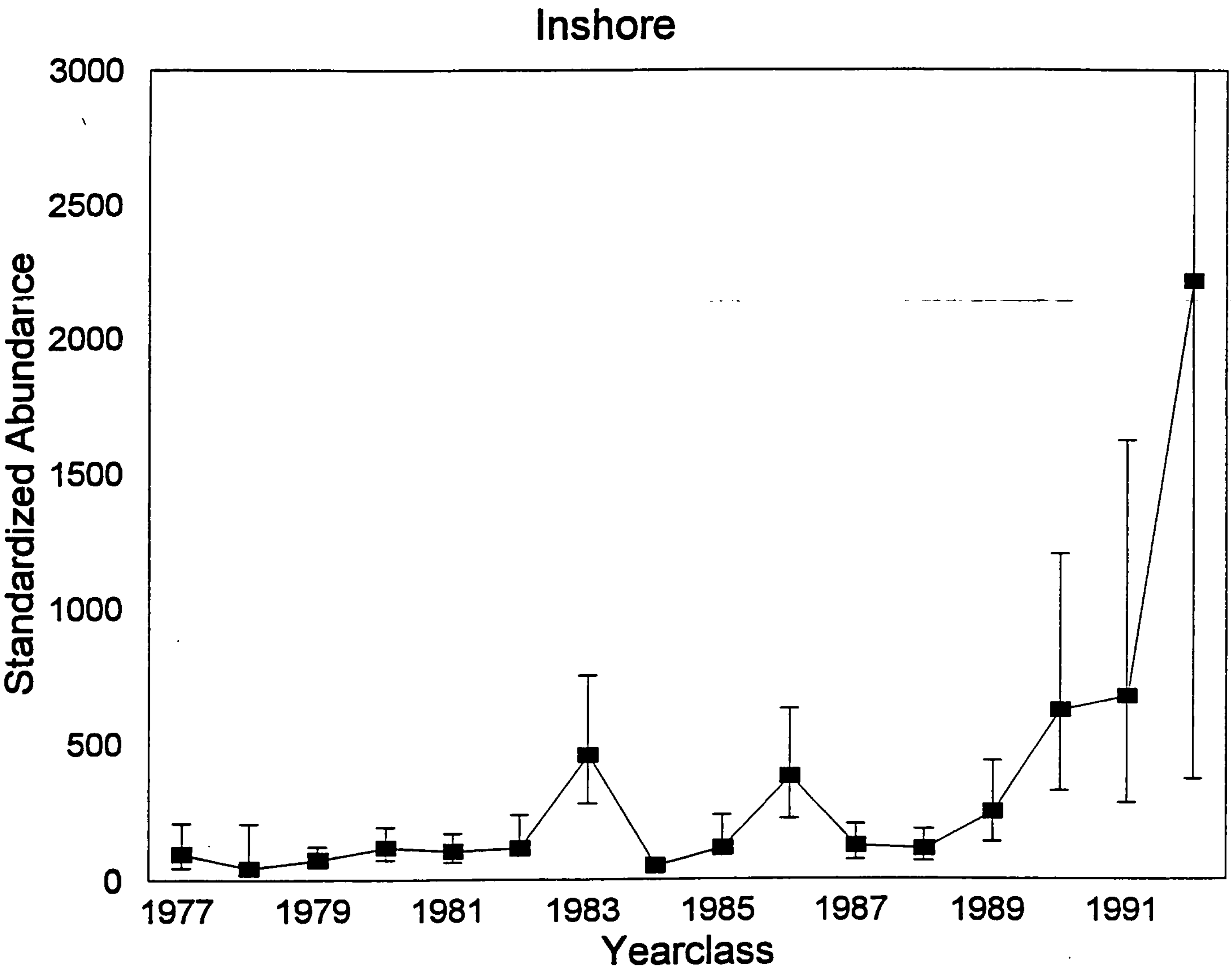


Fig. 3. Standardized abundance and 95% confidence intervals of capelin year-classes from the multiplicative model using inshore indices as input.

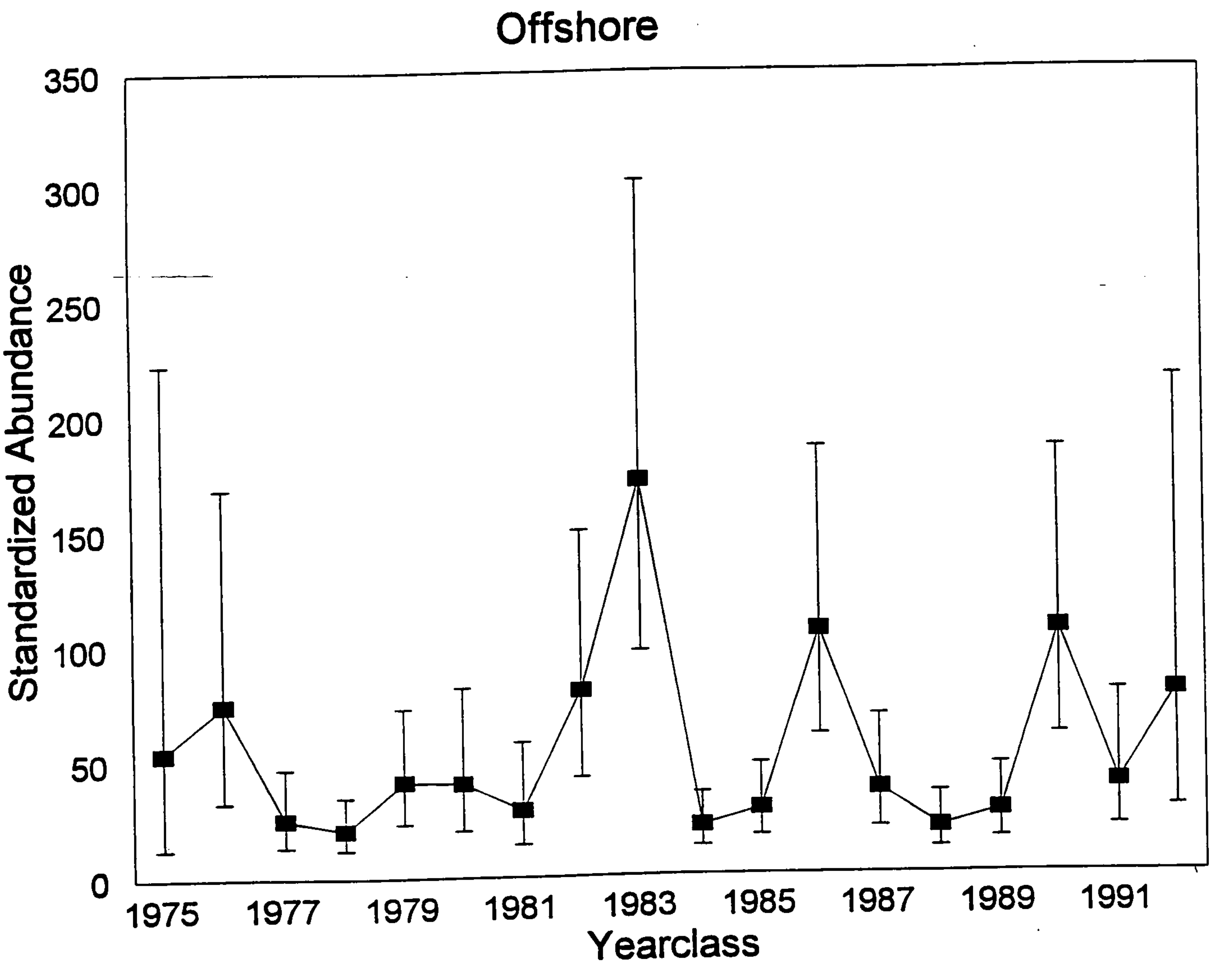


Fig. 4. Standardized abundance and 95% confidence intervals of capelin year-classes from the multiplicative model using offshore indices as input.

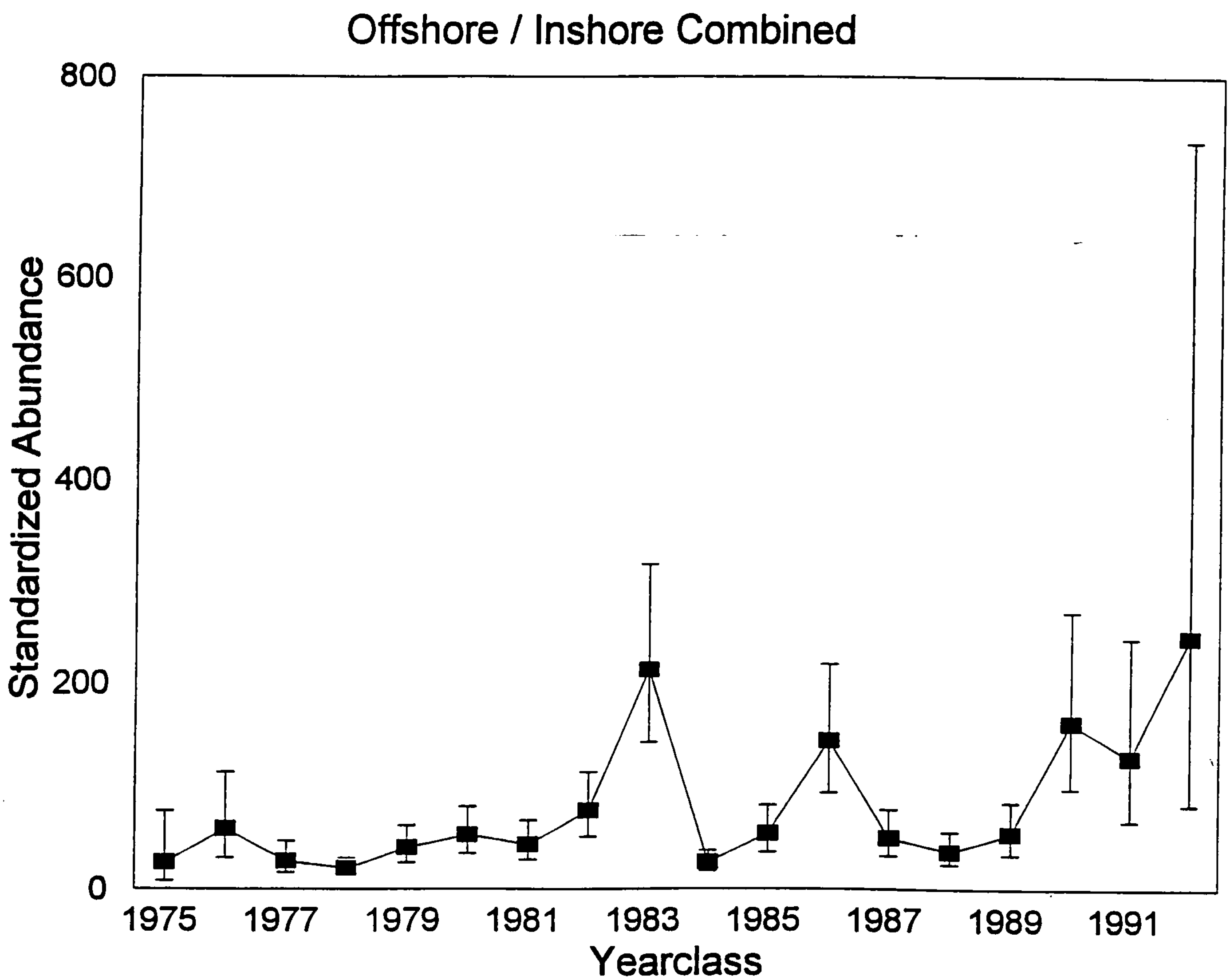


Fig. 5. Standardized abundance and 95% confidence intervals of capelin year-classes from the multiplicative model. Inputs were inshore and offshore indices as well as Russian autumn Div. 2J3K acoustic estimates for calibration.

Appendix 1

List of Participants

Name	Affiliation
Anderson, J.	Fish. Ecol., DFO
Campbell, J. S.	NCSP, DFO
Carscadden, J.	PSMM, DFO
Chardine, J.	Canadian Wildlife Service
Dalley, E.	Fish. Ecol., DFO
Helbig, J.	Phys. Ocean., DFO
Knight, L.	FHM/RMD, DFO
Lang, C.	PSMM, DFO
Lilly, G.	Fish. Ecol., DFO
Miller, D.	PSMM, DFO
Myers, R.	CODE, DFO
Nakashima, B.	PSMM, DFO
Narayanan, S.	Phys. Ocean., DFO
Parsons, D. (Chair)	PSMM, DFO
Pepin, P.	Fish. Ecol., DFO
Shelton, P.	CODE, DFO
Sjare, B.	PSMM, DFO
Stenson, G.	PSMM, DFO
Wheeler, J.	PSMM, DFO
Winters, G.	PSMM, DFO

Appendix 2

1994 NEWFOUNDLAND CAPELIN MANAGEMENT PLAN

JUNE 1994

Appendix 2

1994 NEWFOUNDLAND CAPELIN MANAGEMENT PLAN

I. MANAGEMENT OBJECTIVES:

1) To protect and conserve capelin stocks.
2) To maximize the harvesting, processing and marketing returns from the capelin resource.

II. RESOURCE MANAGEMENT:

A) Whole Frozen Females

The Atlantic total allowable catch (TAC) has been established at 47,545 t. This TAC level is slightly higher than the 1993 level of 45,390 t and reflects the cautious advice provided by scientists on the capelin stocks. The total TAC includes 450 t which has been provided to allow an experimental fixed gear fishery in the Hermitage/Harbour Breton area (3Ps).

This TAC level is sufficient to supply the estimated female capelin market. This is a maximum TAC level. Should capelin runs to the beaches be less than normal, further curtailment of quotas or cessation of fishing will occur.

Closure of the fishery will also occur if the size composition of the catch in an area falls below what is generally acceptable in the market, and dumping of fish could occur. Due to the expected market demands in 1994, the size criteria has been established at 50 count per kilogram. In addition, fishermen will be required to land capelin which are at least 30 percent female. Fishermen should sample their catches to ensure they meet these criteria before taking any capelin onboard their vessel.

The regional allocations are sub-divided on an area and gear type basis. The quotas for the province of Newfoundland and Labrador are detailed in the allocation table.

B) Area sub-divisions

White Bay, north of Cape Fox, will be managed as a separate area for fixed gear. This area will be further sub-divided at Fischott Island.

Notre Dame Bay will be divided into three sections for fixed gear: Cape John to North Head; North Head to Dog Bay Point; Dog Bay Point to Cape Freels. Fogo Island and Change Islands will be included in the section from North Head to Dog Bay Point.

The Southern Shore area, including Trepassey Bay from Cape Pine to Cape Race, will be divided into three sections for fixed gear: Cape Pine to Cape Neddick; Cape Neddick to

Long Point; and Long Point to Cape St. Francis. The Southern Shore area for purse seine will be from Cape Race to Cape St. Francis.

The 4R3Pn area will be divided into five sections for fixed gear: 3Pn and Cape Ray to Broom Point; Broom Point to Point Riche; Point Riche to Big Brook; Big Brook to Cape Bauld; and Labrador.

C) Quota Transfers

Once an area specific quota has been reached that quota area will be closed and processors will have to access areas where quota remains.

Reallocations of quotas will not be considered in 1994 as a precautionary measure to provide for resource conservation.

D) Other Markets:

Where possible, other market requirements are to be satisfied within the allocations established for the frozen female quota. No additional quotas will be provided to supply capelin to these markets.

III. SEASONS:

The capelin season will open on June 11 in 4R (mobile gear), 3P, St. Mary's Bay and the Southern Shore, June 15 in Conception Bay, Trinity Bay and 4R (fixed gear) south of Broom Point, June 20 in Bonavista Bay, Notre Dame Bay and 4R (fixed gear) from Broom Point to Big Brook, and June 25 in White Bay, Labrador and 4R (fixed gear) north of Big Brook. However, in some of these areas industry sampling programs will be implemented to determine when capelin are suitable for harvesting, and the opening date in these areas will be based on those results. In areas where fishermen and processors agree to open the season based upon an industry sampling program, industry must provide the department with the agreed criteria. Established opening dates will only be changed as a result of a unanimous request from all sectors of the industry or if gear is placed in the water in advance of capelin appearing in an area.

The season in each area will continue until the established quota has been reached or the fishery is no longer active. Each quota will be strictly enforced and closures will be based on the recorded landings and projected catch. Notice of closures will be as short as necessary to ensure quotas are not exceeded.

Appendix 2

IV. RESOURCE ACCESS:

A. MOBILE GEAR (PURSE SEINES)

1) No new capelin purse seine licences will be issued in 1994.

2) Fishermen who held a capelin purse seine licence in 1993 are eligible for a licence in 1994.

3) Capelin purse seine licences will be valid for Capelin Fishing Areas 1 - 11 or Capelin Fishing Areas 12 - 14.

4) Fishermen who hold a capelin purse seine licence may not hold a capelin fixed gear licence.

5) The holder of a capelin purse seine licence may exchange his purse seine licence for a fixed gear licence. The applicant may retain all other purse seine licences he holds. The capelin purse seine licence may not be transferred prior to applying for a fixed gear licence. The applicant gives up any rights to a capelin purse seine licence in the future.

B. FIXED GEAR (TRAPS AND BAR SEINES)

1) No new capelin fixed gear licences will be issued in 1994.

2) Full-time fishermen who held a capelin fixed gear licence in 1993 are eligible for a licence in 1994.

3) Fixed gear licences will be valid only for the quota area in which the fisherman resides or has historically fished (one of fishing areas 1-14).

4) Fishermen who hold a capelin fixed gear licence may not hold a capelin purse seine licence.

5) Fishermen are permitted to fish a maximum of two traps and one bar seine per licence.

6) In the Hermitage/Harbour Breton area (3Ps) 50 experimental fixed gear licences will be made available to allow fishermen in that area to assess the potential for a capelin fishery.

Appendix 2

C. OTHER LICENCING PROVISIONS

1) The department will not issue any specific licences to transport capelin. The only vessels permitted to transport capelin are those which were used to catch capelin.

2) Licence holders who did not fish in one of the years 1991, 1992 or 1993 will not be permitted to lease a vessel to participate in the 1994 capelin fishery.

3) The transfer of capelin licences is currently not permitted, with the exception of fishers participating in early retirement programs.

V. **TRIP LIMITS:**

The 50,000 lb trip limit implemented for capelin purse seine vessels in Capelin Fishing Areas 1 - 11 in 1990 will be continued in 1994. In addition, a 50,000 lb trip limit will be implemented for fixed gear vessels in 1994. Trip limits will not apply in Capelin Fishing Areas 12 - 14.

VI. **BY-CATCH RESTRICTIONS:**

In accordance with the Atlantic Fishery Regulations and the Fishery (General) Regulations, only capelin may be retained from catches made in capelin gear. Any by-catch of other species must be released.

Appendix 2

1994 CAPELIN ALLOCATIONS

NAFO AREA	AREA	FIXED GEAR	PURSE SEINE	TOTAL
2J	LABRADOR	150		150
3K	WHITE BAY (1)	4,475	1,500	5,975
	NOTRE DAME BAY (1)	3,925	1,500	5,425
	TOTAL	8,400	3,000	11,400
3L	BONAVISTA BAY	2,245	1,425	3,670
	TRINITY BAY	4,490	1,870	6,360
	CONCEPTION BAY	3,710	3,370	7,080
	SOUTHERN SHORE (1) (2)	2,300	190	2,490
	ST. MARY'S BAY	450	1,680	2,130
	TOTAL	13,195	8,535	21,730
3Ps	PLACENTIA BAY	1,740	260	2,000
	FORTUNE BAY AND WEST (3)	510	30	540
	TOTAL	2,250	290	2,540
4R3Pn	WEST COAST (1) (4)	4,000	6,000	10,000
	NFLD PROVINCE TOTAL	27,995	17,825	45,820
	4ST			1,725
	ATLANTIC COAST TOTAL			47,545

NOTES TO ALLOCATION TABLE:

1. Sub-divisions of the fixed gear quota in White Bay, Notre Dame Bay, Southern Shore and 4R3Pn are detailed on the attached table.

2. Trepassey Bay from Cape Pine to Cape Race is included in the Southern Shore quota area for fixed gear only.

3. The fixed gear quota includes 450 t for an experimental fishery in the Hermitage/Harbour Breton area.

4. The purse seine quota in 4R3Pn is further sub-divided with 3,500 t for vessels over 65 feet and 2,500 t for vessels less than 65 feet.

Appendix 2

1994 CAPELIN FIXED GEAR SUB-DIVISIONS

BAY	AREA	QUOTA
WHITE BAY	CAPE BAULD TO FISCHOTT ISLAND	965
	FISCHOTT ISLAND TO CAPE FOX	325
	CAPE FOX TO CAPE ST. JOHN	3,185
NOTRE DAME BAY	CAPE ST. JOHN TO NORTH HEAD	1,105
	NORTH HEAD TO DOG BAY POINT	2,300
	DOG BAY POINT TO CAPE FREELS	520
SOUTHERN SHORE	CAPE ST. FRANCIS TO LONG POINT	600
	LONG POINT TO CAPE NEDDICK	400
	CAPE NEDDICK TO CAPE PINE	1,300
4R3Pn	SOUTH OF BROOM POINT	640
	BROOM POINT TO POINT RICHE	445
	POINT RICHE TO BIG BROOK	1,430
	BIG BROOK TO CAPE BAULD	775
	LABRADOR	710

Appendix 3. Indices available for use in the multiplicative model.

OBS	Survey	Year	Age 0	1	2	3	4	5	Samp. size	2J	3K
Aerial survey index											
1	A	1982	-	-	5	563	70	23			
2	A	1983	-	-	40	716	478	16			
3	A	1984	-	-	8	215	308	25			
4	A	1985	-	-	115	689	252	80			
5	A	1986	-	-	2	555	308	22			
6	A	1987	-	-	63	345	1639	119			
7	A	1988	-	-	109	766	214	196			
8	A	1989	-	-	14	1275	401	21			
9	A	1990	-	-	124	490	713	19			
	A	1991	-	-	-	-	-	-			
10	A	1992	-	-	184	967	1744	322			
11	A	1993	-	-	86	1068	386	50			
12	A	1994	-	-	402	1684	930	206			
Larval index											
13	D	1991	222	-	-	-	-	-			
14	D	1992	470	-	-	-	-	-			
15	D	1993	336	-	-	-	-	-			
16	D	1994	153	-	-	-	-	-			
Egg deposition index (unadjusted)											
17	E	1991	-	-	151	1232	1639	406			
18	E	1992	-	-	141	742	1338	247			
19	E	1993	-	-	221	2747	992	127			
20	E	1994	-	-	132	565	312	69			
Purse seine catch rate index											
21	M	1981	-	-	1	123	123	112			
22	M	1982	-	-	3	395	58	18			
23	M	1983	-	-	14	341	210	9			
24	M	1984	-	-	4	158	248	20			
25	M	1985	-	-	64	386	143	54			
26	M	1986	-	-	1	441	215	16			
27	M	1987	-	-	14	120	643	47			
28	M	1988	-	-	42	358	107	111			
29	M	1989	-	-	3	510	163	8			
30	M	1990	-	-	10	304	414	10			
31	M	1991	-	-	50	315	219	36			
32	M	1992	-	-	148	705	89	5			
33	M	1993	-	-	51	665	45	3			
Egg deposition index (adjusted)											
34	R	1991	-	-	112	912	1212	301			
35	R	1992	-	-	154	813	1466	271			
36	R	1993	-	-	148	1840	665	85			
37	R	1994	-	-	333	1437	791	175			

Appendix 3. Continued ...

OBS	Survey	Year	Age 0	1	2	3	4	5	Samp. size	2J	3K
Trap catch rate index											
38	T	1981	-	-	1	941	943	831			
39	T	1982	-	-	16	1908	237	95			
40	T	1983	-	-	67	1202	719	26			
41	T	1984	-	-	30	766	1095	93			
42	T	1985	-	-	334	1998	731	245			
43	T	1986	-	-	10	3013	1674	155			
44	T	1987	-	-	124	697	3216	243			
45	T	1988	-	-	323	2271	634	615			
46	T	1989	-	-	38	3447	1083	122			
47	T	1990	-	-	55	2198	3200	83			
48	T	1991	-	-	723	3180	2248	365			
49	T	1992	-	-	730	4056	648	55			
50	T	1993	-	-	675	5622	432	20			
Russian 3L spring acoustic index											
51	C	1982	-	-	12	19	5	1			
	C	1983	-	-	.7	4.3	6.4	1.9			
52	C	1984	-	-	124	50	16	2			
53	C	1985	-	-	231	53	4	0.9			
	C	1986	-	-	18.4	70.9	5.9				
54	C	1987	-	-	46	31	30	1			
55	C	1988	-	-	178	92	34	8			
56	C	1989	-	-	79	97	11	2			
57	C	1990	-	-	156	106	36	2.5			
58	C	1991	-	-	4	3	2	.1			
	C	1992	-	-	-	-	-	-			
59	C	1993	-	-	1	9	1	-			
Canadian 3L spring acoustic index											
60	L	1982	-	<.1	9.7	16.2	2.4	1.0			
61	L	1983	-	<.1	3.4	1.9	1.0	1.0			
62	L	1984	-	.1	21.0	6.2	3.1	1.0			
63	K	1985	-	.2	379.0	81.0	3.8	2.3			
64	L	1986	-	0	59.4	158.0	21.3	1.0			
65	L	1987	-	.3	88.0	18.0	38.9	4.0			
66	L	1988	-	13.6	380.0	66.0	9.7	17.0			
67	L	1989	-	3.4	315.0	96.0	11.0	1.4			
68	L	1990	-	18.9	353.0	169.0	56.0	1.9			
69	L	1991	-	18.7	8.0	3.0	1.0	<0.1			
	L	1992	-	5.7	19.0	6.5	0.7				
Groundfish 3L spring bycatch index											
70	N	1985	-	-	63.0	149.0	14.0	6.0	7		
71	N	1986	-	-	14.0	243.0	80.0	6.0	27		
72	N	1987	-	-	7.0	14.0	65.0	7.0	13		
73	N	1988	-	-	141.0	96.0	43.0	36.0	3		
		1989									
74	N	1990	-	-	23.0	128.0	94.0	8.0	2		
75	N	1991	-	-	58.0	146.0	55.0	8.0	7		
76	N	1992	-	-	421.0	70.0	13.0	1.0	1		
77	N	1993	-	-	81.0	193.0	11.0	1.0	4		
78	N	1994	-	-	474.0	41.0	5.0	4.0	2		

Appendix 3. Continued ...

OBS	Survey	Year	Age 0	1	2	3	4	5	Samp. size	2J	3K
Russian 2J3K fall acoustic index											
79	B	1974	-	-	6.0	27.0	10.0	4.4			
80	B	1975	-	-	27.0	13.0	3.0	1.5			
81	B	1976	-	0.5	7.0	36.0	2.0	.4			
	B	1977	-	-	-	-	-	-			
82	B	1978	-	0.1	1.0	.8	.4	.1			
83	B	1979	-	0	.03	.2	.3	.1			
84	B	1980	-	-	.1	.4	.2	.04			
		1981									
85	B	1982	-	.2	18.0	18.0	1.0	-			
86	B	1983	-	2.5	20.0	16.0	3.0	-			
87	B	1984	-	41.5	20.0	4.0	1.0	-			
88	B	1985	-	0.8	81.0	18.0	3.0	.2			
89	B	1986	-	0.5	19.0	45.0	4.0	.1			
90	B	1987	-	6.0	45.0	7.0	7.0	.2			
	B	1988	-	-	-	-	-	-			
	B	1989	-	-	-	-	-	-			
91	B	1990	-	0	15.0	13.0	3.0	.1			
92	B	1991	-	0	4.0	1.0	1.0	0			
93	B	1992	-	0	0.5	.1	-	-			
Groundfish 3L fall bycatch index											
94	F	1985	-	44	220.0	28.0	.4	0	9		
	F	1986	-	-	-	-	-	-			
	F	1987	-	-	-	-	-	-			
95	F	1988	-	45	261.0	5.0	.5	1.0	3		
96	F	1989	-	57	140.0	71.0	1.7	0	2		
	F	1990	-	-	-	-	-	-			
97	F	1991	-	352	56.0	12.0	-	-	4		
98	F	1992	-	99	466.0	2.0	-	-	2		
99	F	1993	-	154	125.0	66.0	5.1	0	3		
100	F	1994	-	1586	8.0	0	0	0	1		
Groundfish 2J3K fall bycatch index											
101	G	1980	-	4	34.0	31.0	7.0	0.7		3	2
102	G	1981	-	1	77.0	26.0	5.0	1.3		3	1
103	G	1982	-	0	31.0	97.0	6.0	0		1	2
	G	1983	-	-	-	-	-	-			
	G	1984	-	-	-	-	-	-			
	G	1985	-	-	-	-	-	-			
	G	1986	-	-	-	-	-	-			
104	G	1987	-	0	39.0	23.0	41.0	11.9		1	2
105	G	1988	-	15	131.0	37.0	2.0	2.5		2	3
	G	1989	-	-	-	-	-	-			
	G	1990	-	-	-	-	-	-			
106	G	1991	-	5	166.0	49.0	2.0	0.2		1	6
107	G	1992	-	1	248.0	29.0	1.0	0		0	3
108	G	1993	-	7	128.0	87.0	9.0	0		0	8
109	G	1994	-	40	173.0	20.0	3.0	1.1		0	12
Canadian 3L fall acoustic index											
110	H	1993	-	107	4.0	.1	0	0			
111	H	1994	-	332	11.0	.1	.1	0			

Appendix 3. Continued ...

OBS	Survey	Year	Age 0	1	2	3	4	5	Samp. size	2J	3K
Russian 2J3K fall commercial catch rate index											
112	J	1972	-	0	33.0	180.0	59.0	8.0			
113	J	1973	-	0	83.0	99.0	132.0	16.0			
114	J	1974	-	0	92.0	223.0	80.0	56.0			
115	J	1975	-	0	400.0	179.0	53.0	12.0			
116	J	1976	-	3	46.0	437.0	36.0	5.0			
117	J	1977	-	0	12.0	124.0	248.0	26.0			
118	J	1978	-	9	38.0	71.0	97.0	14.0			
119	J	1979	-	3	105	14	3	4			
120	J	1980	-	5	206	185	49	7			
121	J	1981	-	32	248	59	15	13			
122	J	1982	-	6	247	61	5	1			
123	J	1983	-	19	215	256	39	3			
124	J	1984	-	41	262	77	39	5			
125	J	1985	-	1	464	200	19	10			
126	J	1986	-	2	128	419	50	4			
127	J	1987	-	5	340	150	248	27			
128	J	1988	-	5	430	112	14	33			
129	J	1989	-	2	248	332	26	2			
130	J	1990	-	0	208	281	95	3			
131	J	1991	-	5	104	18	0	0			
Canadian 2J3K fall acoustic index											
132	K	1981	-	68	59	7	3	1			
	K	1982	-	-	-	-	-	-			
133	K	1983	-	0	3	1	1	0			
134	K	1984	-	0	35	7	4	.4			
135	K	1985	-	0	54	14	2	.6			
136	K	1986	-	0	7	12	1	.2			
137	K	1987	-	.7	4	1	1	.1			
138	K	1988	-	15.8	96	14	2	3.9			
139	K	1989	-	1.9	59	35	3	.5			
140	K	1990	-	1.4	3	2	1	<.1			
141	K	1991	-	4.7	3	1	1	<.1			
142	K	1992	-	0.1	2	.2	<.1	0			
143	K	1993	-	0.2	1	.3	<.1	<.1			
144	K	1994	-	0.3	.5	.1	<.1	0			
Dalley 3L fall Campelen index											
145	O	1992	-	34	28	-	-	-	6		
146	O	1993	-	6	2	-	-	-	3		
147	O	1994	-	50	8	-	-	-	3		

Notes on indices available for multiplicative model.
- alphabetic codes in multiplicative model computer database

A) Aerial survey index
- age compositions up to 1990 from the commercial fishery
- 1991 survey too early and considered an underestimate
- age compositions 1992-94 from NCSP study
- retained for multiplicative model

D) Larval index
- from NCSP study
- relative year-class strengths have not been validated so it was not used

E) Egg deposition index (unadjusted)
- no. of eggs
- not in multiplicative model because has not been validated as an index of abundance

M) Purse seine catch rate index
- age compositions from purse seine samples
- retained in model - some concern about purse seine catch rate as indicator of abundance but consistent with trap catch rates
- no 1994 fishery

R) Egg deposition index (adjusted)
- age compositions from NCSP study
- egg deposition index adjusted for off-beach spawning
- adjustment not accepted and index not used

T) Trap catch rate index
- age compositions from trap catches
- retained index
- retained in multiplicative model
- no 1994 fishery

C) Russian 3L spring acoustic survey
- 1983, 1986 not used because survey conducted in June, others earlier
- retained and used with other acoustic indices

L) Canadian 3L spring acoustic index
- one-year-olds not used
- retained and used with other acoustic indices

N) Groundfish 3L spring bycatch index
- not used

B) Russian 2J3K fall acoustic index
- one- and five-year-olds not used
- used with other acoustic indices

F) Groundfish 3L fall bycatch index
- four- and five-year-olds not used
- 1994 data not used because of small sample size
- used in model

G) Groundfish 2J3K fall bycatch index
- one- and five-year-olds not used
- used in model

H) Canadian 3L fall acoustic index
- only two years data, not used

J) Russian 2J3K fall commercial catch rate index
- one-year-olds not used
- kept in model

K) Canadian 2J3K fall acoustic index
- one- and five-year-olds not used
- used with other acoustic indices

O) Dalley 3L fall Campelen index
- short series, not validated
- not used