19

This paper not to be cited without prior reference to the authors

International Council for
the Exploration of the Sea

C.M.1982/H:45
Pelagic Fish Committee

SUSTAINABLE YIELD ESTIMATES OF THE BARENTS SEA CAPELIN STOCK

by

Johannes Hamre and Sigurd Tjelmeland

Institute of Marine Research,
Box 1870, N-5011 Bergen, Norway

A B S T R A C T

The Barents Sea capelin suffer mass mortality after spawning. A model is developed to calculate the biomass of spring-spawners using previous autumn acoustic survey estimates of the total stock as input data. It is assumed that the age composition of the March catches reflects the age composition of the spawning stock, and on this basis a maturing length separating spawners from non-spawners has been calculated for the years 1973 - 1980. Based upon the stock estimation of non-spawners on year and total stock estimates next year the natural mortality has then been calculated.

Assuming constant maturing length and natural mortality for the whole period, estimated by fitting the forward calculated juveniles to the total stock next autumn, a value of the maturing length close to the smallest of the values obtained by using the March catches is found. This is consistent with a significant late spawning of young fish, as the age composition of this component is not being reflected in the catches.

Using the estimated values of maturing length and natural mortality, models for growth and reproduction are developed and combined into a long-term simulation model. Varying the exploitation pattern a series of equilibrium states of stock and yield are evaluated and the MSY and corresponding spawning stock level are calculated.

1. INTRODUCTION

The Norwegian capelin fishery has been subjected to various forms of regulation since 1974. From 1979 the fishery has been regulated by a bilateral management agreement between USSR and Norway. According to this, the exploitation is controlled by a seasonal maximum catch quota regulation for the winter fishery and autumn fishery separately, the fishery being closed from 1 May to 15 August. A minimum landing size of 11.0 cm and a minimum mesh size of 16 mm has been enforced.

The purpose of this paper is to describe and discuss the basic theory and data source used for assessing the total allowable catch (TAC) of the Barents Sea capelin stock.

2. MATERIAL

2.1 General biology

The Barents Sea capelin spawn when they are 3-6 years old, depending on the growth rate of the fish. Usually 4 years old capelin dominate the spawning stock. Most of the capelin spawn only once. The most important spawning months are March and April, but spawning occurs to a lesser extent from May to July. Spawning takes place on gravel and sand bottoms within depths from 10-100 m. Spawning areas are located along the coast from Vesterålen in the west to the entrance to the White Sea in the east. After hatching the larvae drift with the current towards the north and east, and 0-group distribution of capelin is shown in Figure 1.

The older capelin is distributed in the northern part of the Barents Sea, and are found north to the ice border at approximately 80°N in the autumn (Figure 1). During summer and autumn capelin mostly occur as scattering layers, although schools suitable for purse seining are found.

In late autumn and winter the stock migrates southwards in front of the advancing ice. The immature capelin do remain in the area off the coast when the maturing stock migrates to the coast to spawn. The immature part of the stock starts its northwards feeding migration in April - June. A typical distribution of capelin during winter time is shown in Figure 2.

2.2 The fishery

The Barents Sea capelin has been exploited almost exclusively by Norway and the USSR. From the middle of the 1960-ties the Norwegian fishery developed rapidly, the annual catch increasing from 20 thousand tonnes in 1964 to 1.5 million tonnes in 1972. Up to 1974 Norway fished more than 95% of the total catch, but subsequently the USSR fishery increased its proportion. Since 1979 the fishery has been regulated by catch quotas, allocating 60% of the catch to Norway and 40% to USSR. Catch statistics since 1964 are shown in Table 1.

The Norwegian fishery developed as a winter fishery and was mainly based upon pre-spawners in the coastal waters. Due to mass mortality immediately after spawning, the catches of post-spawners have been neglectable. In 1968 Norway started to fish capelin also in offshore waters in late summer and autumn. The summer and autumn fishery exploits the total stock above 2 years of age, but the maturing component constitutes the bulk of the catches.

2.3 Catch composition

The catch of capelin in number and weight by age is sampled on a monthly basis, and used as input data in the stock models applied. The catch by age in March each year is assumed to represent the age distribution of the spring spawners which survive the fishery.

2.4 Stock size estimates

The Norwegian Institute of Marine Research has assessed the size and composition of the Barents Sea capelin stock by bio-acoustic method since the early 1970-ies. The bio-acoustic sampling programme has been described and discussed by Dommasnes and Nakken (1975 and 1977) and the results obtained are currently published in reports to "Fiskets Gang" and "Fisken og Havet". Since 1978 the capelin surveys have been carried out jointly by USSR and Norway, and the results have been reported to the USSR/Norwegian Fisheries Commission.

Attempts have been made to survey the stock at various times of the year. The results show that the best condition for obtaining a reliable abundance estimate is in the autumn (Dommasnes 1981). The autumn surveys are therefore chosen as data source for the assessment of TAC. The surveys are carried out in September - October each year. The stock size estimates in number and weight by year-classes for the years 1973 to 1981 are shown in Table 2.

3. BASIC ANALYSIS

The capelin is supposed to suffer mass mortality after spawning. The dynamics of an exploited capelin population are therefore quite different from most other stocks. A special model is therefore needed for the study of the relationship between population size and exploitation. The model we have developed for this particular use is in principle a Beverton and Holt stock model in which the natural mortality is implemented in form of two independent parameters, one proportional to the stock size (in instantaneous terms) and the other as the fraction of the stock which has spawned. In lack of information on post-spawning survival we have in this paper considered the spawning mortality to be total, i.e. that the mortality due to spawning is equal to the stock which succeeds to spawn.

The model is basicly built on the following hypothesis:

a) that the capelin mature according to length, i.e. that all capelin above a certain length at 1 October (termed the maturing length) are going to spawn the following year.

b) that the age composition of the March catches reflects the age composition of the stock which spawns in the spring.

c) that the catch of post-spawners is neglectable.

d) that no post-spawners survive the spawning season.

e) that the growth of the capelin is dependent on stock size.

3.1 Estimates of the spawning length

It has so far been impossible to obtain a reliable acoustic estimate of the capelin stock during the winter when the mature stock component occurs separately. The abundance estimate of the spawning stock one year has therefore to be based on stock abundance estimates obtained the previous autumn. The capelin are classified according to a new scale of maturity based on histological examination of capelin oocytes (Forberg 1982), but a clear anatomic criterion which can be used to separate spawners from non-spawners at this time of the year is still lacking. The spawners have therefore been separated according to the length of the fish.

The idea of using the length of fish to separate spawners from non-spawners is based upon an observed relationship between the growth of capelin and the age composition of the spawning stock. In the middle of the 1970-ies the growth rate of the capelin decreased considerably and this coincided with an increase in the average age of the spawning fish. This observation indicates that the maturing of the capelin is determined by the size of the fish (or by some other physiological prosesses linked to the body size) rather than the age. If so, the age composition of the spawning stock in the subsequent spawning season can be used to estimate the body length in the autumn at which all fish exceeding that length are going to mature next year.

Table 4 shows a typical length/age distribution from an acoustic survey made in the autumn. The position of the line which in this case separates the stocks in an adult and a juvenile part at a length of 14.5 cm is determined by the age composition of the two components concerned. The position of the line, termed the maturing length, is calculated as the length that produces a maturing stock which has an age composition similar to that of the March catches next year (the spawning stock) and a juvenile stock that has an age composition similar to the age composition of the next year autumn stock. Mathematically, the calculation of the maturing length is done by minimizing the least square function:

$$L = \sum_{i=3}^{5} \left(\frac{s_i\ (l)}{s_3+s_4+s_5} - \frac{c_1}{c_3+c_4+c_5} \right)^2 + \sum_{i=3}^{5} \left(\frac{n_i\ (l)}{n_3+n_4+n_5} - \frac{m_i}{m_3+m_4+m_5} \right)^2$$

where:

L Function to be minimized by varying the maturing length l.

s_i Spawning stock in numbers by age i calculated from the previous autumn stock and l.

c_i Spawning stock in numbers by age i (March catches).

n_i Total stock in numbers by age i in the autumn calculated from the previous autumn.

m_i Total stock in numbers by age i in the autumn measured during the acoustic survey.

The catches are taken into account in the calculation of n_i and s_i and a M value of 0.05 per month has been used. The text table below shows the resulting maturing lengths for the years 1973-79.

Years	1973	1974	1975	1976	1977	1978	1979
Maturing length	14.50	14.94	13.96	14.37	14.04	13.79	14.57

This procedure of calculating the maturing length depends to some extent on the chosen M-value. The results will, however, not change significantly for M-values between 0.04 and 0.06.

3.2 Natural mortality estimates

Based on the abundance estimates of juveniles by year-classes one year and the corresponding estimate of the total stock next year the natural mortality of non-spawners have been calculated for the age groups 2 to 3 years and 3 to 4 years separately and the results are given on a monthly basis in the table below:

1973-74	1974-75	1975-76	1976-77	1977-78	1978-79	1979-80
0.056	0.047	0.051	0.048	0.047	0.085	0.053
0.057	0.044	0.068	0.053	0.070	0.080	0.050

The calculations are based on the previous calculated maturing lengths, taking into account the relevant catches.

The M-values derived from 2 to 3 years depend very little on the maturing length, because a very small part of the Barents Sea capelin mature and spawn as 3 years old fish. These M-values therefore give a good indication of the consistency of the data set as far as the acoustic performance is concerned. With exception of the year 1978-79 the calculated M-values are remarkably constant, indicating that the acoustic abundance estimates of this age group has a rather low variance. The calculated M-values of 3 - 4 years are more variable, but are on the same level as the M-values derived from 2 - 3 years old fish. This is in accordance with expectation because the calculated M-values for the older age groups may vary by the variance in the estimated spawning lengths as well.

3.3 Stock-recruitment relationship

Assuming that the mortality due to other causes than fishing and spawning is the same for the spawners and non-spawners, the parent stock and the corresponding yearclass strength measured as two years old fish can be calculated for the yearclasses 1974-1979. The parent stock is calculated as the estimated stock in autumn exceeding the maturing length, reduced by the catches and the natural mortality until the end of April. In this calculation we have applied an overall average maturing length and M-value for all the years combined. This is done because the calculated year to year variation in the estimates are supposed to be due to sample variances and shortcoming of the model used, rather than yearly variation in the true values. In the calculation we have also excluded the age composition of the spawners as decisive for the spawning length, and used the acoustic estimates of non-spawners only. It is known that in some years late spawners (summer spawners) do occur, and this component does usually consist of younger age groups (Prokhorov 1965). The use of the March catch as representative for the age composition of the spawning stock may therefore overestimate the maturing length in years when late spawning is considerable.

The overall maturing length and M-value have been estimated simultaneously by minimizing the function:

$$L = \sum\left[\left(\frac{s_3}{m_3} - 1\right)^2 + \left(\frac{s_4}{m_4} - 1\right)^2\right]$$

where s_3 and s_4 are the calculated number of 3 and 4 years old capelin based on the previous years' estimate of 2 and 3 years old fish exceeding the maturing length, and m_3 and m_4 are the corresponding measured values. The summation includes data from the year 1973-1980 and the relevant catches are also taken into account when this least squares function is calculated. The minimum L-value is obtained for an overall spawning length of 13.8 cm and a M of 0.057 per month.

The estimate of an overall maturing length is close to the smallest maturing length estimate by year. This is consistent with the assumption that the use of the March catch as representative for the spawners overestimate the maturing length of varying degree according to the strength of late spawners.

The strength of 1 year old capelin is underestimated by the acoustic method due to surface schooling (Dommasnes 1981). The strength of 2 years old fish is therefore chosen as index for recruitment. The catch of 1-group fish is neglectable. Estimates of parent stock and corresponding recruitment are shown in table 5.

The stock/recruitment data are fitted to a Beverton and Holt recruitment function of the form

$$R = \frac{R_m \cdot B}{B_o + B}$$

where R = number of recruits x 10^{10} and B = parent stock biomass in million tonnes. The estimated values of the two constant parametres are:

$$R_m = 44.5$$
$$B_o = 0.43$$

The stock/recruitment curve is shown in Figure 3.

3.4 Individual growth

As mentioned previously the growth rate of the Barents Sea capelin was high in the early and late 1970-ies but low in the middle of the period. The reduced growth rate in the middle of the 1970-ies coincides with an increase in the stock biomass measured by the acoustic surveys. Moreover, the average size of the capelin measured as 2 years old fish fluctuate inversely to the estimated yearclass strength (Table 6). These observations indicate that the individual growth rate is dependent on the stock size.

The length distribution of the 2 years old is modelled according to the observed length distribution and yearclass strength. The growth from 2 to 3 years old is modelled according to the observed lengths of 2 years old fish below the maturing length one year and the length of the 3 years old fish next year taking into account the total stock size. The same procedure is used to model the growth of the older age groups. The length by age calculated by the model and the corresponding length by age observed for the years 1974 to 1980 are shown in the text table below:

	Measured			Simulated		
Age:	2	3	4	2	3	4
1974	11.4	12.7	16.0	11.6	13.6	15.6
1975	12.0	13.4	15.1	11.6	13.7	14.3
1976	12.7	14.2	15.3	12.6	14.6	15.3
1977	12.5	15.0	15.9	13.2	15.3	15.8
1978	11.8	14.8	16.0	11.6	14.9	15.9
1979	12.3	14.2	16.0	11.6	14.5	16.0
1980	12.9	15.3	16.6	13.2	15.1	16.0
Mean length at MSY in autumn:				12.8	15.5	16.3
Mean weight at MSY in autumn:				9.0	18.7	22.2
Mean weight at MSY in winter:				17.0	22.7	25.1

4. SUSTAINABLE YIELD ESTIMATES

The models described have been combined into a long term simulation model, in which the fishery is implemented by monthly F-values by age groups and fishing seasons. In winter the modelled fishery exploits the maturing stock only, whereas the autumn fishery generates fishing mortality on all the age groups above 2 years of age. The 2 years old are, however, not fully recruited to the catchable stock, and the F-values are therefore set to one half of the F-values of older ages. This is in accordance with the fishing pattern observed in recent years. Various cases of fishing strategies have been simulated, and the following results are achieved:

Case 1 - No fishing

When fishing mortality is set to zero the model stabilizes on an autumn stock of 2 years old and older at 5.5 million tonnes, of which 1.8 million tonnes are supposed to spawn. The mean value of stock size measured in the acoustic autumn surveys in 1973 - 1980 is approximately 4.5 million tonnes.

Case 2 - No autumn fishery

By setting the autumn F-value to zero, and increasing the winter catches stepwise the model produces equilibrium states of stock and yield as shown in Figure 4 (broken lines). The figure shows that if the stock is fished in the winter only the yield curve has its maxiumum at 1.6 million tonnes, and this MSY occurs when the equilibrium size of the parent stock is 0.33 million tonnes. If the stock is overexploited, i.e. that the spawning stock is reduced below that size, the yield decreases rapidly, whereas a similar underexploitation affects the yield to a much smaller extent.

The capelin is an important food resource for other exploited stocks. In a management context it may therefore be of interest to study the effects of a capelin fishery on the amount of capelin which dies of other causes than fishing, i.e. the natural death.

In Figure 4 is plotted the annual biomass output of the natural mortality against the corresponding equilibrium state of the exploited spawners (broken line). The model produces a maximum biomass output of M of 3.8 million tonnes when the stock is unexploited, whereas this is reduced to 2.6 million tonnes when the yield due to fishing is at maximum.

Case 3 - No winter fishery

In Figure 4 are shown similar curves when the stock is fished during the autumn only (solid lines). This strategy increases the calculated MSY to 1.7 million tonnes, and the maximum is achieved at an equilibrium state of spawners of 0.45 million tonnes. The corresponding output biomass due to M is 2.0 million tonnes. Harvesting the stock in autumn may thus only increase the MSY to some small extent but an intensive autumn fishery will reduce the value of the stock as food resource for other animals considerably. The main reason for this is that the autumn fishery also exploits the immature fish.

Case 4 - Combined autumn and winter fishery

In recent years the annual catch of capelin has been allocated more or less equally on the two fishing seasons. Figure 5 shows the results of the model run when the catch in autumn is equal to the winter catch. The solid line illustrates the sustainable yield as a function of spawning stock, the broken line illustrates the corresponding annual biomass output due to M and the dotted line the steady state of the initial stock in autumn. A MSY of 1.65 million tonnes is obtained by this strategy when the spawning stock is fished down to 0.4 million tonnes. The corresponding stock in autumn is calculated to 3.5 million tonnes, and the biomass output due to M amounts to 2.2 million tonnes. It is noted that in the range of 0.3 to 0.5 million tonnes of the spawning stock, the calculated sustained yield is close to maximum, whereas the corresponding M-output biomass increases by 0.5 million tonnes. Taking into consideration the ecological importance of the capelin stock, this may justify an exploitation strategy which aims at an equilibrium state of spawning stock of 0.5 million tonnes.

5.0 SENSITIVITY ANALYSIS

The main sources of error which may affect the results of the present yield assessment are errors in the acoustic stock estimates and errors in non-measurable model parameters. In order to evaluate the possible impact of these on the calculated stock and yield, several trial model runs have been executed. The following results are obtained:

5.1 Errors in the acoustic stock estimate

It is commonly assumed that the acoustic technique has a tendency to underestimate stock abundance systematically. The estimates should therefore merely be used as an index of abundance rather than abundance estimates in absolute terms.

Figure 6 shows the results of the long-term simulation run where the parameters used are estimated from the acoustic stock estimates scaled up by a factor of 1.5. This upscaling of the basic input data did not alter the estimated spawning length and M significantly, but it changed the stock recruitment curve. The new stock recruitment parameters R_m and B_o were estimated to $79 \cdot 10^{10}$ and 1.6 million tonnes respectively, which flattens out the curve substantially.

In case the autumn stocks of capelin should be 1.5 times larger than . measured by the acoustic autumn surveys, the Figure 6 shows that the maximum obtainable yield could be increased to 1.82 million tonnes, i.e. by a factor of 1.1 compared to the unscaled figures. This maximum yield is achieved at a spawning stock of 0.9 million tonnes. The corresponding autumn stock and biomass output due to M are estimated to 4.7 and 3.2 million tonnes respectively.

Based on these findings it is concluded that a bias in the stock abundance estimate will not change the calculated obtainable yield considerably.

5.2 Errors in model parameters

The model has two parameters which have been judged according to expectation. One is the M used for pre-spawners during the spawning migration (M_2), the other is the mortality of post-spawners. In lack of adequate data for quantifying these two parameters, the M_2 was set equal to the estimated M for non-spawners (M_1), and the survival rate of post-spawners was set to zero.

It is assumed that the grazing by cod constitutes a main part of the mortality in the capelin population, especially for the pre-spawners during winter when they have to cross the distribution area of cod on their way to the spawning grounds. It is therefore possible that M_2 is larger than M_1. In order to investigate the impact of this possibility, the model has been run with M_2-values larger than the estimated M_1. In this case, the stock-recruitment relationship observed in the past fits to a curve which is much steeper. If $M_2 = 0.1$ for instance, the parameters R and B are estimated to $41 \cdot 10^{10}$ and 0.26 tonnes respectively. When the long-term simulation model is run with this set of parameter values ($M_1 = 0.057$, $M_2 = 0.1$, $R = 41 \cdot 10^{10}$, $B = 0.26$) the calculated MSY occurs to be the same as obtained in the basic run. A bias in M_2 is therefore neglectable.

Finally we have investigated the possible effect of surviving post-spawners on stock and yield. In this case we have used the basic parameter values for maturing length, recruitment and mortality, but assumed that 50% of the spawners survive the spawning. The results of the long-term simulation run are shown in Figure 7. It is seen that if the stock is heavily exploited, a 50% survival of post-spawners does not affect the calculated equilibrium stock and yield significantly. The calculated MSY is, however, 10% higher than in the case when spawning mortality was total, and this percentage increases at a higher level of spawning stock. This means that a possible survival of spawners will increase the calculated long-term yield to a certain extent, especially if the stock is under-exploited.

6. CONCLUSIVE REMARKS

1. The Barents Sea capelin is the largest fish resource in European waters. It constitutes the natural basis of the largest European fishery, and is the main food resource for other important species. A proper management of the capelin fishery is therefore a matter of great importance.

2. As a schooling and slow swimming fish, the capelin has a very high availability to purse-seine and pelagic trawl. The improvement of these gears in the 1960-ies, and the subsequent depletion of the pelagic stocks in the Norwegian and the North Sea, resulted in a large increase in fishing effort on capelin in the early 1970-ies. This coincides with the recruitment of three very abundant yearclasses (1971 - 1973), and the catch rose to 2.9 million tonnes in 1977. These yearclasses originated from weakly exploited parent yearclasses, and the large catches in 1976 and 1977 were expected to be far above the obtainable MSY. Regulation of the fishery after the strong yearclasses had passed was therefore considered a matter of urgency in order to preserve the capelin stock.

3. Due to mass mortality after spawning, the main aim of the capelin regulation is to preserve a spawning stock sufficiently large to secure recruitment. In a management context aiming at MSY, knowledge of the stock-recruitment

relationship is therefore most important. In many fish species this relationship is generally variable, but in the case of capelin the data indicate a rather strong relationship (Figure 3). This strengthens the reliability of the present assessment of stock and yield although the data points are rather few.

4. The calculated yield curve (Figure 5) has a maximum of 1.65 million tonnes, corresponding to a spawning stock of 0.4 million tonnes. The average annual catch of the year-classes on which the recruitment curve is based (1974 - 79), may amount to 1.75 million tonnes when the 1979 yearclass has passed the fishery (1984). The yearclasses 1976 and 1977 were, however, recruited from accumulated parent stocks, and are more abundant than the calculated average strength of recruitment at MSY (Figure 3). A calculated MSY slightly below the annual catches in recent years is therefore in accordance with expectation. It should, however, be noted that the calculated MSY refers to the conditions of growth and recruitment which prevailed in the 1970-ies. If these conditions change, the future obtainable capelin catch is expected to change accordingly.
In the winter 1981 for instance the TAC was increased by 300 000 tonnes due to increased growth in 1980 (Table 2).

5. Normally the capelin do not graze during late autumn and winter. In such cases it is usually most profitable to harvest the stock in autumn. However, due to the fishing pattern and behaviour of the fish the assessment shows that an intensive autumn fishery does not increase the yield of capelin substantially. It has moreover been shown that an intensive autumn fishery reduces to a great extent the biomass output of the stock due to other causes than fishing, and thus deteriorates the stock as food resource for other marine animals. On this basis the TAC has been allocated by seasons in order to obtain an additional control of the fishing intensity during autumn.

6. In case of an equal allocation of the annual catch by seasons, the MSY is calculated to be achieved at an equilibrium size of the parent stock of 0.4 million tonnes (Figure 5). This is the minimum level of parent stock the regulation should permit. If this limit, however, is raised to 0.5 million tonnes, the yield will be insignificantly reduced, whereas the stock will increase its importance as natural food resource. 0.5 million tonnes of the spawners which succeed to spawn have in recent years been recommended as guideline to the management of the fishery.

REFERENCES

DOMMASNES, A. 1981. Stock size and mortality estimates for Barents Sea capelin based on acoustic methods. ICES C.M. 1981/H:45. (Mimeo).

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

NAKKEN, O. and DOMMASNES, A. 1975. The application of an echo integration system in investigations on the stock strength of the Barents Sea capelin (Mallotus villosus, Müller) 1971-74. ICES C.M. 1975/B:25. (Mimeo).

PROKHOROV, V.S. 1965. Ecology of the Barents Sea capelin (Mallotus villosus villosus, Müller) and prospects for its commercial utilization. Fish.Res.Bd.Can.Transl. 813, pp 131 (1967).

Table 1. Catch of Barents Sea capelin in the years 1964-81, (thousand tonnes).

YEAR	NORWAY			USSR	Other countries	SUM
	Winter	Summer	Total			
1964	20		20			20
65	217		217	7		224
66	380		380	9		389
67	403		403	6		409
68	483	39	522	15		537
69	436	243	679			679
70	969	332	1301	13		1314
71	1303	69	1372	21		1393
72	1208	348	1556	37		1593
73	1084	207	1291	45		1336
74	751	236	987	162		1149
75	549	394	943	431	43	1417
76	1231	718	1949	596		2546
77	1415	701	2116	822	2	2940
78	772	350	1122	747	25	1894
79	553	556	1109	669	5	1783
80	555	444	999	641	9	1649
81	813+	440+	1238+	710+	28+	1976+

+ Preliminary figures

Table 2. Acoustic estimates of the capelin stock (in million tonnes) by age in autumn 1973-81. Average weight (grams) of each age group given in paranthesis.

YEAR	AGE				SUM 2 years and older
	2	3	4	5	
1973	2.3	0.8	0.4	0.006	3.5
	(5.6)	(18.6)	(23.3)	-	
1974	3.1	1.6	0.07	0.002	4.8
	(5.6)	(9.1)	(21.2)	-	
1975	2.5	3.3	1.5	0.01	7.3
	(6.8)	(10.4)	(16.0)	(19.0)	
1976	2.0	2.1	1.4	0.3	5.8
	(8.2)	(12.4)	(16.4)	(18.2)	
1977	1.5	1.7	0.9	0.2	4.2
	(8.1)	(16.8)	(20.9)	(23.0)	
1978	2.5	1.7	0.3	0.02	4.5
	(6.7)	(16.5)	(20.7)	(23.1)	
1979	2.5	1.5	0.1	0.0005	4.1
	(7.4)	(13.5)	(21.1)	-	
1980	1.9	2.8	0.8	0.006	5.5
	(9.4)	(18.2)	(24.7)	-	
1981	1.8	0.8	0.3	0.008	3.0
	(9.4)	(17.0)	(23.3)	(28.7)	

Table 3.

ACOUSTIC ESTIMATE AUTUMN 1980

Total length mm	Age 1	2	3	4	5	Total number x 10^{-7}	Biomass tonnes x 10^{-3}
6.5- 6.9	105					105	1.0
7.0- 7.4	411					411	4.10
7.5- 7.9	418					418	4.20
8.0- 8.4	862					862	14.70
8.5- 8.9	2354					2354	47.10
9.0- 9.4	3760					3760	87.90
9.5- 9.9	3928	25				3953	120.30
10.0-10.4	3690	75				3765	145.70
10.5-10.9	5731	388				6119	284.10
11.0-11.4	6134	1186	13			7333	387.50
11.5-11.9	3314	2556	4			5874	363.40
12.0-12.4	1276	3456	52			4784	353.10
12.5-12.9	595	3221	170	4		3990	346.20
13.0-13.4	256	3115	459	14		3844	390.80
13.5-13.9	59	2724	1131	14		3928	452.5
14.0 14.4		1836	2317	108		4261	561.5
14.5-14.9		756	2811	197		3764	554.8
15.0-15.4		422	2776	381		3579	604.5
15.5-15.9		92	1800	464	1	2357	447.6
16.0 16.4		43	1453	469	29	1994	437.3
16.5-16.9		7	878	410		1295	327.2
17.0-17.4		7	510	384		901	257.2
17.5-17.9			442	339		781	250.8
18.0-18.4			271	230		501	182.8
18.5-18.9			178	108		286	115.0
19.0-19.4			131	85		216	91.3
19.5-19.9			19	55		74	36.5
Number x 10^{-7}	32893	19909	15415	3262	30	71509	
Number >14.4 cm		1327	11269	3122	30	15748	
Biomass (tonnes x 10^{-3})							6869.10
Biomass fish >14.4 cm							3305

Table 4. Estimates of parent stock (tonnes x 10^{-5}) and recruitment (10^{10} individuals 2 years old).

	1974	1975	1976	1977	1978	1979
Parent stock	3.42	2.74	14.01	11.55	8.56	3.70
Recruitment	24.1	18.1	39.1	33.4	19.7	19.5

Table 5. Mean length $\bar{l}$ (cm) of 2 years old capelin and corresponding total number N (10^{10} individuals).

	1974	1975	1976	1977	1978	1979	1980
$\bar{l}$	11.4	12.0	12.7	12.5	11.8	12.3	12.9
N	56.4	36.1	24.1	18.1	39.1	33.4	19.9

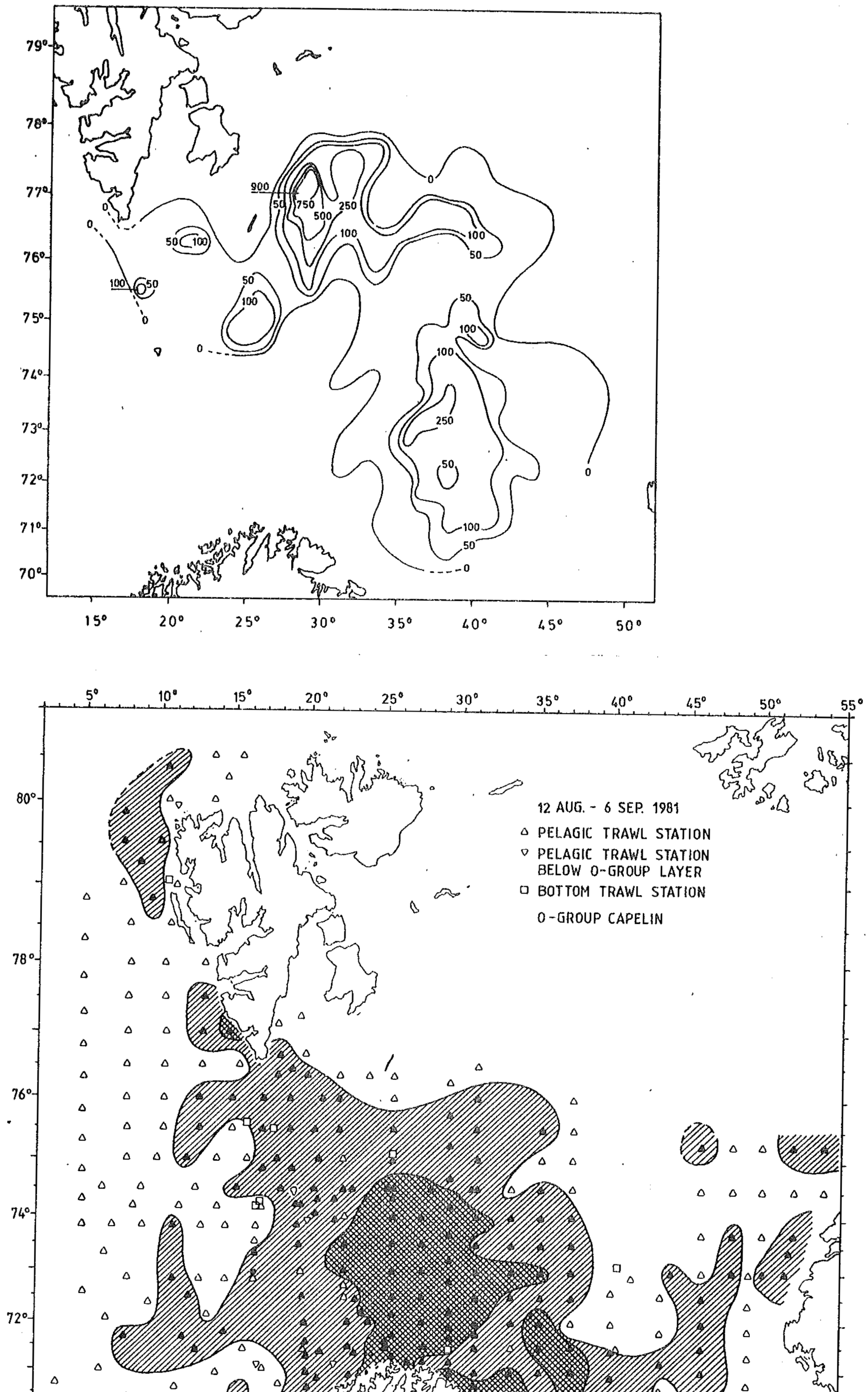

Figure 1. Distribution of 0-group Barents Sea capelin (lower part) and older capelin (upper part) in autumn 1981.

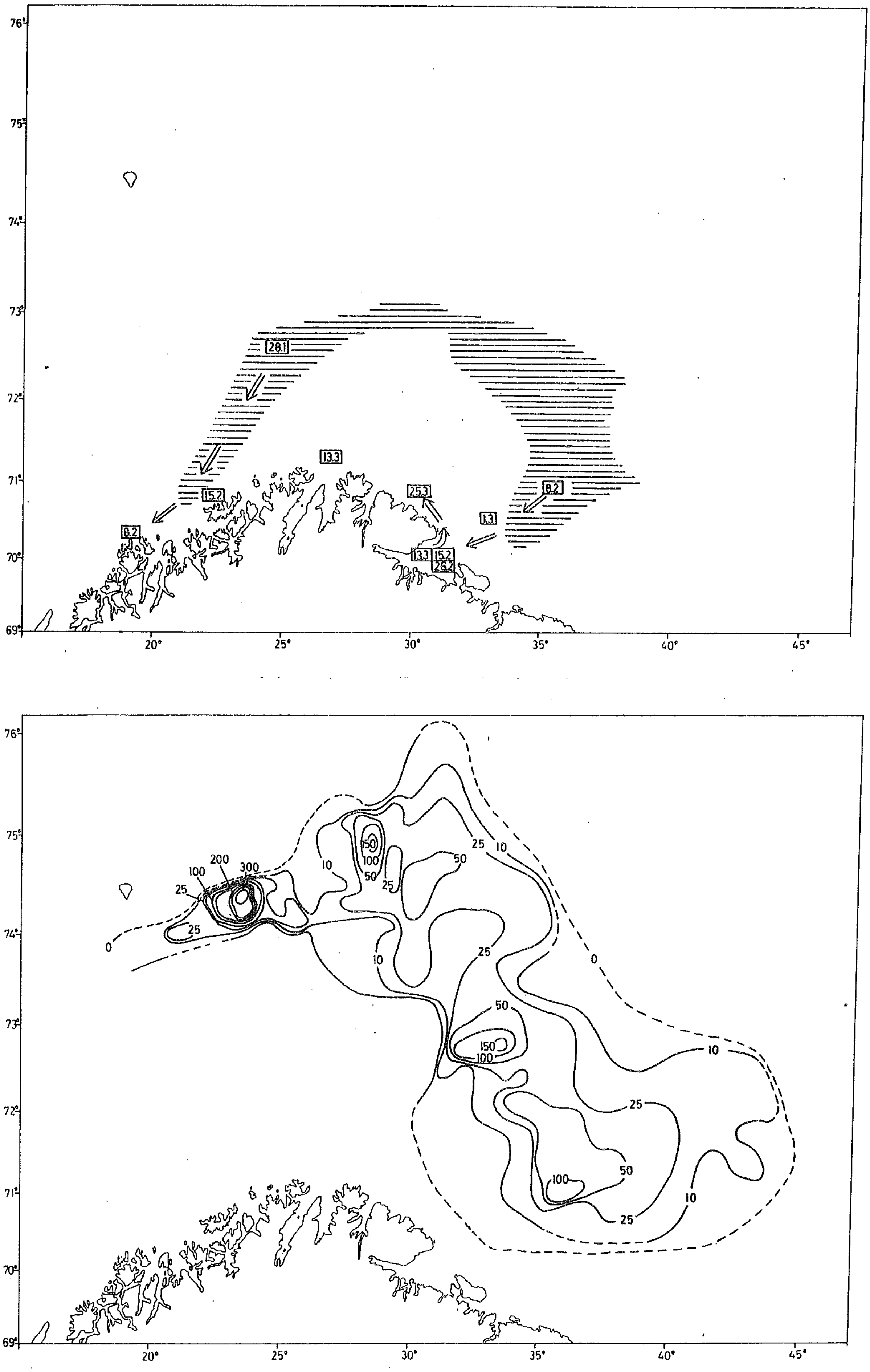

Figure 2. Distribution of mature capelin in winter. The arrows show spawning migration routes (upper part). The lower part shows the winter distribtuion of immatures 1980.

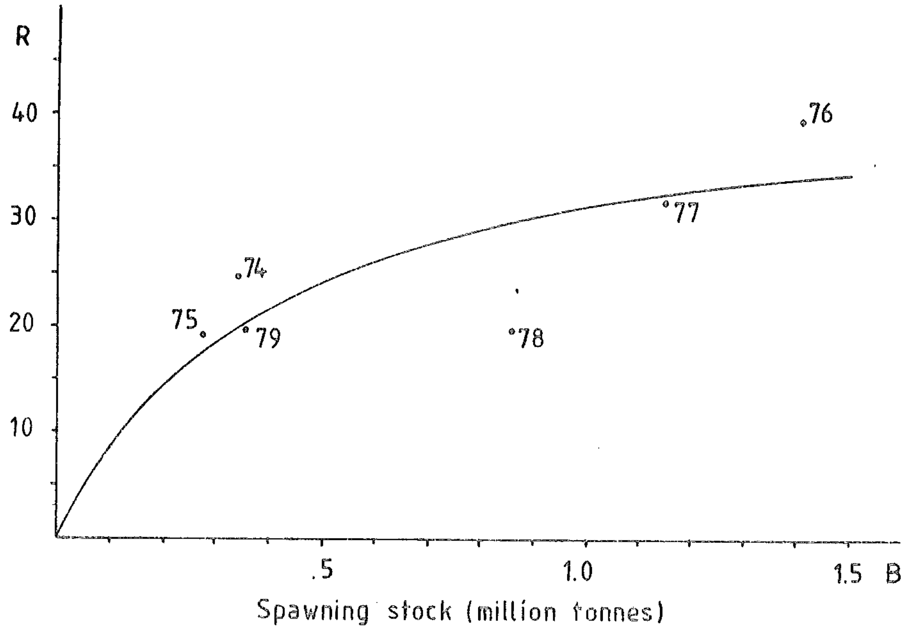

Figure 3. Stock-recruitment relation of Barents Sea capelin. The solid line shows the function $R = \frac{44,5 \cdot B}{0,43 + B}$ where R = recruited individuals x 10^{10} and B = spawning stock biomass in mill. tonnes.

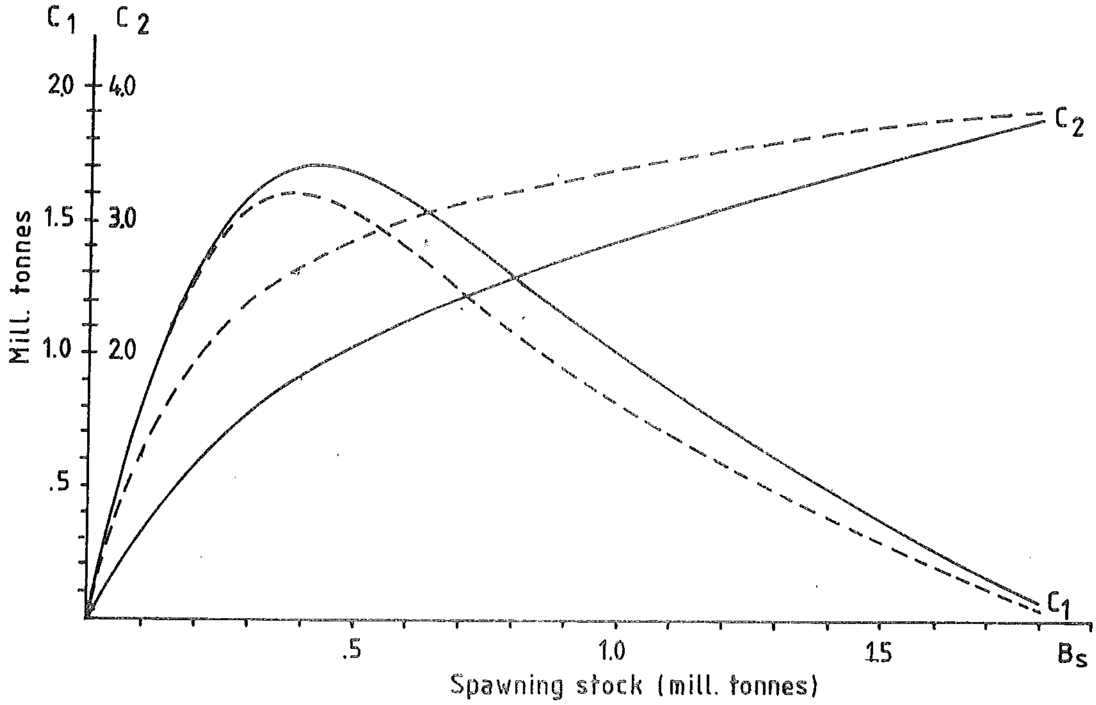

Figure 4. Sustainable yield (C_1) and M-output biomass (C_2) for Barents Sea capelin at different levels of spawning stock (B_s). Broken lines apply to winter fishing only, solid lines to autumn fishing only.

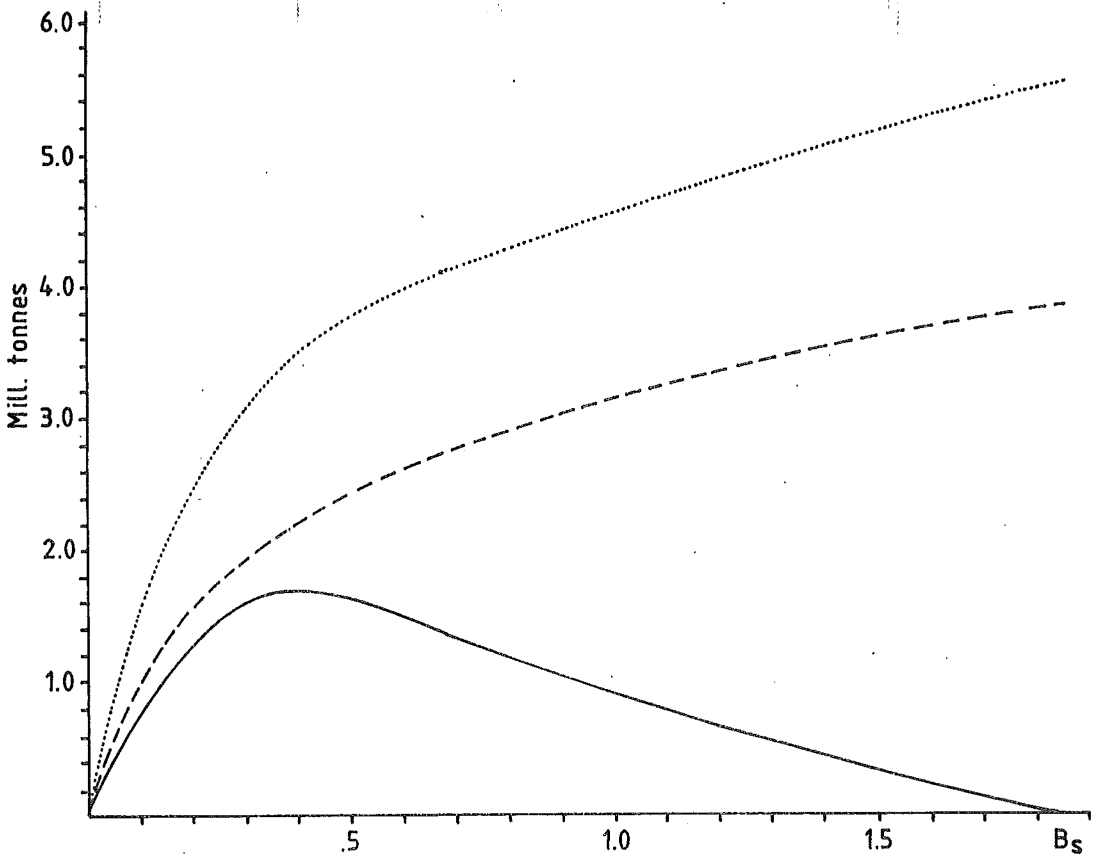

Figure 5. Sustainable yield (solid line), M-output biomass (broken line) and autumn stock (dotted line) for Barents Sea capelin at different levels of spawning stock (B_s) when the annual catch is equelly allocated to the autumn and winter season.

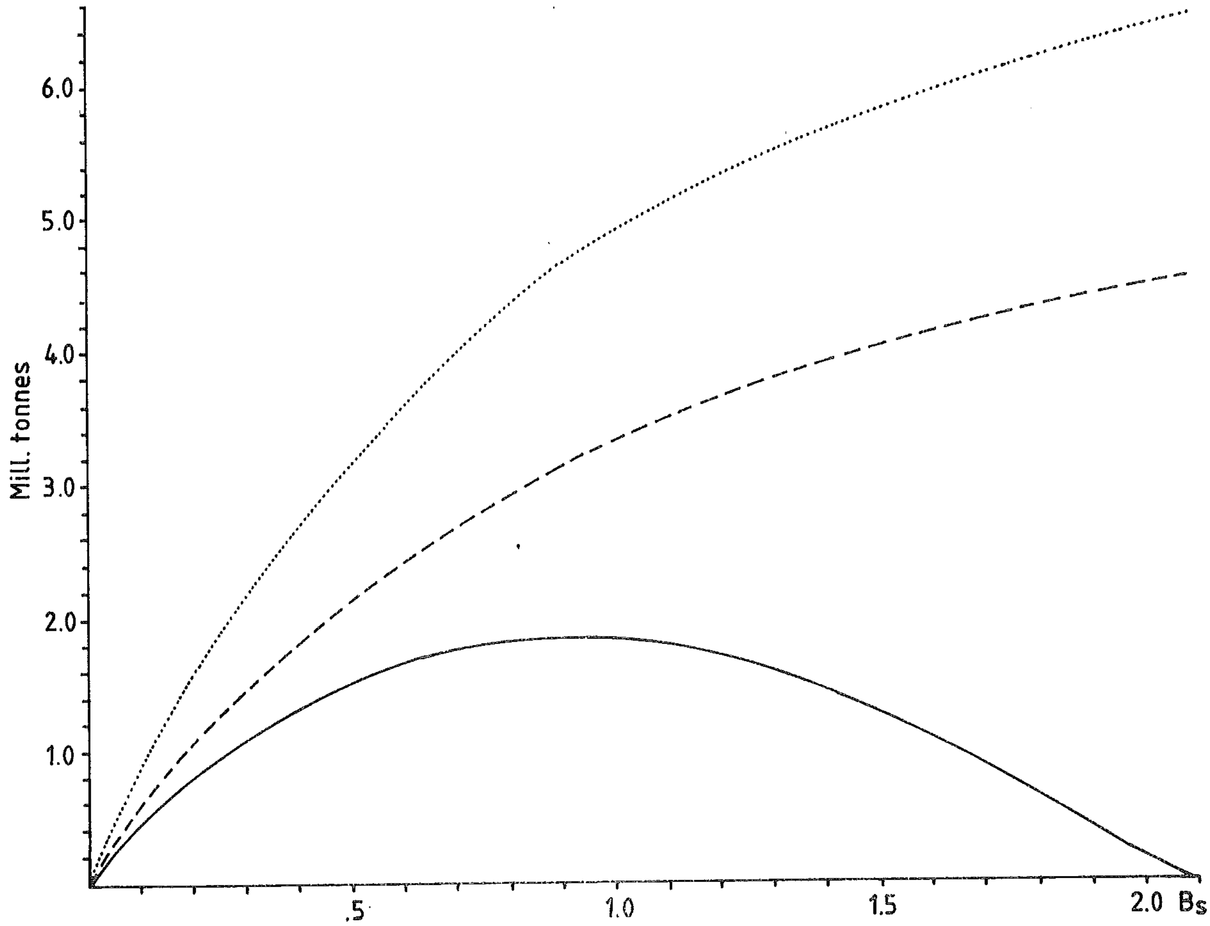

Figure 6. Sustainable yield (solid line), M-output biomass (broken line) and autumn stock (dotted line) at different levels of spawning stock (B_s) when the acoustic estimates are scaled by a factor of 1.5.

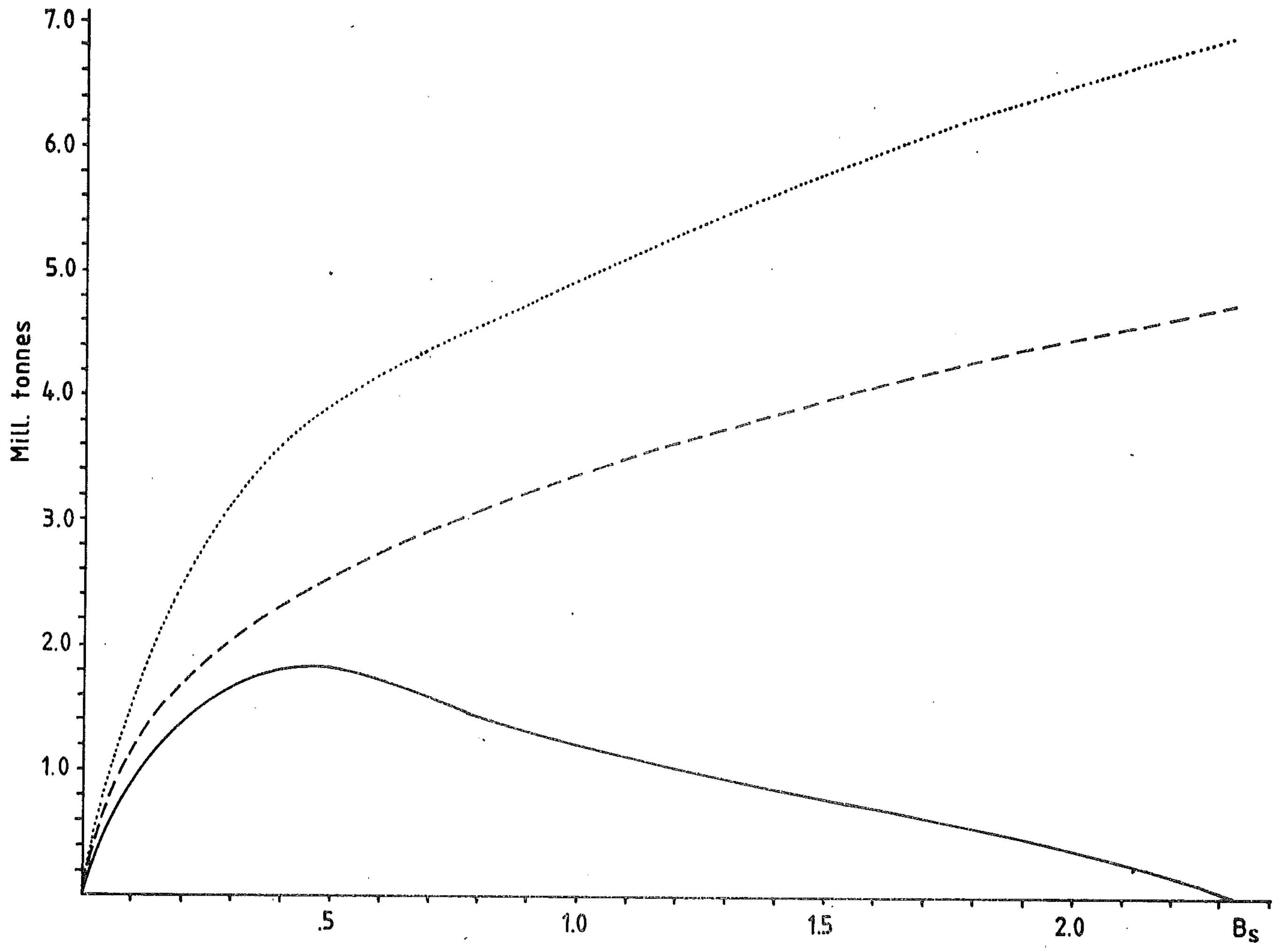

Figure 7. Sustainable yield (solid line), M-output biomass (broken line) and autumn stock (dotted line) at different level of spawning stock (B_s) when a 50 % spawning survival is assumed.