MATURITY STUDIES OF BARENTS SEA CAPELIN.

Variations in length at maturity for female capelin.

By

Knut Forberg

Institute of Fisheries
University of Tromsø
P.O. Box 3083 Guleng 9001 Tromsø

and

Sigurd Tjelmeland

Institute of Marine Research
P.O. Box 1870, 5011 Bergen, Nordnes
Norway

ABSTRACT

The sexual maturation of female capelin in the Barents Sea is studied using a new method based on microscope investigation of eggs. A "length at maturity" (L) is defined, and a method for synthesizing the data is developed. The value of L is found to vary considerably between age groups, between areas, and from one year to the next. Some consequences for the TAC calculating procedure are discussed.

1. INTRODUCTION

The sexual maturation of capelin is a key process to management models for the Barents Sea. In the management model presently in use the maturity is implemented as a function of length, such that all fish above a certain length constitute the mature population. This critical length is referred to as length at maturity. Presently total spawning mortality is assumed and the length at maturity is estimated by comparing the age distribution of the stock as calculated from the autumn data to the age composition of the measured stock (Tjelmeland 1984, Hamre and Tjelmeland 1982). If the maturing could be incorporated in the model on the basis of independent data, the model's reliability could be considerably improved. In recent years a method for classification of maturity based on microscope investigations of eggs has been developed (Forberg, 1983). The present paper summarizes some of the results obtained so far, and suggests improvement of the TAC procedure by analysis of the data sources from new angles and by new methods.

2. A NEW METHOD OF DETERMINING MATURITY

In order to improve the methods for estimating the spawning stock and to develop a method for predicting spawning time, a new scale of maturity has been constructed (Forberg, 1983), based on a histological study of maturing sex cells (Forberg, 1982). Maturity is assessed according to morphological structures in fresh or conserved sex cells studied by low power microscopy. This method is inapplicable to male sex cells due to their small size, and the scale only describes the maturity of female capelin.

In the construction of the maturity scale, stages have been ranked from class I (immature) to class IX (degenerating). A description of the class criteria are given in detail by Forberg, (1983), and an abbreviated version is given here:

Classes IIa, IIb, IIIa-IIIc describe maturity when oocyte growth is slow, roughly within the period from June to November.

Class IV describes maturity when yolk accumulates at a high rate, giving rapid growth of the ovary.

Class V capelin are mature, as all the oocytes have ovulated and are loose in the lumen.

Class VI are spawning capelin,

Class VII are spent, and

Class VIII are spent and recovering.

Classes IV, V and VI can with some practice be detected just as well without using a microscope. The term "class", and Roman numerals are used to avoid confusion with the existing scale in which maturity is decribed in "stages" labelled with Arabic numerals. (Gjøsæter, 1984).

Separation into classes, except for class I, is based on the relative number of second growth phase oocytes (SGP oocytes) within the sample.

The morphology of these oocytes has been described in Forberg, 1982. In the construction of the maturity scale, the description of the transitional condition between immature and early maturing capelin has been emphasized so that ripening fish can be identified as early as possible. Further, the development is described in as many classes as discernible, to facilitate the estimation of the spawning time and to aid in distinguishing between different groups of spawners. Some subclasses are described in order to emphasize minor developmental changes.

To record maturity, a small piece (2X2X2mm) taken from the center of the ovary is spread on a microscope slide and a drop of water added before examination under the microscope using transmitted light. 70X-100X enlargement is used for young stages and about 35X enlargement for advanced stages.

3. A MATHEMATICAL MODEL OF MATURITY

3.1 The maturity function

Figure 1 shows a typical distribution on length and maturity for 2 and 3 year old capelin.

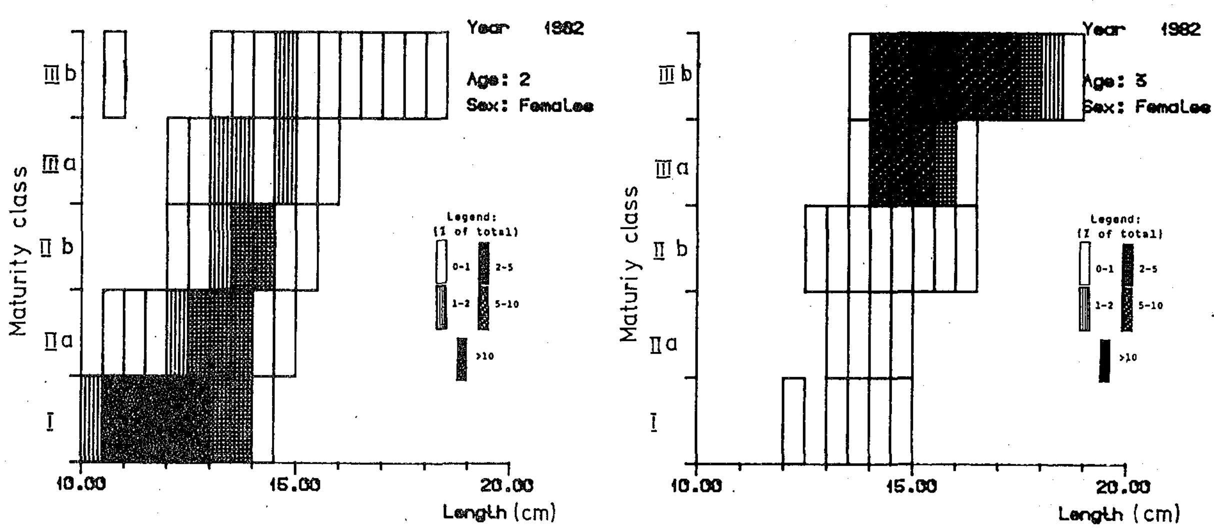


Figure 1. Length distribution within each maturity class (horizontally) and maturity distribution within each 1/2-cm group (vertically) for 2 year old (a) and 3 year old (b) capelin, area VII, 1982.

As is seen from Figure 1, there is a correlation between length and maturity. As the population grows, more fish are found in the higher maturity classes. However, the region in length-maturity space in which the population is found seems to be a little different for 2 and 3 year old fish, the 3 year old fish maturing at smaller size than the 2 year old fish. In order to study variations in maturity independent of the actual length increments of fish it is of importance to find parameters that reflect the correlation between length and maturity. Then variations in these parameters may be studied to reveal additional dependence on age, environmental conditions etc.

The number of mature capelin within each length group increases with length, compared to the number of immature capelin. Thus, we define the number of mature capelin divided by the total number of capelin in each length group to be the maturation function, f(l). The following mathematical model is suggested for the maturation function:

$$f(l) = \frac{1}{1+\exp(4I(L-l))}$$

where: f(l) = the fraction of mature fish in each length group.
L = length at which 50 % of the fish are maturing.
I = the increase in maturity with length (maturity rate) at 50% maturity.

This function has the necessary property of approaching zero at low lengths and 1 at great lengths, and being a two-parameter model, it is flexible enough to be well fit to the data at hand. However, maturity is an ambiguous concept, as it is dependent on the maturity class one uses. Thus, the parameters L and I will be different when different maturity classes are used to define the lower limit of the spawning stock. The ultimate goal is to relate some maturity class to the spawning in April and some other class to the later spawning in June-July. Thus, by studying the number of fish in various classes, one can forecast the timing of the coming spawning season. Fig. 2 shows the empirical maturation function and its associated f(l) for the same data displayed in Figure 1.

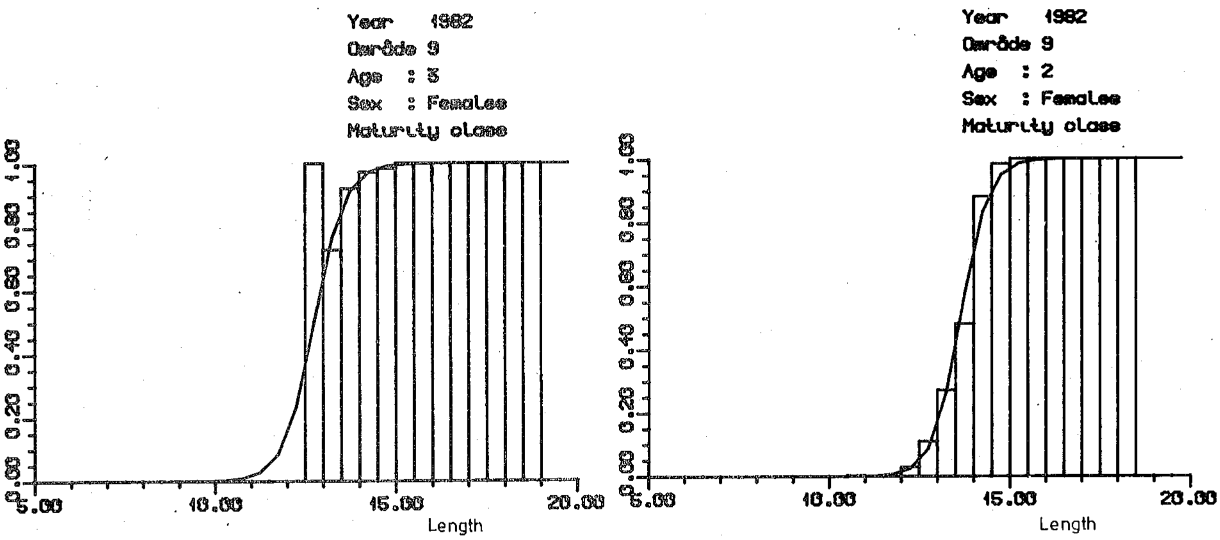


Figure 2. Relative maturity by length as expressed by the maturation function (see the text), for 2 year old and 3 year old capelin, using the same data displayed in Figure 1, and Class IIb as the lower limit of maturity.

3.2 Parameterizing the model

In order to summarize the observations from several years, the parameters L and I must be estimated from the data. Given that the model is correct, the probability of one measured fish being mature is simply given by f(l). For N fish in one length group the probability of exactly r fish being mature is given by the binomial expression

$$h_l(r) = \frac{N!}{r!(N-r)!} f(l)^r (1-f(l))^{N-r}$$

Given several length groups, and supposing the maturation is described by f(l), the probability of obtaining the measured result will be

$$P = \prod_l h_l$$

where the multiplication is extended over all length groups and all the samples within the region of interest.

Here, we have assumed that the same maturation parameters are valid throughout the whole area in which the samples are taken. These parameters are determined by maximizing the above function. It may be shown (Eadie & al, 1971) that the function

$$-2\log \frac{P(L,I)}{P(\hat{L},\hat{I})}$$

is χ^2-distributed with two degrees of freedom. $\hat{L}$ and $\hat{I}$ are those values of L and I that maximize P(L,I). Using this property the parameter estimates and the corresponding confidence intervals may be calculated.

4. LENGTH AT MATURITY (L) DURING THE PERIOD 1978-1983

4.1 Area variation in L

Using the unweighed data from the two areas in which capelin is most abundant (area VII and VIII, Figure 3) in September each year, L is calculated, with class II b as the lower limit for maturing 3 year old capelin. The result of the calculations is shown in Figure 4. with 75% confidence intervals. There is a significant variation in L between areas. The variation is, however, not consistent from one year to the next, L being significantly larger in area VII than in area VIII in 1978 and 1980, while the opposite is true in 1979 and 1983. The observed variation is probably explained either by different and varying physical and/or nutritional conditions in the two areas, or by different groups of the maturing population occupying separate habitats which vary from year to year. With this in mind, care should be taken when maturation data from different areas are used.

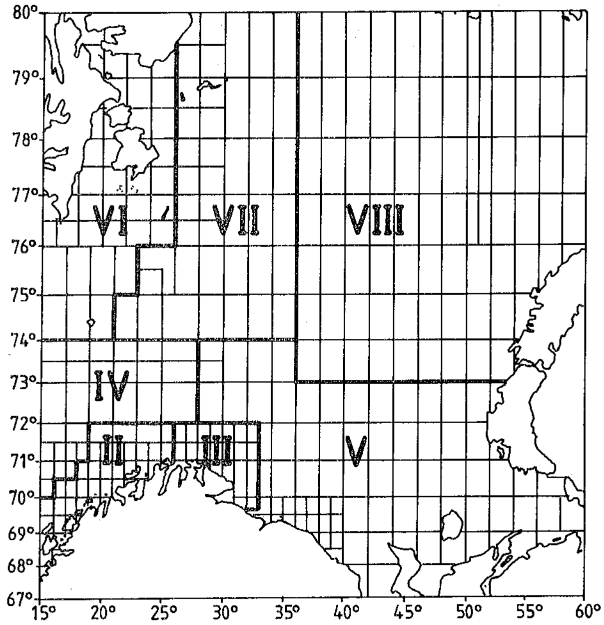


Figure 3. Area division of the Barents Sea.

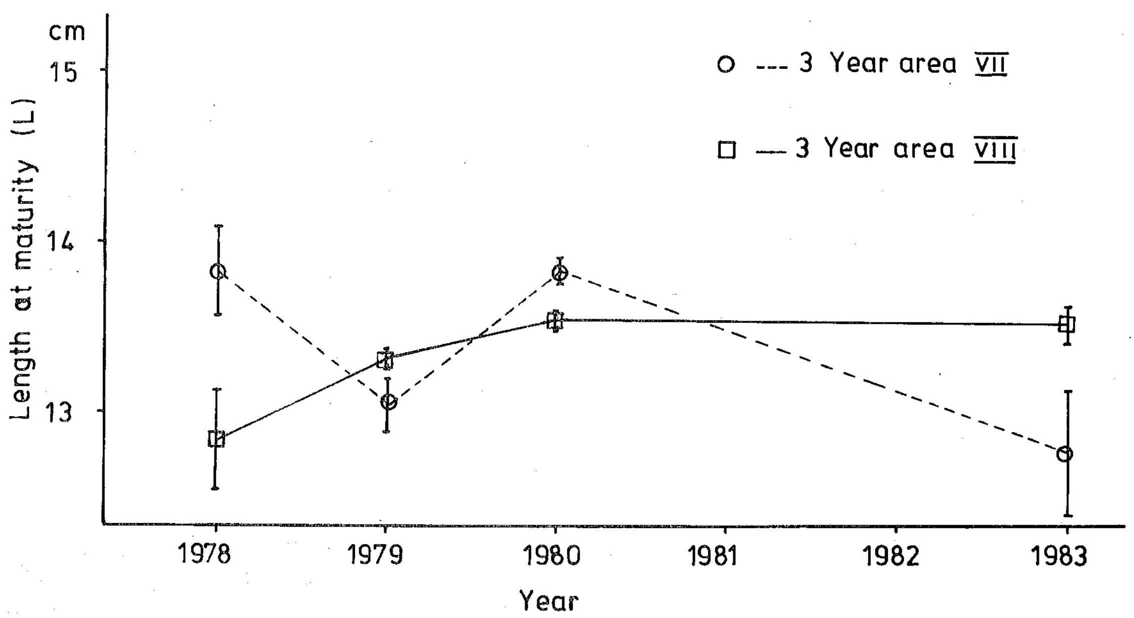


Figure 4. Values of L during 1978 - 1983 for 3 year old capelin from area VII and from area VIII, maturity ≥ IIb. Bars represent 75% confidence intervals.

4.2 Annual variation in L

Using the weighed data from cruises in September each year, L is calculated for each of the maturity groups ≥IIa, ≥IIb, ≥IIIa, and ≥IIIb for 3 year old capelin (fig. 5). For the total spawning stock (≥ class IIa/IIb) there is a considerabl variation in the L-values during the observed period. The L-values are, however, fairly constant for the most mature group (≥ class IIIb), which probably consists of winter spawners only. The trend of variation of L is rather consistent for all maturity groups. The annual variation in L may reflect actual differences in average spawning length from one year to the next or, more probably, differences in timing of the sexual maturation of capelin.

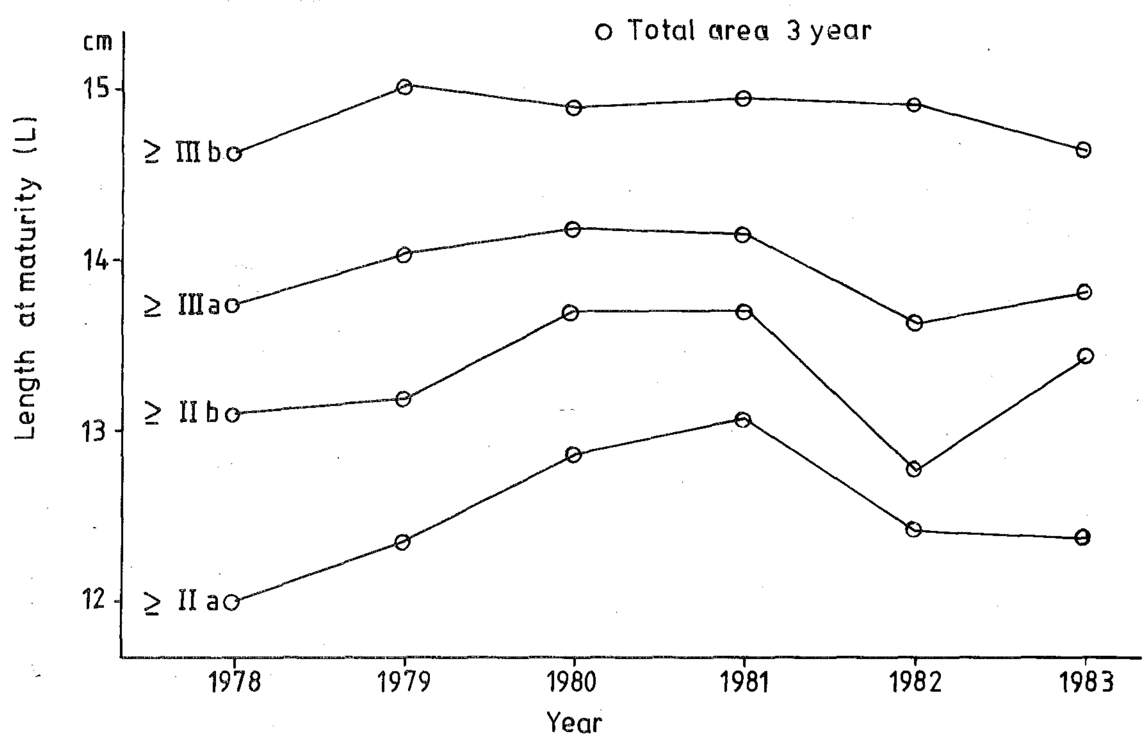


Figure 5. Values of L during the period 1978 - 1983 for different groups of maturing capelin.

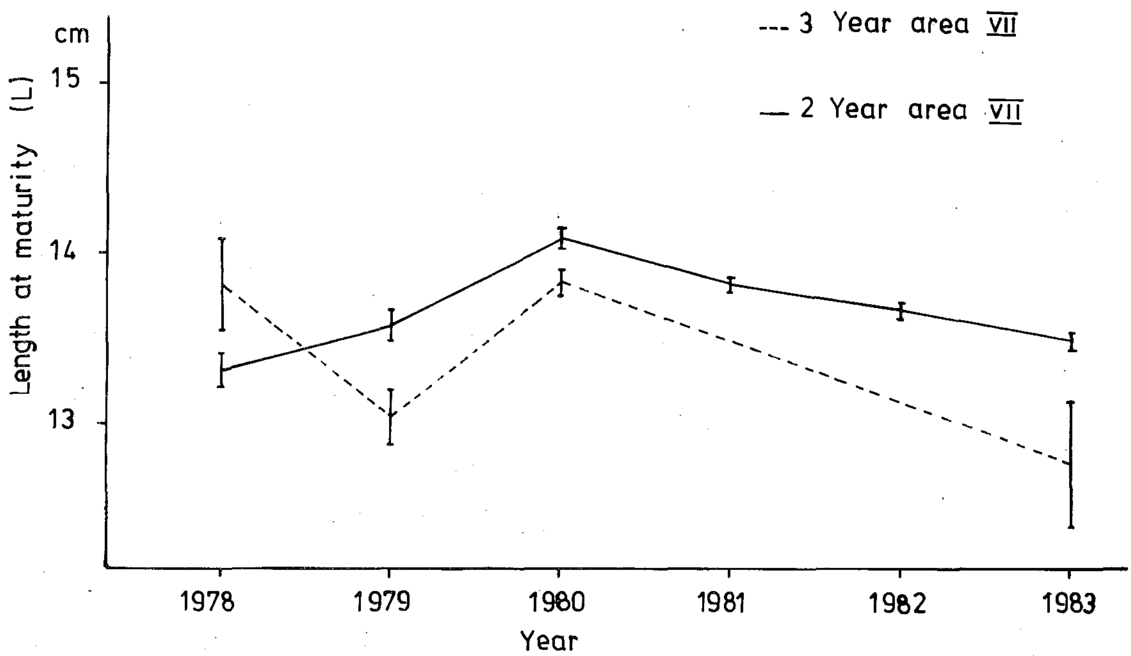
4.3 Age variation in L

Using the unweighed data from the annual cruises in September in area VII, L and the associated 75 % confidence intervals are calculated for 2- and 3-year-old capelin, with Class IIb as a lower limit for the maturing population (Figure 6). The length at maturity for 2-year-old fish is significantly larger than that for 3-year-old fish, except for 1978. 2-year-old capelin are generally smaller than 3- year-old capelin, and for fishes from these groups of the same length, the 2-year-old capelin must have invested a lot more energy per unit time than the 3-year-old capelin in somatic growth. So competing energy requirements may explain differences in maturity rates and, hence, in length at maturity between fishes of different age. A similar relationship was observed in a local stock of capelin in Balsfjord (Forberg, in prep.), between the age group containing only recruits to the spawning stock and the group one year older containing both recruits and repeated spawners. In this instance, delayed maturity among the former is discussed in relation to the competing energy requirements of two processes:

1) High somatic growth during the period of maturation of the young recruits, which delays maturity.

2) Repeat-spawners may have developed an ovary structure such that gonad maturation is more energy efficient compared to first time spawners.

The 2-year-old capelin in the Barents Sea probably solely consist of immatures and maturing first time spawners while the 3-year-old capelin consist of both first time spawners and repeat-spawners. Thus, both hypotheses of energy use may apply for the Barents Sea capelin.



Figur 6. Values of L for 2- and 3-year-old capelin, area VII 1978-1983, using Class IIb as the lower limit of maturity. Bars represent 75% confidence intervals.

5. IMPACT ON THE TAC PROCEDURE

The variation in length at maturity from year to year, between age-groups, and maybe between areas should be taken into account when giving advice on the management of Barents Sea capelin. As it is now, a constant length at maturity is used. Furthermore, the maturation model presently employed treats the length at maturity as a dividing line where all fish below belong to the immature part of the population and all fish above this length belong to the maturing part of the population. However, the most vital question concerning the application of this new maturity scale to a management model has not been dealt with, that of assessing the maturity of the male part of the population.

If an equally good method of assessing the maturity of males can be found, good estimates of the spring spawning population after an autumn acoustic survey may be obtained. However, in order to use this procedure effectively, the maturity parameters should also be predicted for the next autumn. The reason for this is that the autumn catches are assessed by evaluating the effect on the spawning stock 1 1/2 year ahead in time, as referred to the time of advice. So, the full benefit of the suggested procedure relies on some time-varying or growth-dependent model for the maturity parameters being found. The feasibility of this is not yet known.

6. REFERENCES

Eadie, W.T., Drijard,D., James, F.E., Roos, M., and Sadoulet, B.,1982. Statistical methods in experimental physics. (North-Holland publishing company, 291 pp).

Forberg,K. 1982. A histological study of development of oocytes in capelin, Mallotus villosus villosus (Müller). J.Fish. Biol. 20, 143-154.

Forberg,K. 1983. Maturity classification and growth of capelin, Mallotus villosus villosus (M), oocytes. J.Fish. Biol. 22, 485- 496.

Forberg, K. in prep. Structure and behaviour of the spawning stock of capelin (Mallotus villosus (M)) in Balsfjord, Northern Norway.

Gjøsæter, H. 1984. Standard sampling procedure for Barents Sea capelin. A description of standard sampling technique and methods applied to improve the representativeness of the samples. Contribution to the joint Soviet/Norwegian symposium on Barents Sea capelin, Bergen, August 1984. (Included in this volume). 15 pp.

Hamre, J. and Tjelmeland, S. 1982. Sustainable yield estimates of the Barents Sea capelin stock. Int. Coun. Explor. Sea. C.M.1982/H:45, (mimeo).

Tjelmeland, S. 1984. The capelin assessment model - a documentation. Contribution to the joint Soviet/Norwegian symposium on the Barents Sea capelin, Bergen August 1984. (Included in this volume). 17 pp.

Tjelmeland S. and Forberg K. Maturity studies of Barents Sea capelin. A method for assessing early and late spawning capelin. Contribution to the joint Soviet/Norwegian symposium on the Barents Sea capelin, Bergen August 1984. (mimeo). 22 pp.