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Biological Aspects of Capelin and a Sequential Capelin Abundance Model for the Division 3LNO stock

by

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Introduction

The stock of capelin spawning on the Southeast Shoal (Div. 3NO) has been the subject of intensive study recently because of unusual biological characteristics in 1976 (Carscadden, 1978) and declining catches in 1977 and 1978. Annual acoustic surveys in Div. 3NO provided estimates of 1.05, 0.685 and 1.00 million metric tons of capelin in 1975, 1976 and 1977, respectively (Klochkov and Seliverstov, 1978).

Analysis of the 3NO capelin stock using sequential capelin abundance models indicated that for the years 1972-1974 inclusive, the biomass was 400,000-500,000 metric tons but subsequently declined over the next three years to approximately 100,000 metric tons (Carscadden, et al, 1978).

Capelin migrating to the Southeast Shoal to spawn are also subjected to a fishery in ICNAF Div. 3L. It is believed that this fishery not only takes capelin that will spawn in Div. 3NO but also fish that will move inshore to spawn on beaches in Newfoundland.

This paper presents data relevant to the management of the capelin stock occurring in Div. 3LNO.

Capelin Catches and Catch Per Unit Effort

In ICNAF Div. 3L, substantial catches of capelin were first reported in 1974; nominal catches were lower and approximately equal in 1975 and 1976, probably owing to quotas, but declined in 1977 and 1978 (Fig. 1). Estimates of catch per unit effort in Div. 3L (Table 1) do not show a marked decline until 1978.

Table 1. Catch per unit effort (metric tons per fishing day) for USSR trawlers >2000GRT fishing in 3L (April and May combined) and 3N (June).

Year	Catch per unit effort 3L	Catch per unit effort 3N
1972		49.4
1973	24.9*	47.5
1974	43.4	50.1
1975	46.1	42.3
1976	43.7	44.5
1977	39.9	37.9
1978	27.6**	0.81**

* May only
** FLASH data (not by tonnage class)

Catches of capelin in Div. 3NO (Fig. 1) for the years 1973-1976 were in excess of 100,000 metric tons but have declined to approximately 45,000 and 5,000 metric tons in 1977 and 1978, respectively. Estimates of catch per unit effort in the 3N fishery (Table 1) show a peak in 1974 and a decline since then.

Canadian Acoustic Survey 1978

During the period June 11-July 4, 1978, the research vessel, Gadus Atlantica, attempted to locate mature capelin in Div. 3LNO and estimate capelin biomass using acoustic techniques. However, no concentrations of mature capelin were located. Contact was maintained with USSR and Norwegian scientists throughout most of the survey; these scientists reported that their commercial fishing fleets were experiencing problems locating fishable capelin concentrations. An exception occurred when Norwegian purse seiners took most of their total catch in about one day on the Southeast Shoal (G. Sangolt, personal communication). Because of the lack of mature capelin during this period, an acoustic estimate of capelin could not be made.

Both sand launce and immature capelin (believed to be of the 1977 year-class (Fig. 2)) were taken in midwater trawl sets made in the area between the Virgin Rocks and the Southeast Shoal.

Biological Characteristics

The 1974 year-class predominated in both sexes of capelin collected from Div. 3L in May and June (Fig. 3). The 1973 year-class was also strong in both months for both sexes. The 1975 year-class was relatively weak in May and very weak in June.

Mean lengths-at-age of male capelin from 3L (Table 2) were slightly larger than males of the same age from 3N. Females at ages 3 and 4 were slightly smaller than females from 3N while for ages 4 and 5, females were about the same length as females from 3N.

Table 2. Mean length-at-age of capelin from Division 3L, May and June, 1978.

	Age (yr) and Length (mm)			
Males	3	4	5	6
May	183	178	182	
June		182	178	184
Females				
May	141	155	170	188
June	131	151	163	152

In Div. 3N, males of the 1973, 1974, and 1975 year-classes were in approximately equal proportions whereas females of the 1974 year-class were more abundant (Table 3). In both sexes, the 1973 year-class was still strong as 5-year-olds; the strength of this year-class was comparable to the 1969 year-class which was recognized to be strong. The mean lengths-at-age for both sexes in 3N were very small in 1978. Growth appears to have been slower for the 1973, 1974, and 1975 year-classes than for previous year-classes.

Table 3. Percent composition and mean length-at-age (in parentheses) of mature capelin from ICNAF Division 3N, June only.

	Age (yr) and Length (mm)				
Males	2	3	4	5	6
1967		66(184)	30(191)	4(198)	
1969	6(164)	23(182)	68(193)	4(193)	
1970	4(166)	52(184)	40(189)	4(198)	
1972		36(178)	63(185)	1(190)	
1973		5(175)	86(179)	9(182)	
1974		29(187)	41(193)	29(194)	2(192)
1975	5(168)	51(181)	42(194)	2(197)	
1976		59(174)	37(176)	4(180)	1(181)
1977		16(174)	80(184)	4(183)	
1978		31(151)	29(175)	33(179)	7(179)
Females					
1967		49(166)	31(173)	18(179)	2(189)
1969	16(146)	47(159)	32(170)	5(184)	1(194)
1970		52(165)	28(176)	20(182)	
1972		43(158)	52(169)	5(183)	1(186)
1973	1(148)	10(158)	82(165)	7(173)	
1974	1(146)	28(166)	27(176)	42(179)	3(185)
1975	7(148)	39(163)	30(177)	12(185)	11(189)
1976		72(155)	23(162)	4(175)	1(182)
1977		42(151)	57(161)	1(190)	
1978		23(143)	44(157)	31(166)	3(167)

Sequential Capelin Abundance Models (SCAM)

Sequential capelin abundance models (SCAM 1 and SCAM 2) were first used to estimate the biomass of capelin in Div. 3NO (Carscadden *et al*, 1978). The SCAM 1 version was considered to be the most realistic because catches were separated into before and during spawning catches and fishing mortality was considered to occur at the same time as spawning mortality.

For this paper, we have constructed additional sequential capelin abundance models that retain the best points of the SCAM 1 version but also contain improvements. Two models have been constructed: one models the capelin situation in Div. 3L and the second models the capelin situation in Div. 3LNO.

Sequential Capelin Abundance Model 3L (SCAM 3L)

(1) Seasonal Aspects of the Model:

The fishery was assumed to occur on mature fish only from 1 January to 31 May each year. Spawning occurred on 1 June each year. The only mortality occurring after spawning is natural mortality. An annual natural mortality value of 0.3 was used.

(2) Age Structure and Proportions Mature:

Since 6-year-old capelin do occur in the catches in all years, it was assumed that this age was the terminal age. Capelin at ages 5 and 6 were assumed to be 100% mature; therefore, $p = 1.0$ for these ages and only survivors of spawning at age 5 are in the spawning population at age 6. The values of p for ages 3 and 4 were $p = 0.6$ and $p = 0.9$, respectively. These values of p represent the proportions of mature fish in the population on 1 January of that year.

(3) Numbers-at-age:

Numbers-at-age for Div. 3L were calculated from USSR sampling data for 1976 and 1977 (Konstantinov and Noskov 1977, Konstantinov and Noskov 1978) and from Canadian sampling data in all other years (Table 4).

(4) Spawning Mortality:

The calculation of spawning mortality in Carscadden et al (1978) was incorrect and spawning mortality was calculated in the folowing manner.

If the number in the cohort at age t as given as N_t, then pN_t are mature and $(1-p)N_t$ are immature. Therefore, for matures, the annual mortality rate is M + SM and for immatures the annual mortality rate is M.

$$\text{Thus, } N_{t+1} = N_t \left(pe^{-(M+SM)} + (1-p)e^{-M}\right)$$
$$= N_t e^{-M} \left(pe^{-SM} + (1-p)\right)$$

Therefore, Z on the cohort is

$$M - \ln \left(pe^{-SM} + (1-p)\right)$$

Spawning mortalities by sex were calculated using this formula and data from Winters and Campbell (1974). The values of SM for males and females were combined by weighting according to the proportions of males and females in Table 4 of Winters and Campbell (1974).

The calculated SM were

Age	SM
3	1.94
4	1.97
5	1.92

Since these values were almost equal, the mean value for SM of 1.94 was used for all ages from 3 to 6.

Table 4. Numbers-at-age ($x10^{-3}$) of capelin in catches from ICNAF Division 3L, 1972-1978.

Age	1972	1973	1974	1975	1976	1977	1978
3	20482	1740	441357	507592	588684	193635	89377
4	7517	39851	458281	362128	239698	365235	412937
5	371	7675	493899	53229	50128	23949	182241
6	72	539	45521	80046	8994	1796	24844

(5) Fishing Mortality:

In all runs of the model the starting fishing mortality was set and fishing mortalities for the year-class were generated. For example, the 1972 year-class appears as 6-year-olds in 1978. The terminal fishing mortality for this age-class at age 6 was set and fishing mortalities were then calculated in the model for this year-class at each age back to age

3 in 1975. This procedure was repeated for the 1973, 1974, and 1975 year-classes with the same fishing mortality as the 1972 year-class. Thus, in 1977, we calculated fishing mortalities for ages 3, 4, and 5. From these calculated fishing mortalities the highest value was selected as the fishing mortality on age 6 in 1977 (1971 year-class). This procedure was repeated for each year.

The highest fishing mortality was selected because it was assumed that older fish would be mature first and would probably school earlier and be subjected to a longer period of fishing. Within spawning concentrations older, larger individuals appear earlier (Winters and Campbell 1974) and, therefore, would be subjected to fishing over a longer time period.

In initial runs of the model, starting F's on age-classes from 3 to 6 in 1978 were the same. A number of runs were made with starting F's ranging from 0.1 to 2.0. Estimates of effort for the 3L fishery from 1973 to 1978 were calculated by:

$$\frac{\text{Total Catch (minus inshore Canadian catch)}}{\text{C/E (USSR trawlers >2000GRT)}}$$

Estimates of F for ages 4, 5, and 6, weighted by the numbers of the mature population at these ages, were made for 1973-1977 inclusive. Functional regressions of Effort versus weighted F of ages 4 and older were then calculated at different values of terminal $F^{(FT)}$ used in the original model runs. The regression with $F_T = 0.15$ yielded a predicted weighted F for 1978 that was closest to F_T (Fig. 4). Thus, the value for weighted F on ages 4+ was selected as F = 0.15.

The starting F's for ages 4, 5, and 6 were then selected by weighting by the mature population in 1978 calculated in the original run at $F_T = 0.15$. This gave starting values of F in 1978 of 0.14 for age 4, 0.17 for age 5 and 0.20 for age 6.

At $F_T = 0.15$, the mean values for fishing mortality at age, 1973-1976, were calculated; it was found that the mean value of F at age 3 was approximately 25% of the mean value of F at age 6. Thus, the starting F at age 3 was set at 0.05.

(6) The Model - SCAM 3L:

A schematic representation of the model is given in Appendix A.

The exploitation rate μ, in year N, is calculated by:

(A) $\mu = \frac{F}{F+MDF}$ (for oldest age-class)

or

$\mu = \frac{F}{F+MDF}(1-e^{-F-MDF})$ (for younger age-classes)

where, MDF is the natural mortality during the fishing period from the beginning of the year to spawning.

Then, $\frac{C}{\mu}$ gives PM_{BYN}

where, PM_{BYN} is the population of mature fish at the beginning of the year N. We know p, the proportion of mature fish in the population; therefore, PM_{BYN}/p gives TP_{BYN}, the total population at the beginning of the year N.

(B) $T_{BYN}\ e^{MAF}$ gives TP_{ASN-1}

where, MAF is the natural mortality from the end of spawning to the end of the year, and TP_{ASN-1} is the total population after spawning in year N-1.

The population TP_{ASN-1} is composed of a population of matures PM_{ASN-1} that survived spawning and immatures PIM_{ASN-1}. The proportions of matures pM and immatures pIM are not known, but are estimated at this time.

$$\text{Thus, } TP_{ASN-1} \left\} \begin{array}{l} \times\ pM \longrightarrow PM_{ASN-1} \\ \times\ pIM \longrightarrow PIM_{ASN-1} \end{array} \right.$$

(C) Then, $PM_{ASN-1}\ e^{SM}$ gives PM_{BSN-1}

where, SM is the spawning mortality and PM_{BSN-1} is the population of matures before spawning in year N-1.

At this point, F is calculated based on

$$\frac{C}{PM_{BSN-1}} \qquad \text{The value of MDF is known.}$$

(D) Then, $PM_{BSN-1}\ e^{F+MDF}$ gives PM_{BYN-1}

and $PIM_{ASN-1}\ e^{MDF}$ gives PIM_{BYN-1}

where, PM_{BYN-1} is the population of matures at the beginning of the year and PIM_{BYN-1} is the population of immatures at the beginning of the year.

The total population at the beginning of the year $TP_{BYN-1} = PM_{BYN-1} + PIM_{BYN-1}$. We know p, proportions mature at the beginning of the year. Therefore,

$$p = PM_{BYN-1} / TP_{BYN-1}$$

Different values of pM and pIM are chosen until the correct value of p is calculated.

The model is continued for all data available. Estimates of 2-year-olds in each year were estimated by $TP_{BY3}\ e^{0.3}$ + Catch of 2 year-olds in that year.

Sequential Capelin Abundance Model 3LNO (SCAM 3LNO)

(1) Seasonal Aspects of the Model:

The fishery was assumed to occur before spawning, from 1 January to 31 May, and during spawning which occurred on 1 June each year. The only mortality occurring after spawning is natural mortality. An annual mortality value of 0.3 was used.

(2) Age Structure and Proportions Mature:

The age-classes and values for p, proportions mature, used in SCAM 3LNO were the same as used in SCAM 3L.

(3) Numbers-at-age:

Numbers-at-age for 3L were the same as used in SCAM 3L. Numbers-at-age for 3NO for 1978 were calculated using sampling data collected by the Canadian Foreign Fisheries Observer Program. Numbers-at-age for 3NO in years previous to 1978 were from Carscadden et al (1978).

Catches were divided into before spawning and during spawning components in a manner similar to that in Carscadden et al (1978). Any catches occurring in Div. 3L and 3Ø at any time and in Div. 3N prior to June were assumed to be composed of mature prespawning capelin and were treated as a before spawning catch. Catches occurring in Div. 3N any time during and after June were assumed to be composed of spawning capelin; these catches were treated as during spawning catches (Table 5).

Table 5. Numbers-at-age ($x10^{-3}$) of capelin in catches from ICNAF Division 3LNO, 1972-1978. (BS = before spawning, DS = during spawning.)

Age	1972		1973		1974		1975		1976		1977		1978	
	BS	DS	BS	DS	BS	DS	BS	DS	BS	DS	BS	DS	BS	DS
3	76743	239849	28694	422280	828250	454178	1447302	738343	1525341	1594848	199088	539827	89407	50612
4	89026	347483	274461	3675550	965881	595878	1405565	819843	548701	526141	375455	1011798	412983	77175
5	5986	23939	28294	323031	827720	391877	274757	174058	87604	63810	24208	25636	182459	62990
6	787	3046	603	1009	59027	15854	226543	115104	17833	15049	1811	1509	24849	8428

(4) Spawning Mortality (SM):

The values for spawning mortality (SM) were the same as in SCAM 3L.

(5) Fishing Mortality:

As in SCAM 3L, starting fishing mortalities were set and fishing mortalities were then calculated for the rest of that year-class. In years prior to 1978, the starting fishing mortality on age 6 was set by choosing the highest fishing mortality on the spawning component.

In initial runs of the model, starting F's on age-classes from 3 to 6 in 1978 were the same. A number of runs were made with starting F's ranging from 0.1 to 1.5. There was no correlation between fishing mortality and effort and as a result, one value of F could not be set as in SCAM 3L. However, the values of F for all ages in 1978 were known for the runs of SCAM 3L. Thus, SCAM 3LNO was run with starting F's on the during spawning fishery set such that fishing mortalities occurring on the before spawning fishing were the same as the SCAM 3L.

(6) The Model - SCAM 3LNO:

A schematic representation of the model is shown in Appendix B. The exploitation rate μ is calculated by

$$\mu = \frac{F}{F+M} \qquad \text{(for oldest age-class)}$$

or

$$\mu = \frac{F}{F+M}\,(1-e^{-SM-F}) \qquad \text{(for younger age-classes)}$$

Starting with a catch on a cohort during spawning in year N

$$\frac{CDSN}{\mu} \quad \text{gives } PM_{BSN}$$

where, PM_{BSN} is the population of mature fish before spawning in the year N.

A value of fishing mortality before spawning F_{BS} is calculated based on $\frac{C_{BSN}}{PM_{BSN}}$ since we know the value of MDF, the natural mortality during the fishery on before spawning fish.

Then, $PM_{BSN}\, e^{FBS + MDF}$ gives an estimate of PM_{BYN}, the population of mature fish at the beginning of the year. We know the proportion mature, p, therefore the total population at the beginning of the year TP_{BYN} is given by $\frac{PM_{BYN}}{p}$.

The size of the year-class after spawning in year N-1, TP_{ASN-1}, is given by $TP_{BYN}\ e^{MAF}$.

This population TP_{ASN-1} is composed of mature spawning survivors and immature fish. Although we don't know the size of these components of the population, we can estimate the proportion of mature fish pM and immature fish pIM. Thus,

$$TP_{ASN-1} \left\} \begin{array}{ll} \text{x pM} & \text{gives } PM_{ASN-1} \\ \text{xpIM} & \text{gives } PIM_{ASN-1} \end{array} \right.$$

PM_{ASN-1} is the number of mature fish in the population after spawning and PIM_{ASN} is the number of immature fish.

The fishing mortality during spawning F_{DS} is calculated based on

$\frac{C_{DSN-1}}{PM_{ASN-1}}$ knowing SM

then, $PM_{ASN-1}\ e^{SM+FDS}$ gives PM_{BSN-1}, the population of mature fish before spawning.

The fishing mortality before spawning F_{BS} is calculated based on $\frac{C_{BSN-1}}{PM_{BSN-1}}$ knowing MDF then $PM_{BSN-1}\ e^{MDF\ +\ FBS}$ gives PM_{BYN-1}, the population of mature fish at the beginning of the year and $PIM_{ASN-1}\ e^{MDF}$ gives PIM_{BYN-1}, the population of immature fish at the beginning of the year. The total population $TP_{BYN-1} = PM_{BYN-1} + PIM_{BYN-1}$. We know the value of p, the proportions of mature fish in the population at the beginning of the year such that $p = PM_{BYN-1}/TP_{BYN-1}$

Thus, the calculated value of p from the ratio PM_{BYN-1}/TP_{BYN-1} can be compared to the known value of p. Values for pM and pIM are chosen and the calculations made until the proper value of p is estimated.

The model is continued for all data available.

Estimates of 2-year-olds were made by:

$$TP_{BY}\ (\text{age } 3)\ e^{.3} + \text{Catch of 2-year-olds}$$

Results of the Models

Estimates of population numbers, total biomass and mature biomass from SCAM 3L are given in Table 6 and fishing mortalities are given in Table 7. An examination of numbers of 2-year-olds reveals that the 1969 year-class has been the strongest year-class for which data are available. Sampling data has also suggested that the 1973 year-class was strong and the present analysis supports this observation. The 1973 year-class was only slightly weaker than the 1969 year-class.

Estimates of total biomass were highest in 1972 and 1976, that is, when the two strongest year-classes were present in the population as 3-year-olds. The biomass in 1977 was almost as high as 1976 and this appears to be due to the presence of the 1974 year-class which was of moderate strength.

In an effort to obtain an estimate of the strength of the 1976 year-class, the relationship between the numbers of 2-year-olds in Div. 2J3K generated from SCAM 2J3K (Miller and Carscadden 1978) and the numbers of 2-year-olds generated from SCAM 3L was examined. Two estimates of the numbers of 2-year-olds in Div. 2J3K were available and consequently, two functional regressions were calculated to describe the relationships (Fig. 5 and 6). In both cases, the number of 2-year-olds in Div. 3L was positively correlated with the number of 2-year-olds in Div. 2J3K although the estimate from Div. 2J3K with a starting F of 0.200 gave a better fit. The numbers of 2-year-olds in Div. 3L in 1978 predicted from these relationships were 1.16×10^9 from Fig.6 . The numbers of capelin at age were then projected to 1979 and the total biomass and mature biomass calculated. The two options used suggested that the 1976 year-class is weaker than any other year-class on record. Since numbers at age in 1978 were also low, the total biomass in 3L for 1979 is projected to be 80,000-108,000 metric tons (Table 8).

Table 6. Population numbers ($x10^{-3}$) of capelin by year and age, total biomass ('000 tons) and mature biomass ('000 tons) of capelin in Division 3L, weighted F4+ (1978) = 0.15

				Numbers of capelin ($x10^{-3}$)				
Age	1971	1972	1973	1974	1975	1976	1977	1978
2	31021139	4568245	3316424	9715547	28675844	14043001	4397817	
3		22981025	3378435	2450887	7196837	21121446	10403311	3247515
4		3099307	8277914	1217422	833493	2532601	7542697	3730674
5		46017	527322	1406765	154975	100534	404685	1239112
6		1117	4857	55269	94096	10498	5069	40372
Total Biomass (excludes age 2)		429	388	134	208	585	403	191
Mature Biomass		283	318	112	138	375	352	158

Table 7. Fishing mortalities during fishing on mature Division 3L capelin from SCAM 3L.

Age	1972	1973	1974	1975	1976	1977	1978
3	0.002	0.001	0.383	0.133	0.051	0.034	0.05
4	0.003	0.006	0.584	0.712	0.119	0.059	0.14
5	0.009	0.016	0.465	0.452	0.747	0.065	0.17
6	0.009	0.016	0.584	0.712	0.747	0.065	0.20

Table 8. Total numbers in population ($x10^{-3}$), total biomass (m.tons) and mature biomass (m.tons) in Division 3L in 1979 projected from regressions in Fig. 5 and 6.

	Option 1 (from Fig. 5)	Option 2 (from Fig. 6)	
Age	Total Numbers ($x10^{-3}$)	Age	Total Numbers ($x10^{-3}$)
3	859743	3	2134145
4	1159646	4	1159646
5	587123	5	587123
6	111291	6	111291
Total Biomass (Excludes 2-year-olds)	79633	Total Biomass (Excludes 2-year-olds)	107542
Mature Biomass	68379	Mature Biomass	85125

The sensitivity of SCAM 3L to changes in proportions mature at age 4 was tested. It was found that a decrease in the value of p of 1% resulted in a maximum decrease in the estimate of total population of 3.2% and a maximum increase in weighted F on matures of 3.0%.

Estimates of total population numbers, total biomass and mature biomass from SCAM 3LNO are given in Table 9 and fishing mortalities are given in Table 10. In this model, the 1969 year-class is much stronger than other year-classes. The 1972 and 1973 year-classes are approximately equal and about one-fifth as large as the 1969 year-class.

Table 9. Population numbers ($x10^{-3}$) of capelin by year and age, total biomass ('000 tons) and mature biomass ('000 tons) of capelin in Division 3LNO (weighted F4+ = 0.15 in before spawning fishery). Ratio of total biomass in 3L and total biomass in 3LNO.

	Numbers of capelin ($x10^{-3}$)							
Age	1971	1972	1973	1974	1975	1976	1977	1978
2	181781070	40171681	17409637	37903655	35767511	14631754	4492080	
3		134666730	29754109	12857392	28072756	26269884	10762178	3327815
4		19986240	48452591	10606425	4422456	9744658	8869957	3709233
5		154862	3291796	7259656	1529755	405500	1458427	1207593
6		18062	9722	262578	574796	87091	17419	145563
Total Biomass (excludes age 2)		3212	2295	1119	941	814	507	194
Mature Biomass		2100	1838	899	643	568	403	161
Ratio of 3L Total Biomass / 3LNO Total Biomass		0.134	0.169	0.120	0.221	0.719	0.795	0.985

Table 10. Fishing mortalities during fishing on mature Division 3LNO capelin from SCAM 3LNO.

Age	1972	1973	1974	1975	1976	1977	1978
3	0.009	0.064	0.303	0.225	0.431	0.274	0.119
4	0.056	0.243	0.305	1.704	0.244	0.442	0.211
5	0.528	0.289	0.296	0.626	0.908	0.065	0.344
6	0.534	0.348	0.464	1.776	0.892	0.274	0.369

Estimates of total biomass from this model exhibit a downward trend. Estimates for 1972 and 1973 are the highest, in excess of 2 million metric tons. In 1974, 1975 and 1976, the estimates are approximately equal at 0.85-0.92 million metric tons but much lower than 1972 and 1973. The estimates drop again in 1977 and 1978 to 0.57 and 0.24 million metric tons respectively.

The decrease in biomass calculated for Div. 3LNO is sharper than that calculated for Div. 3L (Fig. 7). In addition, during the period 1972-1974, the total biomass estimated for Div. 3L was about 16% of that estimated for Div. 3LNO. This proportion increased from 1976 to 1978 such that in 1978 the estimate for Div. 3L was 99% of the estimate for Div. 3LNO.

The sensitivity of SCAM 3LNO to changes in proportions mature at age 4 was tested. It was found that a decrease in the value of p of 1% resulted in a maximum decrease in the estimate of total population of 3.5% and a maximum increase in weighted F of 9.0%.

Discussion

The models SCAM 3L and SCAM 3LNO make assumptions that are known to be incorrect but when run using the data in the proper manner produce meaningful results. For instance, SCAM 3LNO starts in the 3NO fishery and the numbers from that fishery are then used with the 3L fishery. This model assumes that all fish that are fished in 3L prior to spawning will migrate to the Southeast Shaol to spawn. This is probably incorrect in most years since it appears that the 3L fishery is prosecuted on a mixture of fish some of which will spawn inshore and others of which will spawn on the Southeast Shoal. On the other hand, SCAM 3L ignores the fishery on spawning fish on the Southeast Shoal.

However, the biases of both models have been reduced by the manner in which they have been run. The best estimates of fishing mortalities for Div. 3L were made by relating starting F to effort. This resulted in estimates of biomass of capelin occurring in Div. 3L. Then, by running the SCAM 3LNO with these fishing mortalities in the before spawning component of the model, the biases inherent in SCAM 3LNO have been eliminated. Thus, by knowing the fishing mortalities on the 3L component and working these estimates into the SCAM 3LNO, the 3L portion is correct. As a result, its ultimate spawning destination, whether inshore or offshore, is unimportant and the biases resulting from the original assumption are eliminated. Therefore, within the context of the model, the run of the SCAM 3LNO produced in this document produces the best historical estimate of the capelin population in Div. 3LNO.

In the runs of the models, it was found that the biomass predicted for 1978 for 3L was about the same as for 3LNO suggesting that virtually no fish went to 3NO; this agrees with the observations of scientists and the reported catches for 1978. It may be that the values we are estimating for 3L represent to a large extent the inshore component of the 3LNO stock. In later years, the 3L portion of the stock has accounted for a larger proportion of the total biomass than in earlier years. This could be explained by decreasing recruitment in the 3NO portion of the stock or a change in migration patterns of the 3NO portion or a combination of both.

There is some evidence from morphometric (Sharp et al 1978) and meristic (Carscadden and Misra 1978) studies to suggest that the Southeast Shoal spawning population is a discrete stock. During the first years of the fishery (1972-1977) the predictable occurrence of capelin in this area at the same time as inshore spawning was occurring also suggested that this stock was discrete. None of these observations preclude the possibility that in some years there may be interchange between the areas although this would be expected to be minimal if the differences in meristics and morphometrics were to remain significant. The meristic and morphometric studies investigated fish from year-classes that coincided with earlier years in the fishery and as a result, the possibility that recent changes in migration patterns have occurred cannot be eliminated. Thus, if a change in migration pattern in 1978 occurred, it must have been nearly complete since few capelin appeared in 3NO. Population estimates of inshore spawning capelin are not available. However, qualitative observations of capelin inshore in 1978 suggested that capelin numbers had decreased. No capelin spawned inshore on the south coast of Newfoundland in 1978. The possibility does exist that in years of strong recruitment, the 3NO stock is simply an overflow area but in years of weak recruitment, most of the stock moves inshore to spawn.

Considering the question of recruitment, the results from the SCAM 3L and SCAM 2J3K (Miller and Carscadden 1979) suggest that recruitment has been declining in recent years. The positive correlation in recruitment between the northern and southern stocks also indicates that large scale effects eg. hydrographic conditions are influencing recruitment in both areas. One would assume then that the recruitment from the 3NO spawning would also show the same trends. However, the relationship between the 3L and 3LNO estimates would suggest that the decline in 3LNO has been more dramatic than the decline of the 3L component and the 2J3K stock.

The possibility that the fishery in 3NO may be having a deleterious effect must be considered. Some possible effects have been discussed by Carscadden et al (1978). The annual catches in the 3NO fishery were in excess of 100,000 tons for four years (1973-1976). Although estimates of the strength of the 1973 year-class for 3L indicate it is strong, the SCAM 3LNO suggest that it was not strong. All year-classes calculated from the SCAM 3LNO subsequent to 1973 have been relatively weak. This suggests that the fishery on the spawning grounds in 3NO may have been affecting recruitment in later years. If this fishery is contributing to the decline, the effects may be physical and affecting the eggs and larvae or behavioral and affecting the spawning adults. Anthony and Waring (1978) has suggested that fishing on schools of herring on the spawning grounds may have contributed to the decline of George's Bank herring.

The recruitment mechanisms of capelin are unclear. There may be environmental effects as suggested by the relationship between the recruitment in the 3L and 2J3K stock but the possibility exists that the fishery on the 3LNO stock may be having an adverse effect on recruitment. The doubt as to whether migration patterns may change in response to hydrographic conditions or population size also compounds the analysis of the recruitment problem. In view of these uncertainties, and the importance of capelin as a fish fodder resource, it would seem that a conservative approach should be taken in providing advice on a TAC. This is especially true considering the low biomass estimates projected from the SCAM 3L.

Perhaps the most conservative approach is to assume that the 3NO stock is discrete and that it must be afforded protection. Various options are available ranging from complete closure of the fishery to combinations of closures and quotas. The option of a closed fishing season during all or part of spawning is attractive because this would afford some protection to the spawning adults, eggs and larvae. If the closure were effective in allowing spawning to occur, then a TAC could be somewhat higher providing the fishery concentrated on post-spawning fish. The practicalities of setting such a closed season are difficult. If the season were set at a predetermined time and the spawning biomass was small and arrived after the closed season, the possiblility of eliminating the stock before it spawns still exists. This possibility might be avoided by setting the fishing season very late. It may also be possible to monitor the population for maturity stage and allow a fishery when a predetermined proportion of the stock has spawned.

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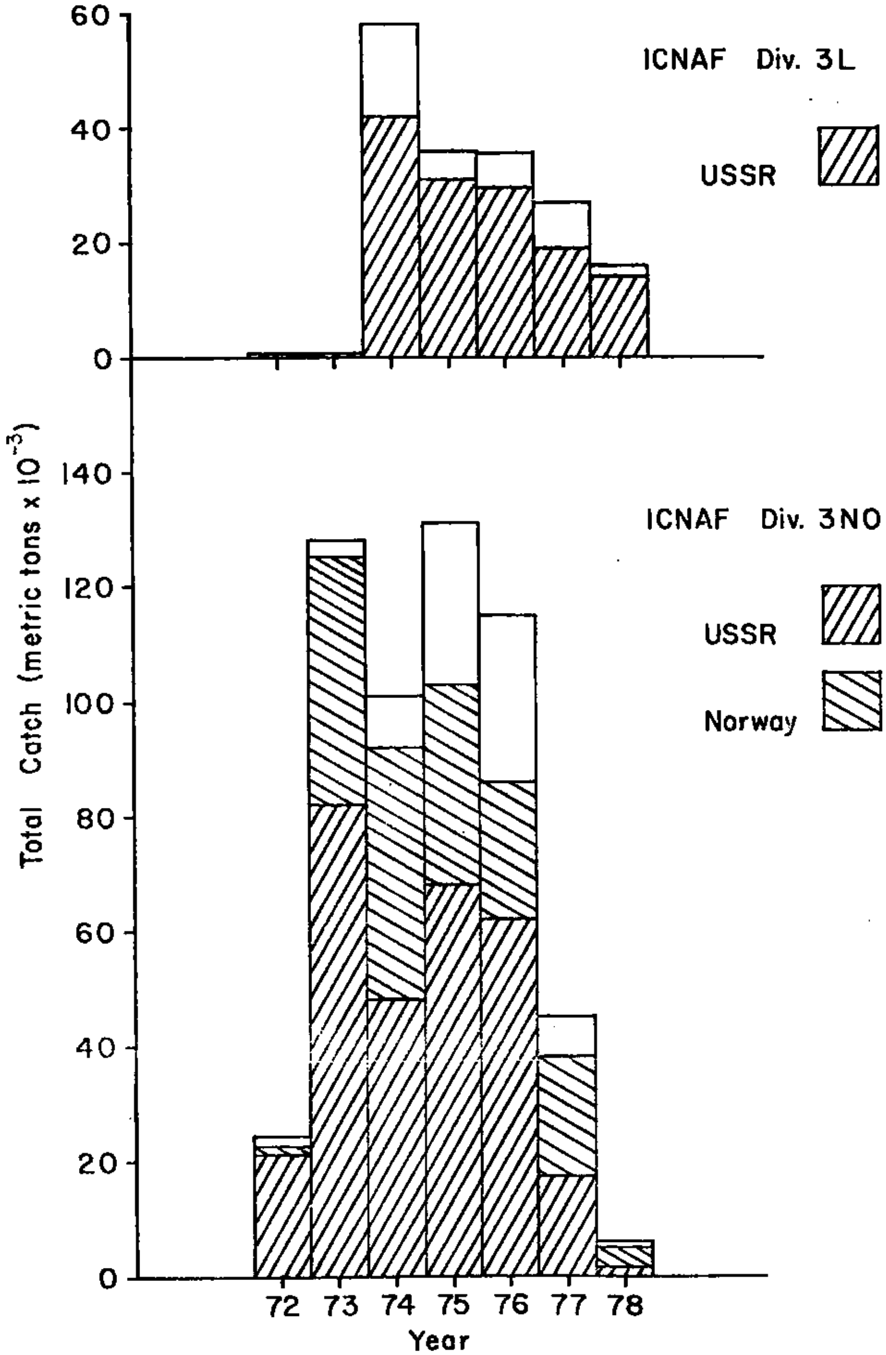

Fig. 1. Catches of capelin in Div. 3LNO.

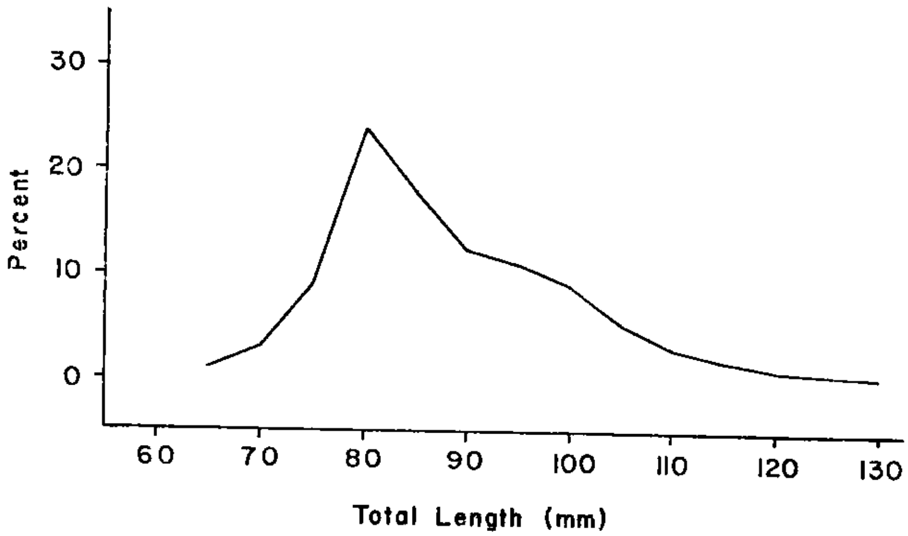

Fig. 2. Length frequency of capelin taken during Gadus Atlantica capelin survey in 3LNO, June 11-July 4, 1978.

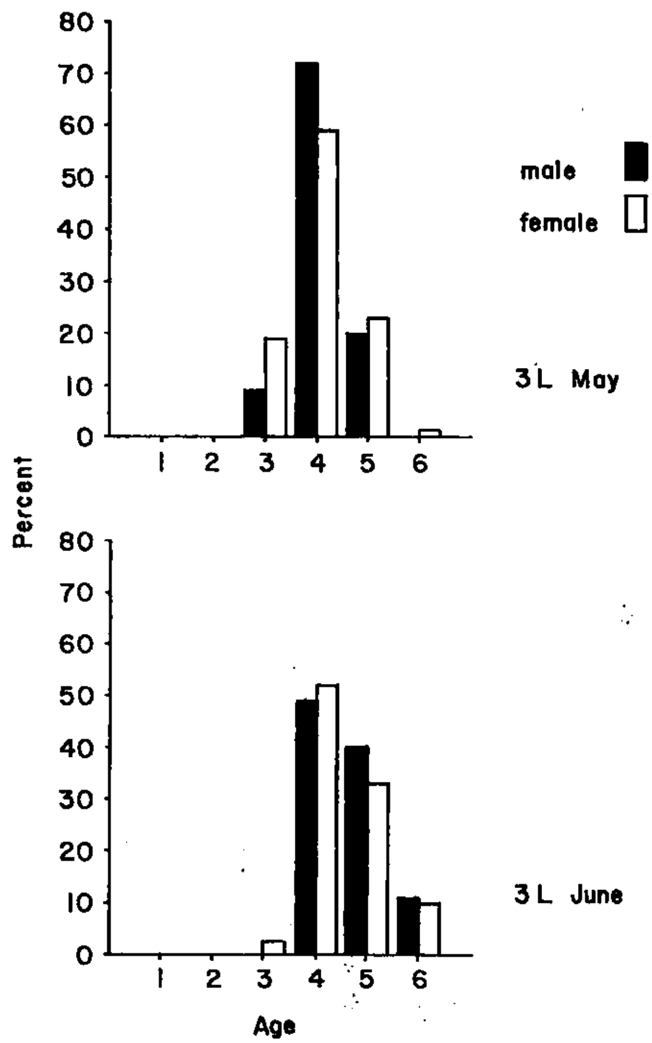

Fig. 3. Age composition of capelin in Div. 3L, May and June, 1978.

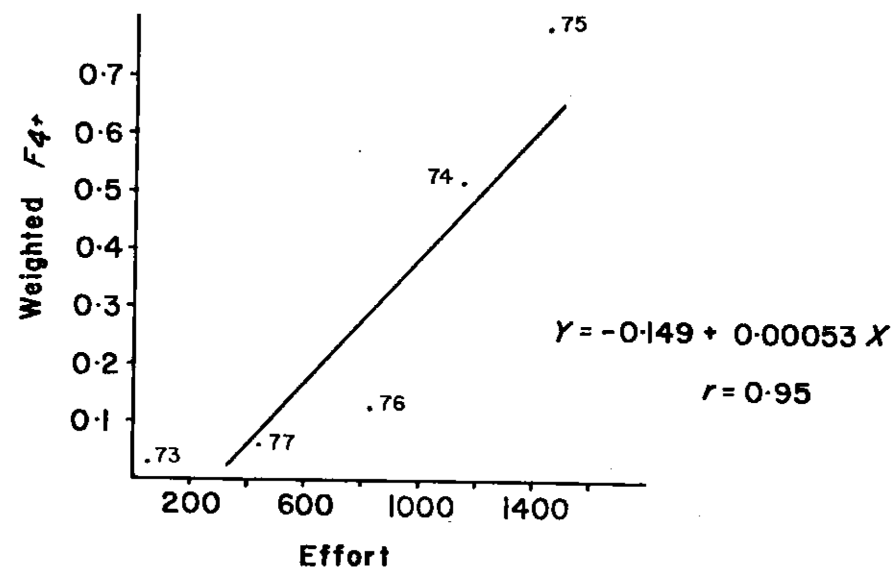

Fig. 4. Functional regression of weighted F for ages 4, 5, and 6 (4+) and effort (fishing days). Points represent years.

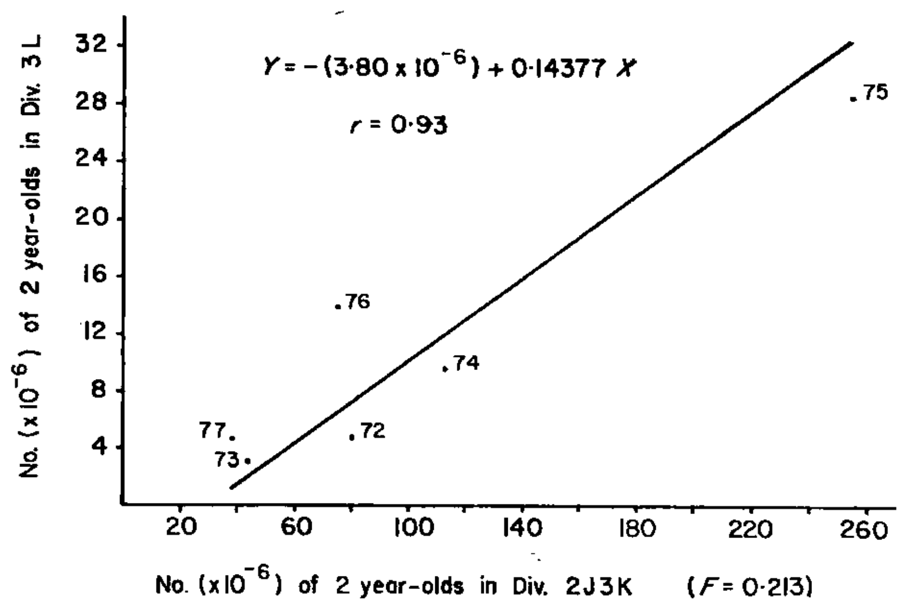

Fig. 5. Functional regression of numbers of 2-year-olds estimated from SCAM 3L against number of 2-year-olds estimated from SCAM 2J3K (F = 0.213). Points are labelled by year.

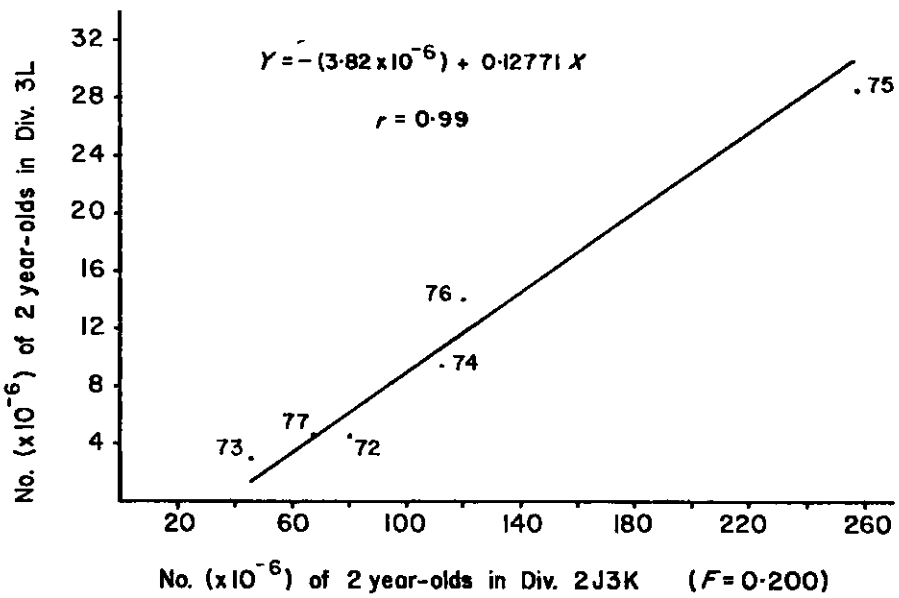

Fig. 6. Functional regression of number of 2-year-olds estimated from SCAM 3L against number of 2-year-olds estimated from SCAM 2J3K (F = 0.200). Points are labelled by year.

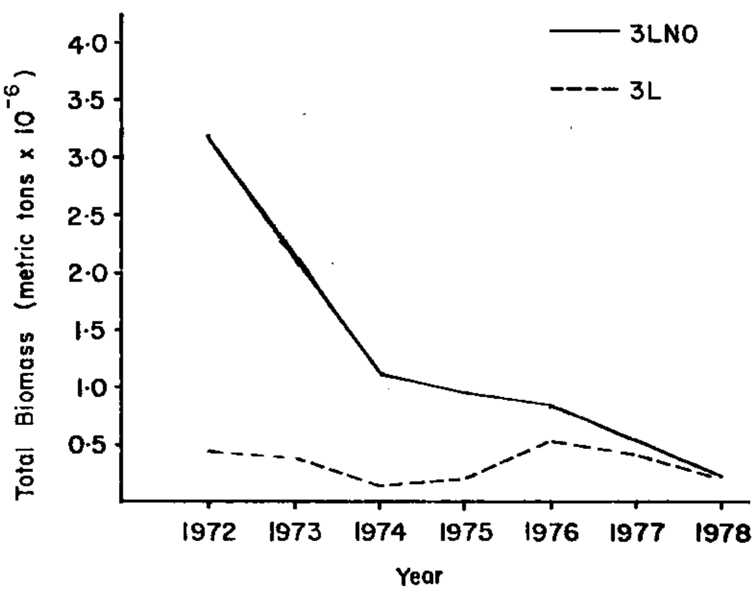

Fig. 7. Total biomass (m.tons x 10^{-6}) of capelin estimated by SCAM 3L and SCAM 3LNO..

Schematic Representation of SCAM 3L

MAF - Natural mortality from end of spawning to end of year.
MDF - Natural mortality from beginning of year to spawning.
SM - Spawning mortality.

(A) $\mu = \frac{F}{F+MDF}$ (for oldest age-class)

$\mu = \frac{F}{F+MDF}(1-e^{-F-MDF})$ (for younger age-classes)

$$\frac{C}{E} \longrightarrow PM_{BYN} \quad P \longrightarrow TP_{BYN}$$

(B) $T_{BYN} \times e^{MAF} \longrightarrow TP_{ASN-1}$ $\begin{cases} \times PM \longrightarrow PM_{ASN-1} \\ \times PIM \longrightarrow PIM_{ASN-1} \end{cases}$

(C) Then, $PM_{ASN-1} \times e^{SM} \rightarrow PM_{BSN-1}$ Calculate F based on

$\frac{C}{PM_{BSN-1}}$ knowing MDF

then, $PM_{BSN-1} \times e^{F+MDF} \rightarrow PM_{BYN-1}$

and

(D) $PIM_{ASN-1} \times e^{MDF} \rightarrow PIM_{BYN-1}$

$$TP_{BYN-1} = PM_{BYN-1} + PIM_{BYN-1}$$

$$P = PM_{BYN-1} / TP_{BYN-1}$$

Fishing only on matures.

Schematic Representation of SCAM 3LNO

MAF - Natural mortality from end of spawning to end of year.
MDF - Natural mortality during period of fishery before spawning.
SM - Spawning mortality

Start with a cohort catch during spawning year N.

$\mu = \frac{F}{F+SM}$ (for oldest age-class)

$\mu = \frac{F}{F+SM}\ (1-e^{-SM-F})$ (for young age-classes)

$\frac{CDS_N}{\mu} \longrightarrow PM_{BSN}$ Calculate on F_{BS} Based on $\frac{C_{BSN}}{PM_{BSN}}$ knowing MDF

then, $PM_{BSN} \times e^{FBS + MDF} \longrightarrow \frac{PM_{BYN}}{P} \longrightarrow TP_{BYN}$

$TP_{BYN}\ e^{MAF} \longrightarrow TP_{AS\ n-1} \begin{cases} \times\ pM \longrightarrow PM_{AS\ n-1} \\ \times\ pIM \longrightarrow PIM_{AS\ n-1} \end{cases}$

Calculate F_{DS} based on

$\frac{C_{DS\ N-1}}{PM_{AS\ N-1}}$ then $PM_{AS\ N-1} \times e^{SM+FDS} \longrightarrow PM_{BS\ N-1}$

knowing SM

Calculate F_{BS} based on

$\frac{C_{BS\ N-1}}{PM_{BS\ N-1}}$ then, $PM_{BS\ N-1} \times e^{MDF + FBS} \longrightarrow PM_{BY\ N-1}$

knowing MDF and, $PIM_{AS\ N-1} \times e^{MDF} \longrightarrow PIM_{BY\ N-1}$

$$TP_{BY\ N-1} = PM_{BYN\ N-1} + PIM_{BYN-1}$$

$$P = PM_{BY\ N-1} / TP_{BY\ N-1}$$

Fishing only on matures.