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Biological aspects of the Div. 3NO capelin stock in 1977 and
a capelin sequential abundance model

by

J. E. Carscadden, D. S. Miller and G. H. Winters
Fisheries and Marine Service
Biological Station, 3 Water Street
St. John's, Newfoundland A1C 1A1

INTRODUCTION

Several unusual points were noted concerning the stock of capelin spawning on the Southeast Shoal in 1976 (Carscadden, 1977). Norwegian catches and CPUE estimates suggested the spawning stock had declined. The biomass of capelin was estimated to be 687,000 tons - a decline from the 1975 estimate of 1.05×10^6 tons (Kovalev *et al.*, 1977). In addition, the spawning season ended earlier and large proportions of unspawned capelin were reported in samples taken near the end of the fishery. Unusually high proportions of immature fish were reported in the catches (Carscadden, 1977).

From all data available, it was suggested that, although number of individuals of capelin was high in 1976 because of the relative strength of the 1973 year-class, the biomass was lower because of slow growth and lower maturation rate of this year-class. There was no evidence to suggest that the reduction in biomass was related to the fishery (ICNAF *Redbook* 1977, p. 62).

In 1977, the Div. 3LNO capelin fishery was carried out primarily by USSR and Norway. This document presents data pertinent to this fishery and its management.

Catches of capelin in Div. 3LNO fishery

Table 1 contains a summary of quotas and catches of capelin from 1972 to 1977 by the two major capelin fishing countries, USSR and Norway. USSR first reported large catches of capelin in Div. 3L in 1974 and in 1975 capelin in Div. 3L came under a separate TAC. In 1975 and 1976, USSR caught its capelin quota in Div. 3L. However, in 1977 the USSR catch in Div. 3L was much reduced - less than 70% of the quota. USSR catches of capelin in Div. 3NO have been substantial since 1973 and the quota was reached in 1975 and 1976. However, in 1977, there was a marked reduction in the USSR capelin catch; this catch was only about 28% of the USSR quota.

Norway has never had a large fishery in Div. 3L and Norwegian capelin catches in Div. 3NO were about the same level in 1973, 1974, and 1975, although the quota was not reached in 1975. However, in 1976 and 1977, the catches were much reduced accounting for less than 45% of the quota in each year.

Catch per unit effort in Div. 3LNO capelin fishery

Details of catch per unit effort (catch per day) in the USSR capelin fishery and Norwegian capelin fishery are given in Tables 2 and 3, respectively. Estimates are from Carscadden (1977), ICNAF *Statistical Bulletin* and FLASH (Foreign Fishing Vessels Licensing and Surveillance Hierarchical Information System).

Although estimates of catch per unit effort tend to differ depending on the source of the information, there is a trend of decreasing C/E in both Div. 3L and Div. 3NO from 1975 to 1977 for both countries. In both 1976 and 1977, C/E estimates for Div. 3L were approximately equal or higher than estimates for Div. 3N. This is unexpected since schools of capelin would be expected to be denser during spawning on the Southeast Shoal (Div. 3N).

Duration of fishing season on the Southeast Shoal

The capelin fishery on the Southeast Shoal usually runs from about 15 June-15 July, that is, during the

capelin spawning period. The peak of the fishing season occurs in June, although in most years catches are also made in July. It was reported (Carscadden, 1977) that the 1976 fishery ended abruptly during the first few days of July.

Under the vessel licensing system initiated by Canada in 1977, foreign vessels must report their position and species being fished at regular intervals. For the USSR, most vessels first reported in Div. 3N fishing capelin on 12 June. Because these vessels reported on a weekly basis, they could have moved into the area up to 6 days previously. Thus, USSR vessels could have been in the area as early as 6 June. According to the reporting dates, at most, nine USSR vessels fished capelin up to 3 July, while three may have fished up to 10 July.

For Norway, the earliest catches were made 12 June and all boats ceased fishing by 3 July.

Norway and Canada attempted to tag capelin in Div. 3LNO between 30 May and 4 June. However, no concentrations of capelin could be found during that time. On 2 June, the tagging vessel was in the Southeast Shoal area and no capelin were recorded.

From the reports to FLASH and observations from the tagging experiment, it is estimated that concentrations of capelin probably did not appear on the Southeast Shoal until about 10 June. Most vessels quit fishing on or about 3 July. Thus, the duration of the capelin fishery in Div. 3N in 1977 was similar to that in 1976.

Biological characteristics

Div. 3LNOP

Percent composition and mean length-at-age of mature capelin from Div. 3N, June, are given in Table 4. As expected (ICNAF *Redbook* 1977, p. 62), the 1973 year-class was relatively strong for both sexes. It has been suggested (ICNAF *Redbook* 1977) that the relative strength of the 1974 year-class was unknown but it was thought to be of average strength and not as strong as the 1973 year-class. The mean lengths of the 1974 year-class were small suggesting that growth of this year-class was slow. By comparing these mean lengths with maturity ogives of capelin (Carscadden, 1977), a maximum of 75% and 70% of the females of the 1974 year-class were mature in the Div. 3N spawning population in 1977.

The average length of 5-year-old males was substantially smaller than 3- and 4-year-olds collected in 1977 and smaller than 5-year-olds collected in previous years. This phenomenon occurred for mature males collected on beaches in Div. 3L (Table 5) and Div. 3P (Table 6). This may be an example of slow-growing fish maturing at a later age. By comparing the mean lengths of mature females, it would appear that the late maturation of slow-growing females was not as prevalent in females as in males. However, it is believed that some females spawn more than once in their lifetime (Templeman, 1948); thus, collections of older females would contain samples of fish that had grown quickly and spawned previously, as well as the slow-growing fish that were spawning for the first time. As a result, it is difficult to draw any conclusions regarding growth and maturation rates of older females unless it is possible to detect repeat spawners.

The relative strength of the 1973 year-class is also apparent in mature capelin spawning on the beaches in Div. 3L and Div. 3P during June 1977 (Tables 5 and 6). In Div. 3P, 1977 was the first year since samples have been collected that 4-year-olds were dominant. In both areas, the 1974 year-class was not only in low proportions (less than 15%) but, like this year-class in Div. 3N, the average lengths were smaller than normal suggesting a slow rate of growth.

Less than 1% of the males sampled and none of the females sampled in Div. 3N in 1977 were immature. The composition of capelin at different maturity stages collected between 21 June and 27 June is given in Table 7. These data indicate that about 40% of the males and 70% of the females had not begun to spawn at the time of capture. One set was made on 27 June, the last day of operation, by our research vessel in the Southeast Shoal area. From this set, 79% of the males and 92% of the females were at maturity stages 1 or 2, indicating that most of the fish in the catch had not spawned.

Div. 2J-3K

Collections of capelin from Div. 2J-3K in 1975, 1976, and 1977 (Table 8) illustrate the relative strength of the 1973 year-class. This year-class was dominant in both 1975 and 1976 and strong in 1977 for males and dominant in all years for females. Although this year-class was very strong in 1975, the proportions of mature fish in the population were small adding support to the theory that a lower proportion than usual of this year-class matured as 3-year-olds in 1976 (Carscadden, 1977).

Hydrographic conditions

Fig. 1 represents bottom isotherms for the period 19 June to 28 June on the Southeast Shoal. These data indicate the bottom temperatures were not outside the temperature range believed to be preferred by

capelin (Pitt, 1958). There were pockets of warmer water (approximately 4.0°C), although these are still within the preferred temperature range. Large concentrations of cod were observed in the warmer waters but we found no capelin in this area, although the cod had been feeding on capelin. These warm water regions are small compared to the cooler waters and it is doubtful that this warm water would have any profound effect on the capelin in the area. Surface temperatures were approximately 9.0°C, again in reasonable agreement with surface temperatures recorded in previous years.

Sequential capelin abundance models (SCAM) - Div. 3NO

Two models have been developed that provide estimates of the population of capelin that contribute to the Div. 3NO fishery. The models are modified versions of virtual population analysis. It is known that capelin undergo a high spawning mortality (Winters and Campbell, 1974) and in the Div. 3NO population this spawning mortality occurs about the same time as the capelin fishery.

The following assumptions and input data were used in the models.

(1) Calculation of spawning mortality (Sm)

The data used in the calculation of spawning mortality were obtained from Winters and Campbell (1974). The proportion of mature fish in the population before spawning (p) was taken from Table 6 of Winters and Campbell. The value for Z was estimated for males and females combined by weighting according to the proportions of males and females in Table 4 of Winters and Campbell. Natural mortality M was assumed to be 0.3 for this calculation and throughout the models.

From the relationship $Z = M + pSm$, we obtained the following spawning mortalities:

Age 3	Sm = 0.95
Age 4	Sm = 1.97
Age 5	Sm = 1.91

(2) Since the Div. 3NO fishery takes only mature capelin, it was assumed that partial recruitment was equal to the proportion of mature fish in the population prior to spawning and fishing. Values for the proportion of mature capelin (p) were arbitrarily chosen to be used in the models. From a maturity ogive (Fig. 2) for males and females combined, using data from Carscadden (1977), the mean lengths corresponding to the selected p values were estimated.

<u>Age</u>	<u>p</u>	<u>Mean length (mm)</u>
3	0.60	157
4	0.90	175
5+	1.00	>180

It was assumed that no fish were mature at age 2. This assumption is not entirely valid since mature 2-year-olds are taken in some years. However, 2-year-olds do not occur in the catch every year and it was assumed that the numbers of mature 2-year-olds were small in comparison to the size of that age-group in the population.

It was assumed that five years was the terminal age of the population.

(3) Catch-at-age

Catches-at-age were calculated from Norwegian and USSR sampling data and/or data from ICAAF research documents whenever possible. This was possible for 1974, 1975, and 1976. For 1972, 1973, and 1977, Canadian research data were used. Catches-at-age for Div. 3NO were calculated for males and females separately and then combined. Catches from ages greater than 5 were added to age 5 catches to give an estimate of catches for age 5+.

(4) The starting values of F at age 5, 1977 (F_{t77}) were set at 0.8, 1.0, and 1.2. The values of F at age 5 in other years (1972-1976), year t, were calculated by

$$\frac{\text{Effort}_t}{\text{Effort}_{1977}} \times F_{t77}$$

where

$$\text{Effort}_t = \frac{\text{Catch}_t(3NO)}{C/E}$$

Estimates of catch per unit effort were taken from Table 2 and are for June, USSR vessels with greater than 2,000 GRT. The values of F at age 4, 1977, were set the same as the value of F, age 5, 1977. The values of F, age 3, 1977, were set by multiplying the value of F, age 5, 1977, by the

ratio of the mean values of generated fishing mortalities at age 4, 1972-1975, for $F_{t77} = 1.0$. For example, at $F_{t77} = 1.0$, the calculation of F , age 3, is

$$\frac{0.74}{1.24} \times 1.0 = 0.60.$$

This calculated value was then used to calculate a value for F , age 3, for $F_t = 1.2$ and $F_{t77} = 0.8$, by multiplying 0.6×1.2 and 0.6×0.8 .

It should be noted that all values of fishing mortality apply only to the mature portion of the population.

(5) Final biomass estimates were calculated by multiplying the total of mature capelin by the mean weight of an individual capelin in the population. The mean weight for 1978 was an average of the weights for 1972-1977.

(6) Sampling data for Div. 2J-3K in October and November 1977 (Table 8) suggest that the 1975 year-class is not strong. We have assumed that the 1975 year-class is comparable in size to the 1971 and 1972 year-classes. A recruitment value of the 1975 year-class as mature 3-year-olds in 1978 was calculated from the mean of the estimates from the model of mature 3-year-olds of the 1971 and 1972 year-classes. This value was used in projecting the mature stock size at the beginning of the capelin fishery in Div. 3NO in 1978.

SCAM 1

It is known that the Div. 3NO fishery occurs before and during spawning and because of this, the total catch was partitioned into a before-spawning catch and a during-spawning catch. Any catches occurring in Div. 3Ø at any time and in Div. 3N prior to June were assumed to be composed of pre-spawning mature capelin. Any catches occurring in Div. 3N during and after June were assumed to be occurring on spawning fish. The catch in Div. 3NO was divided into these two components:

$$C_{tBS} = \text{catch before spawning in year } t$$

$$C_{tDS} = \text{catch during spawning in year } t$$

These proportions were then used to calculate the numbers at age that were taken before and during spawning (Table 9).

The following is a description of the model illustrated in Fig. 3. As an example, we have demonstrated the calculation of the abundance of a year-class beginning at age 5, year t , through to age 4, year $t-1$. The calculated values of N_t and N_{t-1} are the numbers of capelin in the population at the start of the fishery and spawning season in Div. 3NO in years t and $t-1$.

(A) The catch in year t , C_t , has been partitioned into C_{tBS} and C_{tDS} . We know that the total fishing mortality contributes to both of these catches. In addition, there is a spawning mortality occurring at the same time as C_t is being taken. The exploitation rate, μ_t , on the portion of the population from which C_{tDS} is taken, is

$$\mu_t = \frac{F_{tDS}}{F_{tDS} + Sm} \quad (\text{fishing complete on year-class})$$

or

$$\mu_t = \frac{F_{tDS}}{F_{tDS} + Sm} \left(1 - e^{-F_{tDS} - Sm} \right) \quad (\text{fishing incomplete on year-class})$$

The fishing mortalities occurring before spawning and during spawning are determined by an iterative process that is completed when a predetermined value of F_t , the total fishing mortality on the mature population in year t , is reached. In this case, we used three predetermined values of $F_t = 0.8, 1.0,$ and 1.2 .

(B) The population at the end of spawning in year $t-1$, N_{t-1AS} , is

$$N_{t-1AS} = (N_t) e^M.$$

(C) In this population, N_{t-1}^{AS} , there is an unknown number of mature fish that survived spawning N_{t-1}^{ASM} as well as immature fish N_{t-1}^I . These immature fish did not undergo any fishing mortality and their natural mortality is assumed to be zero during the short spawning and fishing period. Let p_S = proportion of mature fish in N_{t-1}^{AS} . Therefore,

$$p_S = \frac{N_{t-1}^{ASM}}{N_{t-1}^{ASM} + N_{t-1}^I} .$$

It is known that p_S is very different from p , the proportion of mature fish in the population at the start of the spawning and fishing period because of the fishing mortality and high spawning mortality on mature fish.

In year $t-1$ the total catch is composed of fish taken during the spawning period, C_{t-1}^{DS} , and fish taken before spawning, C_{t-1}^{BS} . The value of F_{t-1} is found by an iterative process (Doubleday, 1975) and a value for N_{t-1}^{BSM} , the number of the mature population before fishing and spawning, can be found. Thus,

$$\frac{N_{t-1}^{BSM}}{BSM} + \frac{N_{t-1}^I}{I} = N_{t-1}$$

and

$$p = \frac{N_{t-1}^{BSM}}{N_{t-1}^{BSM} + N_{t-1}^I}$$

Only the value of p is known. Therefore, a value of p_S is chosen, F_{t-1} is found by an iterative process, a value of p is calculated and compared to the known value of p . The process of estimating p_S is continued until the known value of p is calculated. We then have the population size, N_{t-1} , before spawning and fishing, as well as an estimate of the numbers of mature fish in the population before spawning and fishing, N_{t-1}^{BSM} .

This process is continued until the numbers of individuals in each year-class at each age have been calculated. In the case of age 2, we have assumed that no fish of this age are mature. The calculation simply is

$$N_t = (N_{t+1}) e^M$$

and the catch at age 2 is added to give

$$N_t = (N_{t+1}) e^M + C_t .$$

It should again be noted that the calculated values of F are fishing mortalities on the stock of mature capelin only.

SCAM 2

In this model, the fishery and the spawning of capelin are assumed to be separate with all fishing preceding spawning. Only a total catch is used in the calculations. An illustration of this model is given in Fig. 4.

(A) The population N_t in time t is given by

$$N_t = \frac{C_t}{\mu_t}$$

where

$$\mu_t = (1 - e^{-F}) .$$

M is assumed to be zero over the brief fishing period and spawning mortality, S_m , does not occur until after the fishery.

(B) The population surviving spawning and fishing in year $t-1$, N_{t-1}^{AS} , is given by

$$N_{t-1}^{AS} = (N_t) e^M .$$

(C) We know that there are survivors of spawning and fishing N_{t-1}^{ASM} , as well as immature fish N_{t-1}^I that we assume undergo neither natural mortality nor fishing mortality. The proportion of mature fish that survive spawning, p_S , is

$$p_S = \frac{N_{t-1}^{ASM}}{N_{t-1}^{ASM} + N_{t-1}^I} .$$

The value of N_{t-1} is given by

$$N_{t-1} = \left(\frac{N_{t-1}}{ASM} \right) e^{Sm} + C_{t-1} + \frac{N_{t-1}}{I}$$

The value of p , the proportion of mature capelin in the population prior to spawning and fishing is known. A value of p_S is estimated, the values of N_{t-1} and p are calculated, and the value of calculated p is compared to the known p . This process is repeated until the correct value of p is calculated.

The estimated population size of age 2 fish in the population is

$$N_t = (N_{t+1}) e^M + C_t$$

since p for age 2 is assumed to be zero.

Results

The results of the runs of models, using the three values of fishing mortality, age 5, 1977, are given in Tables 10, 11, and 12 for Model 1 and in Tables 13, 14, and 15 for Model 2. Estimates of mature biomass from Model 1 are higher in all years, although the trends are the same using both models.

It is apparent that, during the first three years of the fishery, 1972-1974, the numbers of fish and biomass of mature capelin were relatively constant and higher than the last three years, 1975-1977. During the latter three years, the estimated biomass was less than half that of the first three years.

The trends in year-class strength can be examined in part a of the tables. The estimation of the size of the 1969 year-class at age 2 was included in the table because this year-class has previously been cited as a strong year-class (ICNAF *Redbook* 1977). The calculations using these models support these observations. The 1973 year-class has also been noted as being strong (ICNAF *Redbook* 1977). However, estimates from the models would indicate that the 1973 year-class was not as strong as the 1969 year-class and, in some cases, it was only one-half the strength of the 1969 year-class. Our model suggests that the 1970 year-class was intermediate in strength between the 1969 and 1973 year-classes.

During 1975 and 1976, substantial portions of the mature spawning stock were removed by the commercial fishery. The values for these proportions are higher in calculations from Model 2 because the estimated values of biomass are lower.

The projections to estimate the size of the spawning stock in 1978 revealed that the mature biomass in 1978 would be approximately equal to the 1977 biomass.

Discussion of the models

The higher estimates from SCAM 1 were expected because this model accounts for fishing mortality during the spawning, while Model 2 does not. However, research samples indicate that, even during the spawning season, capelin that have not spawned are being taken in the fishery. Thus, Model 1 tends to overestimate the true population size.

On the other hand, SCAM 2 does not account for the fish that are taken during spawning. Thus, the results from Model 2 tend to underestimate the true capelin abundance. However, more exact data are not available and the results are presented as ranges of the spawning population (Table 16). Thus, the range of biomass in 1977 of mature capelin was probably between 80,000 and 130,000 metric tons.

The predicted strength of the 1970 year-class was unexpected because this year-class did not appear strong in our sampling data. However, the greater strength of the 1969 year-class may have obscured the strength of the 1970 year-class.

The relatively low abundance of the spawning stock in 1975, predicted from the models, is also

unexpected. The Norwegian catch was well below the Norwegian quota in that year, but Sangolt and Ulltang (1976) suggested that different hydrographic conditions in 1975 contributed to reduced catchability of capelin for the Norwegian gear. The low predicted biomass in 1975 may be explained in part by the values of p used in the models. We have used constant values of p for each age throughout the running of the models. Ideally, the true values from sampling data should be used. However, because it is difficult to sample both immatures and matures because of differences in distribution prior to the spawning season (Seliverstov and Kovalev, 1976), empirical values of p are not available.

GENERAL DISCUSSION

In 1977, capelin abundance on the Southeast Shoal appeared to be low as evidenced by low catches by both USSR and Norway. In addition, Norway experienced low catches in Div. 3N in 1976 and USSR information indicated that stock biomass of capelin was reduced. In 1977, for the first time in several years, USSR failed to reach its capelin quota in Div. 3L. Mature capelin occurring in Div. 3L in spring are believed to be composed of a mixture of capelin moving to spawn in inshore Div. 3L and offshore to spawn in Div. 3N. Catch per unit effort has shown a steady decline since 1975. The declines in catch and catch per unit effort were unexpected because the 1973 year-class was recognized to be relatively strong.

Two models developed to estimate capelin abundance in Div. 3NO have indicated that the stock biomass in 1977 was very low. Furthermore, the predicted biomass estimates of mature capelin in Div. 3NO in 1976 and 1975 are substantially lower than acoustic estimates from USSR surveys (Seliverstov and Kovalev, 1976; Kovalev *et al.*, 1977). The decline in abundance of capelin in recent years may be attributable to one or more of several factors: changes in migration patterns, variations in recruitment and effects of the fishery.

(1) Change in migration patterns

Carscadden (1977) and Sangolt and Ulltang (1977) introduced the possibility that the Southeast Shoal capelin were altering their patterns of migration to the spawning grounds and suggested more capelin were moving inshore rather than offshore to spawn. We have no hydrographic data to support this hypothesis. Leggett *et al.* (1976) presented evidence to suggest that the Southeast Shoal stock is distinct from other capelin stocks.

(2) Natural fluctuations in recruitment

There is no information available on the stock-recruitment relationship of capelin in the Northwest Atlantic. Gjosaeter (1972) reported that, for Barents Sea capelin during the period 1951-1961, recruitment fluctuated by a factor of 17 times with the lowest only 20% of the average. Furthermore, the size of the parent stock fluctuated by a factor of 11 times and the lowest abundance estimate was 20% of the average. Winters (1975) estimated the surplus production of capelin in the ICNAF Area to be on the average 1.25×10^6 metric tons and suggested that the TAC for capelin should not exceed 20% of the spawning stock size. The present quota in the entire ICNAF Area is 500,000 metric tons, established in 1975.

(3) Effects of a fishery

There are a number of ways fishing could affect future recruitment into a fishery. A fishery on immature fish could have a serious effect. Our samples from the stock of capelin fished in Div. 2J-3K suggest that mostly maturing fish are taken in the autumn fishery. Sampling data from the USSR fishery in Div. 3L prior to the spawning season also indicate that most capelin taken in the fishery are mature.

If the catch of pre-spawning mature fish is too high, resulting in inadequate spawn deposition, subsequent recruitment into the fishery of that year-class would be lowered. It is known that mature fish are taken before spawning in Div. 3N, 3Ø, and in 3L. The fishery on the Southeast Shoal population in 1972 was light but the fishing pressure increased in 1973 and has remained at that level since. The models presented in this paper suggest that a decline in biomass may have first occurred in 1975 but certainly occurred in 1976 and 1977. However, the proportions of the mature stock taken by the fishery in 1973 and 1974 did not exceed one-third of the total biomass. Thus, overfishing of the mature pre-spawning biomass cannot totally explain the decline in capelin biomass in recent years.

The presence of large concentrations of fishing vessels on the spawning grounds may be exerting a deleterious effect on the spawning fish. Little is known of the physical damage to eggs and larvae that may be occurring by dragging trawls through the spawning grounds. In an experiment on the capelin spawning grounds off northern Norway, it was found that egg mortality was approximately four times higher in eggs stirred up by trawl bobbins than undisturbed eggs and larvae from the bobbin tracks (Bakke and BJORKE, 1973). However, the authors concluded that, even if all disturbed eggs died, the overall effect would be insignificant since approximately 1% of the spawning ground was affected by trawl doors. Although Dragesund *et al.* (1971) reported that both natural mortality and mortality of disturbed capelin eggs was low. Burd and Wallace (1968) suggested that mechanically-disturbed herring

eggs might produce larvae of reduced viability. The high values of fishing mortality would also cause some concern that the intense activity of fishing vessels is affecting the spawning behaviour of capelin on the Southeast Shoal.

Although the exact causes of the decline in the stock in Div. 3NO cannot be determined at present, the extent of the decline in the latter years and the projected low level in 1978 suggest that a revision of the TAC is advisable. We have suggested that the mature stock of capelin in Div. 3NO in 1977 was 80,000-130,000 metric tons and the stock in 1978 would be approximately the same. Using these values and the earlier suggestion (Winters, 1975) that the TAC be 20% of the stock biomass, a reduction in the TAC in Div. 3NO for 1979 to 20,000 metric tons should be considered. Even if a strong year-class were to be detected in the population, bringing the stock size up to the 1972-1974 levels, our estimates suggest that the quota should not exceed 80,000 metric tons. In addition, serious consideration should be given to the closure of the capelin fishery on the spawning grounds for short periods to ensure that capelin are able to spawn undisturbed. Periods of 2-3 days at the start of the spawning season, approximately 10 June, 2-3 days in the middle of the spawning, centred approximately 25 June, and 2-3 days at the end of the spawning season, approximately 10 July, are suggested.

An increase in sampling the capelin stock in Div. 3L and 3NO, both on research cruises and in the fishery, would yield better values of the proportion of mature fish in each age-class before spawning, as well as a more precise partitioning of the catch into spawners and pre-spawners during the fishery. This, in turn, would increase the precision of the models.

Intensive monitoring of the capelin fishery in Div. 3NO with precise records of the catch and effort on a daily or at the extreme, a weekly basis, might provide adequate data for a DeLury estimate of capelin abundance. The tagging experiment conducted by Norway should also be repeated.

Although some predictions for 1978 can be made, these predictions do not give maximum input into setting a quota for 1979. The value of the models as a predictive tool would be enhanced if all data from the Div. 3NO fishery and Div. 2J-3K sampling data were available in December of the same year as the fishery. This would allow a prediction of the spawning biomass to be made for the coming year and a revision of the TAC if necessary.

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Table 1. Quotas and catches of USSR and Norwegian capelin fisheries in ICNAF Div. 3LNO, 1972-1977.

USSR

	1972		1973		1974		1975		1976		1977	
	Q	C	Q	C	Q	C	Q	C	Q	C	Q	C
3L	-	430	-	847	*	42942	28000	30541	28000	29420	26400	17966
3NØ	-	20598	-	83721	*	48855	62000	67704	62000	63610	58300	15918

* Total Quota 3LNOPs USSR 85000
Total Catch 3LNOPs USSR 91797

NORWAY

	1972		1973		1974		1975		1976		1977	
	Q	C	Q	C	Q	C	Q	C	Q	C	Q	C
3L	-	0	-	0	*	282	7000	0	7000	282	6600	0
3NØ	-	653	-	41293	*	43682	53000	37477	53000	23178	49900	21499

* Total Quota 3LNOPs Norway 43000
Total Catch 3LNOPs Norway 43964

(Quotas to 1977 and nominal catches to 1976 from ICNAF Summ. Doc. 77/VI/23. 1977 Catches from FLASH.)

Table 2. Capelin catch per unit effort (catch per day) for USSR, ICNAF Div. 3L, 3N and 30, 1972-1977.

Year	ICNAF Div.	Months	C/E	Gear & GRT	Source	
1972	3N	June	49.4	OT >2000	ICNAF Stat. Bull.	
1973	3L	May	24.9	OT >2000	ICNAF Stat. Bull.	
	30	May	36.4	OT >2000	ICNAF Stat. Bull.	
	3N	June	47.5	OT >2000	ICNAF Stat. Bull.	
1974	3N0	May, June	34.9	MWT >2000	ICNAF Stat. Bull.	
	3N	June	50.1	MWT >2000	ICNAF Stat. Bull.	
1975	3L	April	44.3	MWT >2000	ICNAF Stat. Bull.	
	3L	May	48.1	MWT >2000	ICNAF Stat. Bull.	
	3L	April, May	46.1	MWT >2000	ICNAF Stat. Bull.	
	3L		38.7		Canadian Surveillance	
	30	May, June, July	53.2	MWT >2000	ICNAF Stat. Bull.	
	3N	May	52.5	MWT >2000	ICNAF Stat. Bull.	
		June	42.3	MWT >2000	ICNAF Stat. Bull.	
		July	34.0	MWT >2000	ICNAF Stat. Bull.	
	3N	May, June, July	47.4	MWT >2000	ICNAF Stat. Bull.	
		3N0	May, June, July	51.7	MWT >2000	ICNAF Stat. Bull.
	1976	3L	April	43.5	MWT >2000	ICNAF Stat. Bull.
		3L	May	43.8	MWT >2000	ICNAF Stat. Bull.
3L		April, May	43.7	MWT >2000	ICNAF Stat. Bull.	
3L			45.5		Canadian Surveillance	
3N		May	31.8		ICNAF Stat. Bull.	
		June	44.5			
		July	30.6			
30		May, June, July	40.1			
		May	40.0	MWT >2000	ICNAF Stat. Bull.	
		June	44.2			
30		July	30.4			
		May, June, July	41.0			
3N0		May, June, July	40.5			
3N0			35.5		Canadian Surveillance	
1977	3L	April	27.5	MWT >2000	FLASH	
		May	39.0		FLASH	
		June	31.9		FLASH	
	3L	April, May	36.1		FLASH	
		May	36.5		FLASH	
		June	3.8		FLASH	
	30	July	51.0		FLASH	
		May, June, July	18.3			
	3N	May	12.3		FLASH	
		June	37.9		FLASH	
		July	36.0		FLASH	
	3N	May, June, July	32.9		FLASH	
	3N0	May, June, July	30.7		FLASH	

Table 3. Capelin catch per unit effort (catch per day) for Norway, ICNAF Div. 3N, 1974-1977.

Year	ICNAF Div.	Months	C/E	Gear & GRT	Source
1974	3N	June	226.7	MWT-708	Nfld. Biol. Stn. Records
		July	70.5	MWT-708	Nfld. Biol. Stn. Records
		June, July	122.5	MWT-708	Nfld. Biol. Stn. Records
	3N	June	156	PS-500-999.9	ICNAF Stat. Bull.
		July	156	PS-500-999.9	ICNAF Stat. Bull.
		June, July	156	PS-500-999.9	ICNAF Stat. Bull.
1975	3N	June	472.0	PS-500-999.9	ICNAF Stat. Bull.
		July	475.1	PS-500-999.9	ICNAF Stat. Bull.
1976	3N	June	209.6	PS-500-999.9	ICNAF Stat. Bull.
		June	126.0	PS-150-499.9	ICNAF Stat. Bull.
		July	266.3	PS-500-999.9	ICNAF Stat. Bull.
		July	186.2	PS-150-499.9	ICNAF Stat. Bull.
1977	3N	June	168.4	PS-500-999.9	FLASH
		June	87.7	PS-150-499.9	FLASH
		July	123.4	PS-500-999.9	FLASH
		July	119.2	PS-150-499.9	FLASH

Table 4. Percent composition and mean length-at-age (in parentheses) of mature capelin from ICNAF Division 3N, June only.

Males	Age (yr) and Length (mm)						N
	2	3	4	5	6	7	
1967		66(184)	30(191)	4(198)			307
1969	6(164)	23(182)	68(193)	4(193)			811
1970	4(166)	52(184)	40(189)	4(198)			25
1972		36(178)	63(185)	1(190)			106
1973		5(175)	86(179)	9(182)			44
1974		29(187)	41(193)	29(194)	2(192)		350
1975	5(168)	51(181)	42(194)	2(197)			539
1976		59(174)	37(176)	4(180)	1(181)		295
1977		16(174)	80(184)	4(183)			198
<u>Females</u>							
1967		49(166)	31(173)	18(179)	2(189)		323
1969	16(146)	47(159)	32(170)	5(184)	1(194)		1000
1970		52(165)	28(176)	20(182)			25
1972		43(158)	52(169)	5(183)	1(186)		244
1973	1(148)	10(158)	82(165)	7(173)			256
1974	1(146)	28(166)	27(176)	42(179)	3(185)		400
1975	7(148)	39(163)	30(177)	12(185)	11(189)		1126
1976		72(155)	23(162)	4(175)	1(182)		1119
1977		42(151)	57(161)	1(190)			732

Table 5. Percent composition and mean length-at-age (in parentheses) of mature capelin from ICNAF Division 3L, June.

<u>Males</u>	Age (yr) and Length (mm)						N
	2	3	4	5	6	7	
1967		21(188)	63(198)	15(201)	1(206)		920
1969		20(192)	76(194)	4(185)			50
1970							
1972		5(179)	95(188)				100
1973		3(178)	79(185)	18(187)			767
1974		24(187)	47(193)	29(196)	<1(195)		904
1975		26(187)	69(198)	4(200)	<1(206)		1241
1976		51(185)	48(194)	1(196)			1189
1977		3(176)	93(191)	5(177)	<1(177)		2972
<u>Females</u>							
1967		16(166)	19(176)	62(182)	3(186)		613
1969							
1970							
1972		18(157)	75(168)	7(176)			100
1973		7(171)	67(171)	19(176)	2(193)		81
1974		17(166)	29(177)	51(181)	4(184)		342
1975		15(164)	51(179)	23(186)	24(187)	7(189)	156
1976		45(164)	28(175)	20(182)	2	5(200)	60
1977		14(153)	80(166)	5(185)	<1(199)	<1(195)	528

Table 6. Percent composition and mean length-at-age (in parentheses) of mature capelin from ICNAF Division 3P, June.

<u>Males</u>	Age (yr) and Length (mm)						N
	2	3	4	5	6	7	
1973	1(170)	48(174)	42(182)	8(186)			577
1974	15(173)	55(185)	21(191)	8(195)			978
1975	3(162)	71(187)	24(192)	1(190)	1(194)		563
1976		73(184)	25(187)	2(192)			890
1977		7(174)	86(190)	8(182)			627
<u>Females</u>							
1973	3(144)	49(160)	34(170)	14(173)			95
1974	21(160)	50(171)	22(178)	7(179)	1(187)		219
1975	6(139)	54(170)	29(180)	8(184)	2(197)		187
1976		72(167)	22(177)	5(191)	2(191)		60
1977		8(163)	87(169)	5(180)			39

Table 7. Percent composition of capelin at different maturity stages. Southeast Shoal, June 19-27, 1977.

	Maturity Stage					N
	0	1	2	3	4	
Males	1	8	35	54	2	144
Females	0	28	45	2	25	669

Stage 1 = maturing
 Stage 2 = ripe
 Stage 3 = partially spawned
 Stage 4 = spawned

Table 8. Percent composition, percent mature and mean length-at-age (in parentheses) of capelin from Div. 2J3K.

	Age (yr) and Length (mm)						N
	1	2	3	4	5	6	
<u>Males</u>							
Oct. 1975	<1(118)	86(149)	14(180)		<1(196)		370
% mature	0	40	98		100		
Oct. Nov. 1976	2(128)	51(152)	45(173)	2(182)			167
% mature	33	100	100	100			
Oct. Nov. 1977		9(158)	47(175)	44(185)	<1(198)		368
% mature		66	93	100	100		
<u>Females</u>							
Oct. 1975	<1(120)	77(143)	16(170)	4(183)	<1(189)	1(189)	430
% mature	0	54	91	100	100	100	
Oct. Nov. 1976	1(127)	44(140)	47(158)	7(187)	1(202)		132
% mature	0	98	100	100	100		
Oct. Nov. 1977		9(153)	38(170)	50(180)	3(192)	4(209)	425
% mature		75	95	99	100	100	

Table 9. Catches of capelin by age and year before spawning (BS) and during spawning (DS) in 3NO.

Age	Catches of capelin ($\times 10^{-3}$)											
	1972		1973		1974		1975		1976		1977	
	BS	DS	BS	DS	BS	DS	BS	DS	BS	DS	BS	DS
2	3,094	48,479	3,683	4,883	4,883	4,883	79,522	62,481	38,604	65,730	30	3,017
3	56,261	239,849	26,954	422,280	386,893	454,178	939,710	738,343	936,657	1,594,848	5,453	539,827
4	81,509	347,483	234,610	3,675,550	507,600	595,878	1,043,437	819,843	309,003	526,141	10,220	1,011,798
5+	6,331	26,992	20,683	324,040	347,327	407,731	368,025	289,162	49,332	83,997	274	27,145

Table 10a. Numbers of capelin ($\times 10^{-3}$) by year and age, mature biomass (m. tons) of capelin in 3NO estimated using SCAM 1 with fishing mortalities at age 5+ as given in Table 10b and % of mature population caught by fishery.

Age	Number of capelin ($\times 10^{-3}$)									
	1971	1972	1973	1974	1975	1976	1977	1978		
2	37,947,069	20,444,678	9,376,532	5,143,243	14,914,985	4,792,834				
3		28,111,880	15,145,790	6,908,099	3,803,862	10,944,094	3,548,362	5,333,333		
4		4,531,451	13,056,029	6,893,923	2,926,087	1,214,895	4,175,346	1,429,082		
5+		211,405	667,327	1,410,916	964,156	235,218	92,472	488,365		
Biomass		595,728	575,593	437,728	182,620	244,060	154,943	148,241		
% caught	4		22	23	72	45	27			

Table 10 b. Starting fishing mortalities at age 5+ and generated fishing mortalities. All fishing mortalities occur on mature fish.

Age	Fishing mortality					
	1972	1973	1974	1975	1976	1977
3	0.03	0.08	0.30	1.97	0.70	0.48
4	0.23	1.02	0.35	2.67	4.40	0.8
5+	0.32	1.95	1.47	2.28	1.81	0.8

Table 11a. Numbers of capelin ($\times 10^{-3}$) by year and age, mature biomass (m. tons) of capelin in 3NO estimated using SCAM 1 with fishing mortalities at age 5+ as given in Table 11b and % of mature population caught by fishery.

Age	Numbers of capelin ($\times 10^{-3}$)							
	1971	1972	1973	1974	1975	1976	1977	1978
2	35,439,937	19,158,305	8,899,476	4,762,989	13,058,936	4,120,054		
3		26,254,551	14,192,822	6,554,688	3,522,164	9,569,099	2,974,918	5,000,000
4		4,113,392	12,180,172	6,452,479	2,763,860	1,095,188	3,539,210	1,162,474
5+		175,269	601,109	1,267,505	895,206	213,651	79,448	386,432
Biomass		552,912	537,525	409,218	170,814	214,977	130,866	132,093
% caught		4	24	25	77	51	32	

Table 11b. Starting fishing mortalities at age 5+ and generated fishing mortalities. All fishing mortalities occur on mature fish.

Age	Fishing mortality					
	1972	1973	1974	1975	1976	1977
3	0.03	0.08	0.32	2.51	0.85	0.60
4	0.26	1.13	0.38	3.18	7.16	1.0
5+	0.40	2.45	1.84	2.85	2.26	1.0

Table 12a. Numbers of capelin ($\times 10^{-3}$) by year and age, mature biomass (m. tons) of capelin in 3NO estimated using SCAM I with fishing mortalities at age 5+ as given in Table 12b and % of mature population caught by the fishery.

Age	Numbers of capelin ($\times 10^{-3}$)							
	1971	1972	1973	1974	1975	1976	1977	1978
2	33,621,645	18,491,500	8,501,995	4,701,862	11,822,477	4,312,985		
3		24,907,527	13,698,840	6,260,227	3,476,879	8,653,108	2,589,366	4,833,333
4		3,862,769	11,544,954	6,219,799	2,621,209	1,076,413	3,117,845	984,068
5+		151,243	557,981	1,173,930	850,752	199,466	70,766	320,661
Biomass		523,430	513,128	392,118	164,633	197,462	114,853	122,368
% caught		4	25	26	80	56	36	

Table 12b. Starting fishing mortalities at age 5+ and generated fishing mortalities. All fishing mortalities occur on mature fish.

Age	Fishing mortalities			
	1972	1973	1974	1975
3	0.03	0.09	0.34	2.63
4	0.28	1.22	0.391	3.89
5+	0.48	2.94	2.21	3.42

Table 13 a. Numbers of capelin (000) by year and age, mature biomass (m. tons) of capelin in 3NO estimated using SCAM 2 with fishing mortalities at age 5+ as given in Table 13b, and % of mature population caught by fishery.

Age	Numbers of capelin (000)							
	1971	1972	1973	1974	1975	1976	1977	1978
2	24,496,919	14,826,046	6,918,578	3,996,909	8,210,439	3,550,618		
3		18,147,764	10,983,405	5,087,203	2,954,637	5,977,244	2,553,070	4,000,000
4		2,645,341	8,418,871	5,018,594	2,131,588	902,771	2,062,167	1,039,199
5+		121,683	401,903	980,500	732,066	159,418	49,792	241,378
Mature biomass		356,989	391,023	318,687	138,521	143,671	89,112	106,584
% caught		6	32	32	95	76	46	

Table 13 b. Starting fishing mortalities at age 5+ and generated fishing mortalities. All fishing mortalities occur on mature fish.

Age	Fishing mortality					
	1972	1973	1974	1975	1976	1977
3	0.03	0.07	0.32	2.93	1.21	0.44
4	0.20	0.72	0.28	3.44	7.46	0.80
5+	0.32	1.95	1.47	2.28	1.81	0.80

Table 14 a. Numbers of capelin (000) by year and age and mature biomass (m. tons) of capelin in 3NO estimated using SCAM 2 with fishing mortalities at age 5 as given in Table 14b, and % of mature population caught by fishery.

Age	Numbers of capelin (000)							
	1971	1972	1973	1974	1975	1976	1977	1978
2	22,549,976	14,467,430	6,710,782	3,980,276	7,403,475	3,004,112		
3		16,705,433	10,717,736	4,933,264	2,942,315	5,379,445	2,148,208	4,000,000
4		2,509,551	7,738,666	4,892,026	2,076,624	894,057	1,796,454	849,630
5+		101,077	377,280	897,615	697,535	148,863	43,376	196,284
Biomass		349,000	368,604	307,310	136,014	131,651	76,461	100,156
% caught		6	34	33	97	83	54	

Table 14 b. Starting fishing mortalities at age 5+ and generated fishing mortalities. All fishing mortalities occur on mature fish.

Age	Fishing mortality					
	1972	1973	1974	1975	1976	1977
3	0.03	0.07	0.34	2.94	1.54	0.55
4	0.21	0.83	0.29	4.87	7.60	1.0
5+	0.40	2.45	1.84	2.85	2.26	1.0

Table 15 a. Numbers of capelin (000) by year and age, mature biomass (m. tons) of capelin in 3NO estimated using SCAM 2 with fishing mortalities at age 5+ as given in Table 15b, and % of mature population caught by fishery.

Age	Numbers of capelin (000)							
	1971	1972	1973	1974	1975	1976	1977	1978
2	21,995,420	14,188,529	6,684,629	3,969,545	6,942,736	2,643,411		
3	16,257,567	10,511,121	4,913,889	2,934,365	5,038,107	1,880,995	4,000,000	
4	2,405,803	7,527,451	4,793,593	2,066,791	888,435	1,625,023	724,513	
5+	87,412	363,964	848,095	679,412	142,833	39,237	167,190	
Mature biomass	338,321	360,558	301,900	135,387	125,219	68,205	95,934	
% caught	6	35	33	97	88	61		

Table 15 b. Starting fishing mortalities at age 5+ and generated fishing mortalities. All fishing mortalities occur on mature fish.

Age	Fishing mortality				
	1972	1973	1974	1975	1976
3	0.03	0.07	0.34	2.95	1.79
4	0.22	0.86	0.29	5.02	7.70
5+	0.48	2.94	2.21	3.42	2.71

Table 16. Summary of predicted biomass estimates of mature capelin using the two sequential capelin analysis models with terminal fishing mortality values of 0.8, 1.0 and 1.2.

Model	Biomass (000)													
	1972		1973		1974		1975		1976		1977		1978	
$F_T = 0.8$	595,728	356,989	575,593	391,023	437,728	318,687	182,620	138,521	244,060	143,671	154,943	89,112	148,241	106,584
$F_T = 1.0$	552,912	349,000	537,525	368,604	409,218	307,310	170,814	136,014	214,977	131,651	130,866	76,461	132,093	100,156
$F_T = 1.2$	523,430	338,321	513,128	360,558	392,118	301,900	164,633	135,387	197,462	125,219	114,853	68,205	122,368	95,934

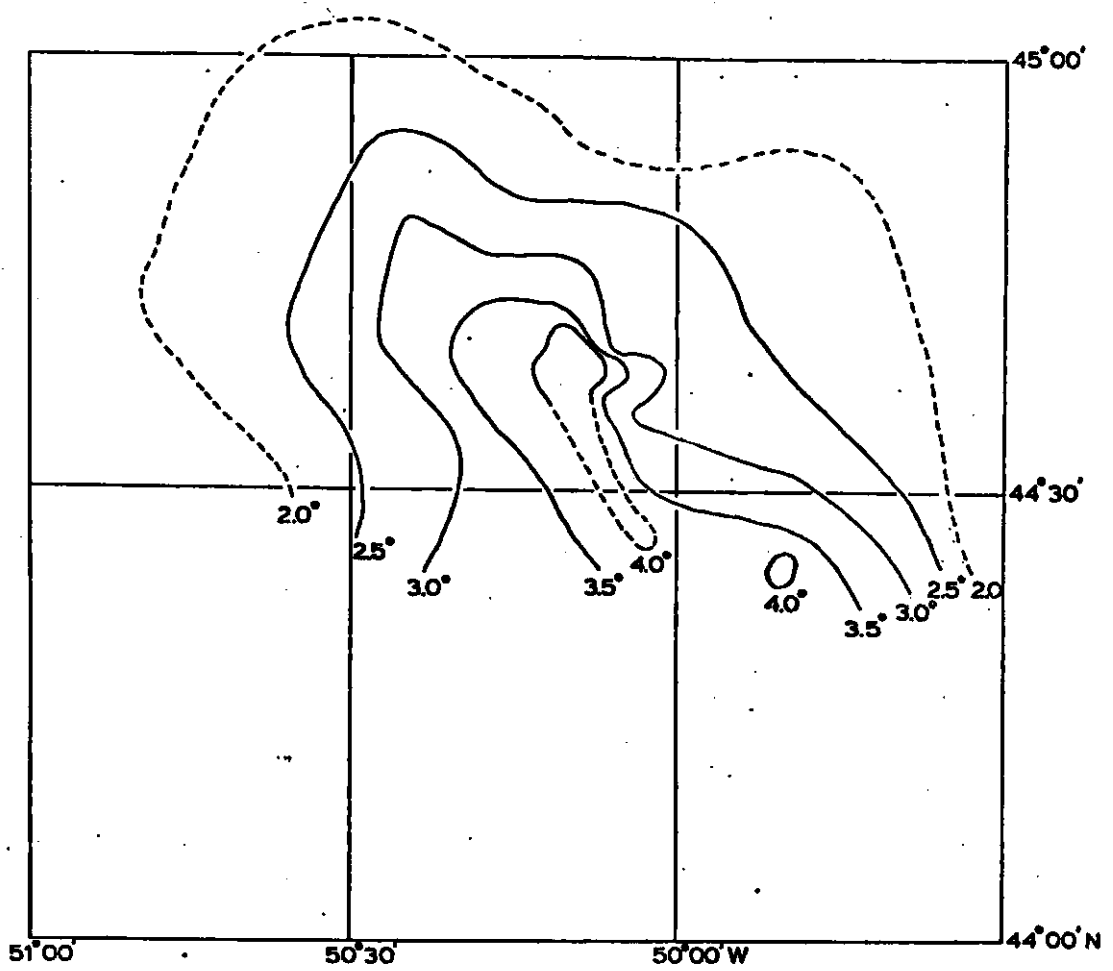


Fig. 1. Bottom isotherms on southeast shoal, June 19-28, 1977.

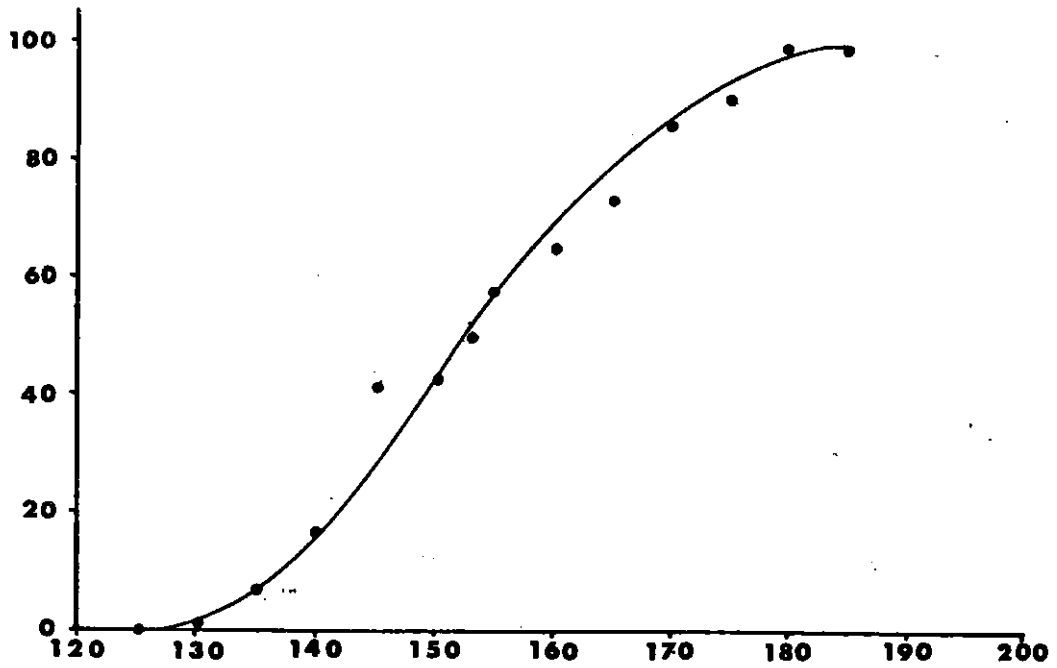


Fig. 2. Maturity ogive for capelin, males and females combined.

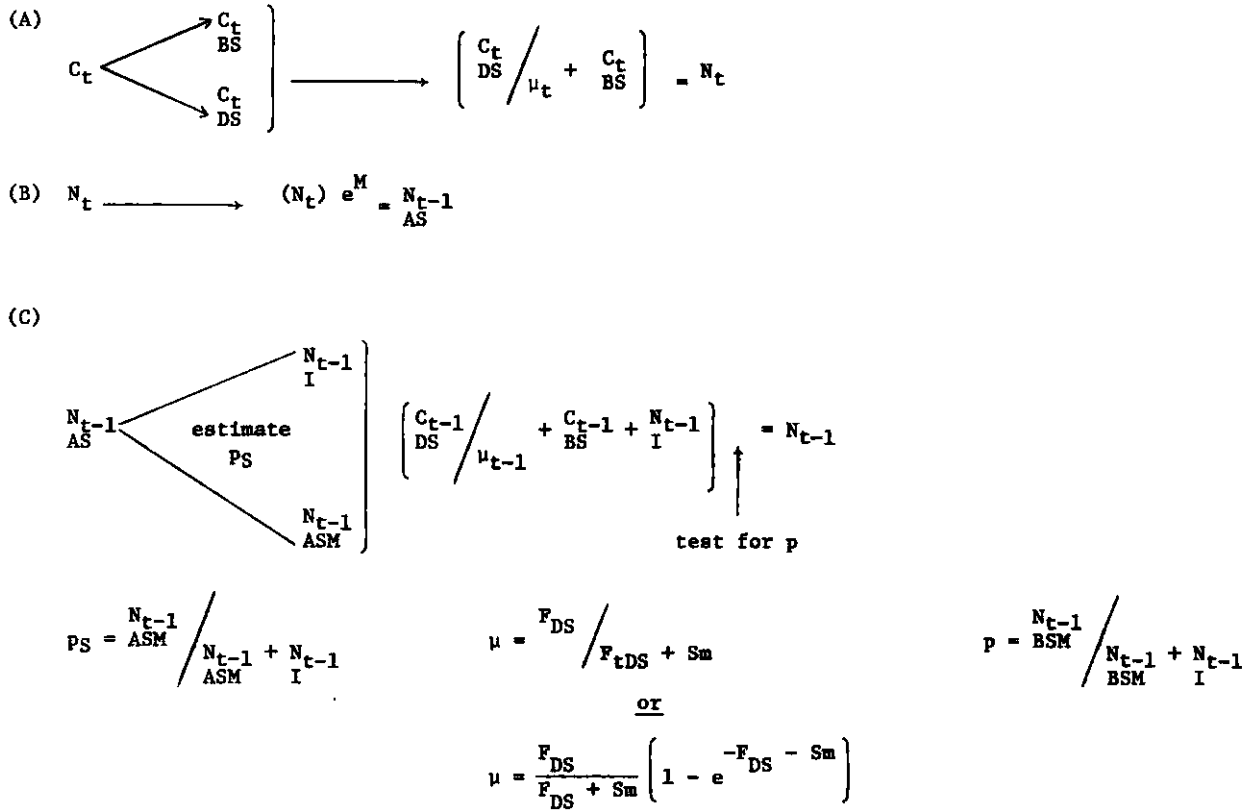


Fig. 3. Sequence of computations involved in Sequential Capelin Abundance Model 1.

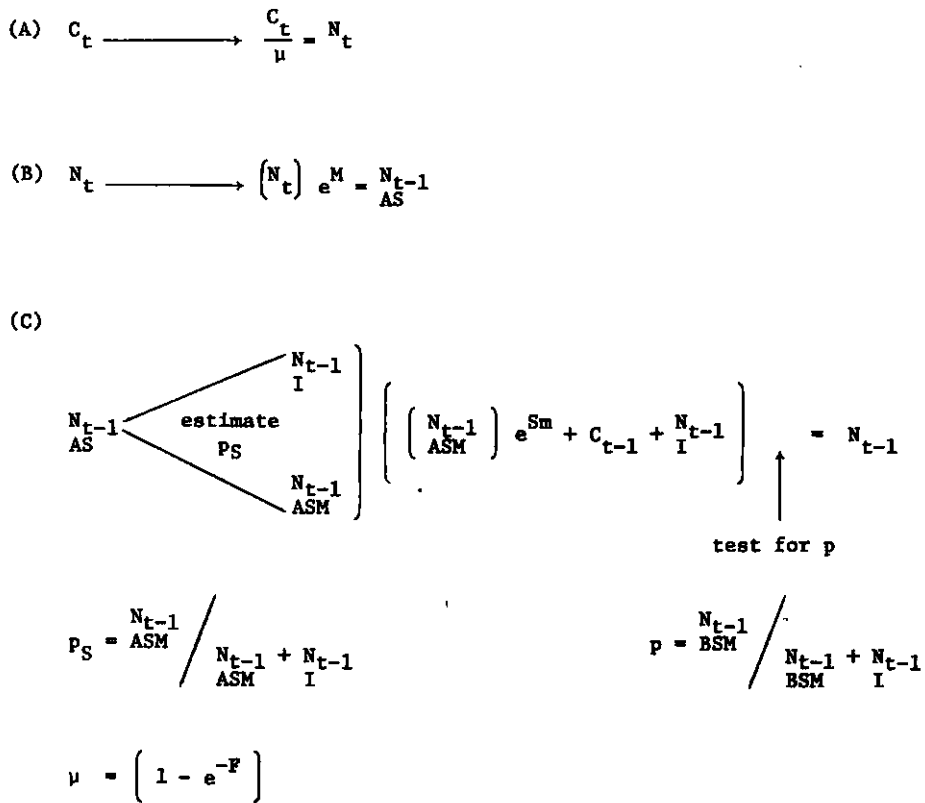


Fig. 4. Sequence of computations involved in Sequential Capelin Abundance Model 2.