ASSESSMENT AND MANAGEMENT OF BARENTS SEA CAPELIN

by

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ABSTRACT

The history of the Barents Sea capelin fishery and fishery regulations is reviewed. Basic assessment data and theories are described and discussed in the light of the population dynamics governing the sustainable yield.

1. INTRODUCTION

The large scale capelin fishery in the Barents Sea developed in the latter half of the 1960's, when Norwegian purse seiners started to fish capelin on the spawning grounds during the winter seasons. The increase in fishing effort on capelin had two main reasons, (1) an improved fishing technique due to the introduction of the power block and (2) a large transfer of fishing effort from other fisheries due to the collapse of the herring and mackerel stocks in the Norwegian and North Sea. The rising catches may also to some extent be a result of an increased capelin stock due to the disappearance of the herring.

The present paper reviews the history of the Barents Sea capelin fishery and the regulation measures introduced to conserve the stock. The management of the fishery is described and discussed in the light of the present knowledge on the population dynamics which govern the sustainable yield. In conclusion emphasis is laid on current management problems and areas of current research.

2. THE FISHERY

The Barents Sea capelin stock is exploited almost exclusively by Norway and the USSR. Table 1 summarizes the yearly catches since 1958, which, prior to that year, are very small. The Norwegian purse seine fishery was originally located in coastal waters during winter and early spring and the catches rose to above 200 000 tonnes in 1961. In the next 3 years the catches declined to a very low level, caused by an obvious decline in the abundance of the yearclasses 1958-1960 (Olsen 1968). This temporary disappearance of capelin coincided with the recruitment of two extraordinarily strong herring yearclasses, (1959 and 1960). It is likely that the feeding area of young herring in those years overlapped with the distribution area of juvenile capelin and this could be the reason for the disappearance of the capelin in the early 1960's.

From 1964 onwards, the Norwegian winter catches grew continuously reaching 1.3 mill. tonnes in 1971. There is a temporary decline to 0.55 mill. tonnes in 1975, and then an increase to a record catch of 1.4 mill. tonnes in 1977. In 1978, the Norwegian winter fishery was subjected to a national catch quota regulation. The quota was however not filled and the regulation had probably no effect on the total catch. Since 1979 the Norwegian winter catches have been effectively limited by a bilateral catch quota regulation agreement between Norway and USSR.

A Norwegian summer and autumn fishery for capelin started in 1968 and the catches rose to above 700 000 tonnes in 1977. This fishery's catch was limited to 350 000 tonnes in 1978 by a national catch quota regulation and since 1979 the fishery has been regulated according to the fishery agreement with USSR. Fishing is conducted in the feeding area in offshore waters and is based on the maturing capelin and juveniles.

Prior to 1974, the USSR capelin catches were small and below 50 000 tonnes. A large scale fishery developed in the middle of the 70's, and the annual catch reached a peak of 822 000 tonnes in 1977. The USSR capelin fishery has been regulated according to the fishery agreement with Norway since the winter of 1979.

Table 1. Catch of Barents Sea capelin in the years 1959-83 (1000 t.)

Year	Norway			USSR	Other countries	Sum
	Winter	Summer	Total			
1959	80		80			80
60	90		90			90
61	230		230			230
62			0			0
63	30		30			30
64	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		2545
77	1415	701	2116	822	2	2940
78	772	350	1122	747	25	1894
79	542	544	1086	669	5	1760
80	542	434	976	641	9	1626
81	716	393	1109	721	28	1858
82	*558	*601	*1159	*596		*1755
83	*706	*615	*1321			

* Preliminary figures.

3. STOCK MEASUREMENTS

The size and composition of the Barents Sea capelin stock have been assessed by various methods, such as age composition, tagging and acoustic techniques. Larvae production has, moreover, been introduced as index of spawning stock, and data from the international 0-group survey of the Barents Sea is recorded as indices of recruitment.

3.1 Age composition data

Published data on the age composition of spawning capelin covers 1954 and onward. Dommasnes (1984) has reviewed and discussed the available information and concludes that there is a periodic change in the age composition of the spawning stock. In the latter half of the 1950's the spawning capelin was relatively young, the stock being dominated by the 3-year-old capelin. In this period two-year-old spawners occur whereas the five-year-olds are very scarce. This pattern changes in 1960, when the four-year-olds dominate for the next 5 years. In this period, the two-year-old spawners disappear whereas the contribution of the five-year-old spawners increases. In 1965-67 the capelin have again matured at an early age but after 1967, the four-year-olds and older capelin dominate the spawning component. The changes in the age distribution of capelin are governed by the growth rate, and shows that the maturation of capelin is determined by the size and not by the age. The short lifespan indicates that the fish suffer mass mortality after spawning.

3.2 Assessment based on tagging

The Norwegian Institute of Marine Research tagged maturing capelin in the winters of 1970 to 1975. Internal steel tags were used and recoveries were retained by magnets installed in the meal plants. The analyses of the tagging data are published by Dragesund et al. (1973) and by Dommasnes (1977) and indicate that the method is not sufficiently accurate to be used for catch quota regulations. The main sources of error were nonrandom mixing of the tagged fish (within season recoveries only), and high and variable tagging mortality. The Norwegian tagging programme was therefore terminated in 1976.

3.3 Larvae and O-group surveys

The O-group capelin are reported in the international larvae surveys since 1965, but the data have not been applied to stock assessment as basis for fishery management.

Larval density studies have been applied as basic data for estimating parent stock (Salvanes, 1984). For the years 1972-76 the larvae abundance estimates are closely correlated to the Norwegian winter catches, but deviate to some extent from the acoustic stock abundance estimates. This is also to be expected since the larvae surveys covered the spawners on the Norwegian coast only.

In order to monitor the distribution area of early hatched capelin larvae in the Barents Sea, a capelin larval survey based on the Gulf III plankton sampler was initiated in 1981. The results from these surveys are presented to this symposium in a paper by Alvheim (1984). The distribution and abundance of capelin larvae have been remarkably constant in the years 1981-84 although the estimated size of the parent stock, based on the acoustic surveys, has varied considerably. The larval abundance estimates as indices of parent stock are, however, considered to have low reliability, and no firm conclusion on the state of the spawning stocks can be drawn from this study.

3.4 Acoustic stock measurements

Acoustic surveys on the Barents Sea capelin have been carried out since 1971. Attempts have been made to survey the stock at various times of the year and, for various reasons, September - October is preferred. The distribution of capelin and measurements of the abundance by areas and ages are obtained. Details of the surveys and the survey results are described and discussed in a paper to this symposium (Dommasnes and Røttingen 1984).

During the period under study, large changes are observed in the distribution of the capelin and in the size and composition of the stock. In the early 1970's, the capelin had a southwesterly distribution pattern, which expanded north- and eastwards in the course of the first half of the 1970's. The most north- and easterly distribution pattern occured in 1975 (Figure 1). In the subsequent years the capelin withdrew towards the southwest, reaching the most southwesterly distribution in 1981. A slight northeasterly movement is observed in later years, indicating that a new period of expansion towards north and east has started. These changes in the distribution pattern seem to be linked to changes in the hydrographical condition of the Barents Sea and may become decisive for growth and recruitment conditions, and thus the obtainable yield of capelin in the coming years. These are topics and areas of research which will be discussed in a later session of this symposium (Gjøsæter and Loeng 1984).

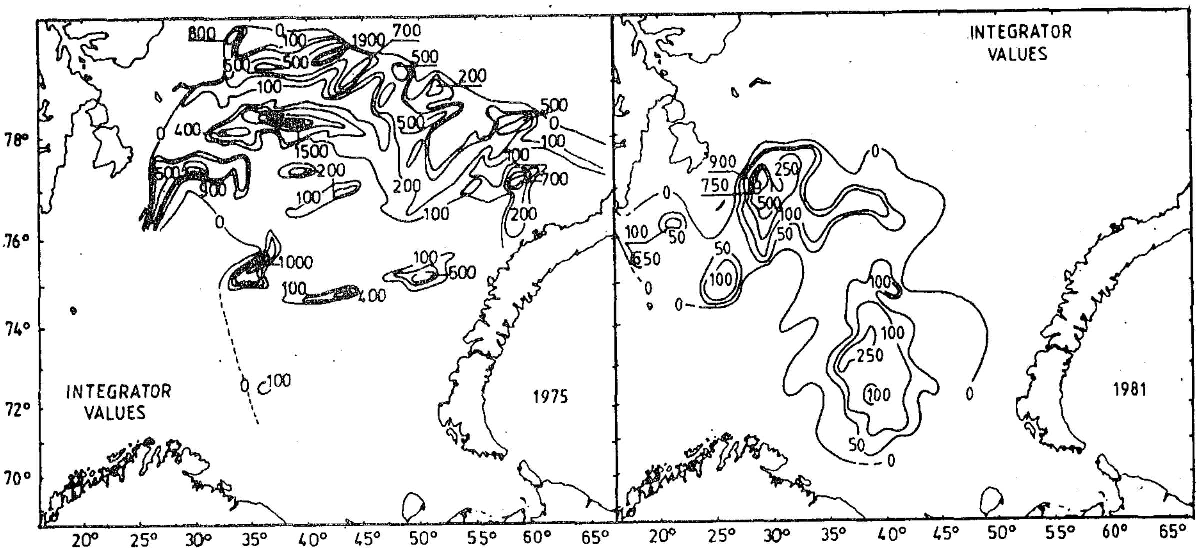

Figure 1. Integrated echo intensity (mm deflection/nautical mile) of capelin in 1975 and 1981.

The acoustic abundance estimates of the catchable stock in weight and average weight by age obtained since 1973 are summarized in Table 2. In 1973-75, when the stock expanded towards the north and east, three very abundant yearclasses (1971-73) were recruited to the catchable stock and the stock biomass increased from 3.5 mill. tonnes to 7.3 mill. tonnes. The growth rate decreased considerably in these years, the average weight of the 3-year-olds, which constitute the main age group of prespawners, went down from 18.6 grams in 1973 to 9.1 grams in 1974. The 2-year-olds were also small, below 6 grams in 1973 and 1974.

The biomass has varied but has, in general, declined. The lowest estimate of 2.6 mill. tonnes was obtained in 1983. The growth increased in 1980 and has later remained at a high level. In general, the table shows a relation between high abundance and low average weight by age and that an increase in the growth rate is followed by a reduction in the life span of the capelin.

This relation between abundance, growth rate, and life span of the capelin supports the basic hypotheses on which the capelin assessment model is built, namely that the growth rate is density dependent, that the maturation of capelin is determined by the size of the fish and that the capelin suffers mass mortality after spawning.

4. FISHERY REGULATIONS

In 1978, the USSR/Norwegian Fisheries Commission agreed to regulate the Barents Sea capelin fishery bilaterally. A closed season regulation from 1 May to 14 August was introduced and the allowable catch of juvenile capelin below 11 cm was limited to 15% in weight. The opening date of the autumn fishery has later been changed to 1 September (1984) and the bycatch limit of undersized fish (below 11 cm) reduced to 10% (1981). In 1981 a minimum mesh size of 16 mm in capelin nets (trawls and purse seiners) was introduced.

A bilateral USSR/Norwegian catch quota regulation of the fishery has been in force since the winter of 1979. Total allowable catch (TAC) is agreed upon for the autumn and winter fishery separately and the table below summarizes the agreed TAC and corresponding catches by seasons (in 1000 tonnes).

	TAC			Catch		
Year	Winter	Autumn	Total	Winter	Autumn	Total
1979	925	900	1825	894	866	1760
1980	900	700	1600	890	736	1626
1981	1200	700	1900	1212	646	1858
1982	800	800	1600	828	927	1755
1983	1100	1200	2300	1112		
1984	600	800	1400			
Mean	920	850	1770	990	790	1750

Prior to the bilateral agreement with USSR, Norway regulated its capelin fishery by catch quotas in the winters of 1974 (7.2 mill. hl) and 1978 (11.5 mill. hl) and in the autumn of 1978 (3.5 mill. hl). Various closed areas were introduced to protect spawners on main spawning grounds, and juveniles on main feeding grounds.

5. THE ASSESSMENTS OF STOCK AND YIELD

5.1 Fishery management 1974-78

Based on knowledge and experience derived from various research activities, it has been decided to use the acoustic stock measurements in autumn as basis for the management of the capelin fishery.

Table 2. Acoustic estimation of the capelin stock (million tonnes) by age in autumn 1973-82. Average weight (grammes) for each age group are given in parantheses.

Year	Age 2	Age 3	Age 4	Age 5	Sum 2 years and older
1973	2.3 (5.6)	0.8 (18.6)	0.4 (23.3)	0.006 -	3.5
1974	3.1 (5.6)	1.6 (9.1)	0.07 (21.2)	0.002 -	4.8
1975	2.5 (6.8)	3.3 (10.4)	1.5 (16.0)	0.01 (19.0)	7.3
1976	2.0 (8.2)	2.1 (12.4)	1.4 (16.4)	0.3 (18.2)	5.8
1977	1.5 (8.1)	1.7 (16.8)	0.9 (20.9)	0.2 (23.0)	4.2
1978	2.5 (6.7)	1.7 (16.5)	0.3 (20.7)	0.02 (23.1)	4.5
1979	2.5 (7.4)	1.5 (13.5)	0.1 (21.1)	0.0005 (28.7)	4.1
1980	1.9 (9.4)	2.8 (18.2)	0.8 (24.7)	0.006 -	5.5
1981	1.8 (9.4)	0.8 (17.0)	0.3 (23.3)	0.008 (28.7)	3.0
1982	2.8 (9.0)	1.3 (20.9)	0.05 (24.9)		4.2
1983	1.9 (9.5)	0.7 (18.9)	0.01 (19.4)		2.6

When Norway limited its catch of capelin in the winter of 1974 to 7.2 mill. hl, this was based on the results of the acoustic stock measurements in 1972 and 1973 (Dommasnes and RØttingen (1984), Tables 1 and 2). Comparing the two estimates it is seen that the contribution of 3-year-olds and older capelin in 1973 declined to less than half of the 1972 measurements (12.0 mill. hl in 1973, 26.6 mill. hl in 1972). These age groups were assumed to constitute the bulk of spawners in the next winter and, taking into account that 12 mill. hl capelin had been caught in previous years (Table 1), it was felt that a free fishery in 1974 could endanger recruitment. No attempt was, however, made to evaluate consequences of an alternative management policy due to lack of basic knowledge (stock - recruitment relationship, natural mortality, consistency of the acoustic stock measurements). The catch quota of 7.2 mill. hl for the winter fishery in 1974, was thus introduced as an act of discretion.

The winter fishery in 1974 turned out to be rather poor and thus in accordance with expectation. This was, in fact, the first time that a large change in stock abundance, measured by the new acoustic technique, was tested by the output of the fishery and the result yielded conditional confidence in the method. The catch quota was not filled before the first week of April, and the regulation had probably little effect on the attainable catch.

Table 3. Acoustic abundance estimate autumn 1981.

Total length (cm)	Age					Total number $\times 10^{-7}$	Biomass tonnes $\times 10^{-3}$	Biomass (cumulative)
	1	2	3	4	5+			
6.5- 6.9	1805					1805	16.2	
7.0- 7.4	3180					3180	31.8	
7.5- 7.9	5814					5814	75.7	
8.0- 8.4	6387					6387	115.2	
8.5- 8.9	5723	8				5731	120.6	
9.0- 9.4	5188	34				5222	135.0	
9.5- 9.9	4142	132				4274	129.3	
10.0-10.4	2643	256				2899	108.2	
10.5-10.9	2162	470				2632	113.6	
11.0-11.4	786	896				1682	88.5	
11.5-11.9	299	1743	5			2047	127.4	
12.0-12.4	162	3069	19			3250	233.7	
12.5-12.9	125	4195	59			4379	363.5	
13.0-13.4	50	3276	229	4		3559	342.4	
13.5-13.9	20	2347	466	1		2834	315.1	1864.8
14.0-14.4	7	1532	641	2		2182	276.5	1549.7
14.5-14.9		676	701	20		1397	201.4	1273.2
15.0-15.4		355	705	140	4	1204	197.4	1071.8
15.5-15.9		164	697	199		1060	189.8	874.4
16.0-16.4		94	468	197	2	761	155.4	684.6
16.5-16.9		79	344	259		682	155.6	529.2
17.0-17.4		67	157	172	4	400	106.7	373.6
17.5-17.9		52	162	182	6	402	120.0	266.9
18.0-18.4		38	66	129		233	77.7	146.9
18.5-18.9		17	51	49	10	127	46.3	69.2
19.0-19.4			15	2		17	7.8	22.9
19.5-19.9			5	19		24	11.5	15.1
20.0-20.4			1	3		4	2.3	3.6
20.5-20.9			2			2	1.3	1.3
No.$\times 10^{-7}$	38493	19500	4793	1378	26	64190		
No.>13.4	27	5421	4481	1374	26	11329		
Biomass							3865.6	

In autumn of 1974, a new important change in the composition of the stock occured (Dommasnes and Røttingen (1984), Table 3). The same age groups as those which had matured and spawned the previous years (3 and older) appeared to be very numerous, but the mean length of the fish had drastically declined (9.1 cm against 15.6 cm in 1973 for 3-year-olds). According to the maturity scale in use (Monstad 1971) these small sized fish were not expected to mature and spawn the next winter. It was therefore concluded that the maturing stock in the winter 1975 might become even smaller than in the year before. The risk of overfishing the spawners in the winter of 1975 was thus even larger than in 1974, but due to the large stock of juveniles it was decided not to limit the Norwegian 1975 winter catch. It was noted that the slow growth of the 3-year-old capelin could be density-dependent and, if so, an increased exploitation could be preferable in order to reduce the population density (Anon 1975).

Table 4. Acoustic abundance estimate, autumn 1975.

Total length (cm)	Age					Total number $\times 10^{-7}$	Biomass tonnes $\times 10^{-3}$	Biomass (cumulative)
	1	2	3	4	5+			
5.5- 5.9	25					25	0.1	
6.0- 6.4	7					7	0.0	
6.5- 6.9	7					7	0.0	
7.0- 7.4	19					19	0.2	
7.5- 7.9	158					158	1.9	
8.0- 8.4	460	45				505	8.9	
8.5- 8.9	1848	21				1869	38.6	
9.0- 9.4	4049	285				4334	114.0	
9.5- 9.9	4483	806				5288	166.8	
10.0-10.4	4975	1305				6278	242.9	
10.5-10.9	2549	3439	33			6022	265.2	
11.0-11.4	1008	5254	1041	41		7347	358.4	
11.5-11.9	320	8223	3084	88	12	11727	692.2	
12.0-12.4	82	6435	4085	292		10909	773.0	
12.5-12.9		4455	5402	503	35	10388	880.8	
13.0-13.4		2696	4397	855		7956	788.9	
13.5-13.9		1655	3553	742		5943	671.6	3636.5
14.0-14.4		681	2724	984		4393	562.5	2964.9
14.5-14.9		241	1920	906		3063	456.0	2402.4
15.0-15.4		269	1564	583		2412	389.1	1946.4
15.5-15.9		150	902	1069	18	2145	400.1	1557.3
16.0-16.4		108	681	841		1627	343.8	1157.2
16.5-16.9			530	636		1164	281.9	813.4
17.0-17.4			224	569	32	826	232.3	531.5
17.5-17.9			146	464		610	183.7	299.2
18.0-18.4			111	157		265	91.7	115.5
18.5-18.9			7	59		66	23.8	23.8
No.$\times 10^{-7}$	19990	36068	30406	8789	97	95353		
No.>13.4		3104	12364	7010	50	22514		
Biomass							7995.5	

The Norwegian winter fishery in 1975 yielded less than 6 mill. hl, the availability of capelin being obviously lower than in 1974. These events strengthened the confidence in the acoustic method and demonstrated that the maturation of capelin depends on size rather than age. The observations further indicated that the growth was density-dependent, and the dynamics of such a population will, to a very large extent, be determined by the individual's growth.

In 1976 and 1977, 3 rich yearclasses (1971-73) matured and spawned in 2 years, resulting in correspondingly rich catches. The consistency of the bio-acoustic stock estimates and their conformity with the catches in these years further strengthened the reliability of the acoustic method. In the autumn of 1977 the stock had declined to 4.2 million tonnes (Table 2), and due to this Norway regulated its capelin fishery by a catch quota of 15 million hl in 1978.

5.2 The TAC for 1979

When the rich yearclasses of 1971-73 had passed the fishery in 1978, a regulation of the catch was considered as a matter of urgency. The USSR/Norwegian Fishery Commission therefore requested scientists from the two countries to evaluate the state of stock and submit proposals for necessary joint management actions. Two meetings of scientists were held in 1978 and the following important agreements were made: (a) A TAC-assessment of capelin should be based on acoustic stock measurements carried out jointly in the autumn; (b) the assessment period should cover the autumn and subsequent winter fishery and (c) the TAC-assessment should aim at a minimum stock of spawners of 500 000 tonnes (Anon 1978, a and b).

The 500 000 tonnes minimum spawning stock was judged according to a rough evaluation of stock-recruitment data from previous years. The agreements provided a basis for calculating TAC for the 1979 winter fishery, and the principals of this first TAC-calculation for capelin may be summarized in the following paragraphs (Anon 1978, a and b).

The acoustic stock estimate in numbers by yearclass in successive years was used to calculate the total mortality (Z) and, adjusted by the catch, the natural mortality (M) by age. The estimated M-values from 2- to 3-year-old fish were then taken as the natural mortality of non-spawning capelin. The following values were obtained.

1974-75, M = 0.77
1975-76, M = 0.78
1976-77, M = 0.65

The estimates refer to 1 year periods starting with 1 October. On the basis of results of the USSR investigations on the seasonal feeding patterns of cod (regarded as the main capelin eater), the M values were divided in two periods, 1 October - 1 May and 1 May - 1 October, in proportion 75% and 25% respectively.

The fishing pattern (F-values) of the previous years were then calculated on the basis of the catch by season using the VPA-method.

The 1978 stock in number by age, derived from the acoustic survey in September, was taken as input data of the initial catchable stock. Applying mean values of F and M from previous years, the total allowable catch which would maintain a spring spawning stock of 500 000 tonnes was then calculated, assuming that the catch would consist of prespawners only, and that the spawners would be dominated by the 4-year-olds and older fish. The calculations were made on the basis of number by age, and the spawning biomass was converted to weight by using observed mean weight of spawners in March.

Based on this calculation of TAC, the USSR/Norwegian Fishery Commission agreed to limit the total winter catch in 1979 to 925 000 tonnes.

The 1978 acoustic stock estimate of 2-year-old capelin was further applied to calculate a preliminary TAC for the 1979-80 period. This was done by projecting the measured stock of 2-year-old capelin one year ahead, using average M- and F-values and weight by age calculated for previous years. This prognosed stock of 3-year-old capelin in the autumn 1979 was taken as the main component of the 1980 winter spawners and used as initial stock in a similar TAC-calculation for the period one year ahead (1979-80). This TAC was calculated to 1.8 mill. tonnes. It was, however, stressed that this TAC should be considered with caution and had to be reassessed and adjusted if necessary when new stock data from the 1979 autumn survey become available (Anon 1978, b). Based on this advise, the Commission agreed to limit the total autumn catch in 1979 to 900 000 tonnes, allocating 900 000 tonnes as preliminary TAC for the winter fishery in 1980.

5.3 The TAC for 1980

The same procedure of TAC-calculation has in principal been followed in the subsequent years. The group of scientists, who meet (in Hammerfest) immediately after the joint acoustic autumn survey, reassesses the prognosed stock and preliminary TAC-estimate made the previous year. The stock abundance measurements are reduced by the remaining catch quota per 1 October, and the natural mortality and an initial stock of spawners per 1 January is reassessed. From this stock the final winter TAC is derived. The calculated stock of non-spawners is then projected ahead to the opening for the autumn fishery and used as initial stock for a preliminary TAC-estimate of the next regulation period. A proportion of the latter TAC is recommended as TAC for the autumn fishery.

The simple stock model used for TAC-calculations in 1978 had distinct shortcomings. The lack of an adequate technique to separate spawners from non-spawners in the acoustic stock estimate was an obvious source of error for the calculation of spawning stock and mortality as well. It was realized that the maturity scale in use was inapplicable for this purpose and a new investigation was initiated to construct a scale which could predict the spawning time. The results obtained are published by Forberg (1982 and 1983) and in a paper to this symposium (Forberg and Tjelmeland 1984).

As mentioned previously (section 3.1), the maturation of capelin appears to be more linked to the size of capelin than to the age and, at the joint USSR/Norwegian capelin meeting in 1979, it was suggested to separate potential spawners from non-spawners by the length of fish. A new parameter, the maturation length was introduced, defined as the length of capelin (in September) at which all fish exceeding that length are supposed to mature and spawn the next winter. The capelin smaller than that length were considered juveniles (Table 3). The maturation was thus assumed to be independent of age of capelin and a selected maturation length would therefore determine the age composition of the maturing component stock estimate. By comparing this age composition to that of the subsequent winter spawners using data from the catches in March, the maturation length could be determined. By this method the 1979 Hammerfest meeting calculated the maturation length for the years 1974 to 1979, and found that the length had varied between 15.2 cm and 13.7 cm (Anon 1979). The latter was observed in recent years. The 1979 meeting therefore agreed to apply a maturation length of 13.5 cm for the 1980 management advices. The 1979 acoustic stock estimate was thus divided into a maturing stock component containing all capelin exceeding 13.5 cm and a juvenile stock consisting of the smaller fish. A spawning stock prognosis by the 1 January 1980 was calculated, and a catch of 800 000 tonnes in the winter of 1980 was found to reduce that stock to 507 000 tonnes, whereas the preliminary recommended TAC of 900 000 tonnes winter catch would reduce the spawning stock to 425 000 tonnes. Pointing to the various uncertainties in the estimate, the scientists recommended 900 000 tonnes as final TAC for the winter fishery in 1980. This recommendation was approved by the USSR/Norwegian Fishery Commission.

The estimated stock of juveniles (capelin smaller than 13.5 cm) was projected ahead and used as input data for the TAC calculation of the the subsequent regulation period. Based on this stock prognosis a TAC of 1.6 mill. tonnes was calculated for the autumn catch 1980 plus the winter catch in 1981. It was however recommended that not more than 700 000 tonnes should be allocated to the autumn fishery in 1980, and that the remaining 900 000 tonnes should be set as preliminary TAC of the winter 1981. This recommendation was adopted by the Fishery Commission (See section 7).

5.4 The TAC for 1981

The results of the acoustic capelin survey in 1980 were in good agreement with the stock prognosis made in 1979 with respect to number at age, but due to extraordinarily good individual growth in 1980 the biomass of maturing capelin was far above expectations. The mean length at age had increased substantially (Dommasnes and Røttingen 1984), and, assuming a length dependent maturation scale, a larger proportion of the stock was expected to mature and spawn the next winter. It was calculated that by applying a maturation length of 14.5 cm in the 1980 stock measurement, a catch of 1.2 mill. tonnes for the winter 1981 would reduce the biomass of spawners slightly below 800 000 tonnes, and the Norwegian scientists of the 1980 Hammerfest meeting were of the opinion that the preliminary TAC for the winter 1981 (900 000 tonnes) should be increased to 1.2 mill. tonnes. The USSR scientists were however of the opinion that the new stock situation should be considered with caution and recommended 1.0 mill. tonnes. The Fishery Commission accepted the 1.2 mill. tonnes TAC for the winter fishery in 1981. The 1980 Hammerfest meeting considered the prospects for the 1981-82 catch to be far below that of the current regulation period due to recruitment of a weaker yearclass (1978) and higher expected mortality of post spawners. By projecting the juvenile stock (capelin smaller than 14.5 cm) one year ahead and using this as expected catchable stock in the autumn 1981, the meeting assessed a preliminary TAC of 1.3 to 1.5 mill. tonnes for the 1981-82 regulation period depending on the expected maturation length in 1981. Based on this study the meeting recommended a TAC of 700 000 tonnes for the autumn fishery in 1981. This recommendation was approved (Anon 1980).

5.5 The TAC for 1982

The acoustic stock measurements obtained in the autumn 1981 were in good agreement with the projected stock based on the previous year abundance measurements of juveniles. The 1981 Hammerfest meeting agreed to assess the TAC, according to the same procedure as last year. Details of the calculated TAC's appear in the table below (l_s= maturation length):

TAC winter 1982	1982 Spawners		TAC autumn 1982	TAC winter 1983	1983 Spawners	
	l_s = 14.0	l_s = 14.5			l_s = 14.0	l_s = 14.5
600	584	381	500	500	948	815
700	493	291	600	600	810	679
800	401	201	700	700	671	544
900	312	113	800	800	533	411
1000	223	32	900	900	397	279
			1000	1000	262	150

Based on this study, the meeting recommended that 800 000 tonnes be fished in the winter 1982. This was a somewhat larger catch than should be permitted according to the agreed minimum spawning stock, (500 000 tonnes), but judging from estimated mortality of 1980-81, which was found to be extraordinarily high, the meeting considered the 1981 stock measurements to be underestimated. This recommended TAC was approved by the Fishery Commission, whereas a recommended 800 000 tonnes TAC for the autumn fishery in 1982 was increased by the Commission to 900 000 tonnes (Anon 1981).

5.6 The TAC for 1983

The acoustic stock survey in the autumn 1982 gave abundance estimates which were unreasonably high, especially for the 1980 yearclass, which was previously assumed to be below average. In the 1982 survey this yearclass was strong and the older yearclasses were also measured above the expectation. This observation together with the fact that the intercalibration data of the acoustic instruments onboard the participating research vessels did not tally (Dommasnes and Røttingen 1984), gave rise to doubts about the reliability of the measurements. But, lacking definite observations which could be used to alter the stock measurements, the 1982 Hammerfest meeting accepted the survey results as basic data for the next year TAC assessment. This resulted in a recommended winter catch of 1.1 mill. tonnes and an autumn catch of 1.2 mill. tonnes for the year 1983. (Anon 1982).

5.7 The TAC for 1984

When the results of the 1983 acoustic stock survey became available it was obvious that the 1982 stock had been overestimated, particularly the stock of juveniles (1980 yearclass). The contribution of 2 and 3 years old capelin, which according to the 1982 stock prognosis should have been at a level of 5 mill. tonnes in 1983, were reduced to 2.5 mill. tonnes. Older capelin were missing, but this was in accordance with the expectation. The capelin was now considered to be seriously threatened by overfishing, taking into account the large autumn TAC in 1983. The 1983 Hammerfest meeting therefore recommended cutting the 1983 autumn TAC by 20% if possible. No definite TAC-recommendation for the winter fishery in 1984 was made, but an allowable catch of 500 000 tonnes was indicated. This catch limit was later recommended by the ACFM. For the 1984 autumn fishery, a catch of 600 000 tonnes was recommended which may imply a winter catch in 1985 somewhat above 800 000 tonnes (Anon 1983)

No reduction of the 1983 autumn TAC was agreed upon and the USSR/Norwegian Fishery Commission suggested that their governments set the TAC of 1984 to 600 000 tonnes and 800 000 tonnes for the winter and autumn fishery respectively. It may therefore be concluded that the present management strategy of capelin approved by the two countries last year represents an increased exploitation policy. This gives reason for concern about the future development of the capelin fishery in the Barents Sea.

6. SUSTAINABLE YIELD ESTIMATES

The guideline for a regulation of a fishery is the expected effects on the sustainable yield. The effects of the minimum landing size of capelin and the closed season regulation have not been assessed in detail. There is no doubt that such measures are of importance in optimalizing the sustainable yield, particularly the closed season regulation. The capelin has a short growth period and the yield can only be optimized if the fishing strategy is adjusted so that the fishing starts at the end of the growth period.

The effects of the catch quota regulation have, on the other hand, been assessed by modelling the exploitation of the capelin stock to determine the sustainable yield. As to the details of the matematical model used, reference is made to the documentation of the model presented in a paper to this symposium. (Tjelmeland 1984). The model is, in principle, a Beverton and Holt stock model in which the natural mortality is implemented in the form of two independent parameters, one proportional to the stock size, and the other as the fraction of the stock which has spawned. The model assumes that the capelin mature according to length, as was the basic hypothesis in the TAC-calculation. In the long term yield estimate it is further supposed that the maturation length is constant and does not vary with year. This additional hypothesis allows another method of estimating this length, provided that the natural mortality of juveniles is also constant and that all the postspawners die.

There are two features of the effects of a length-dependent maturity scale on the acoustic estimate (see Tables 3 and 4). The maturation length determines the age composition of the potential spawners. This was previously applied to estimate the maturation length by comparison with the age composition data derived from the catches in March. The maturation length will, however, also determine the abundance estimates of juveniles at age and thus the mortality estimates derived from comparative abundance estimates of yearclasses by year, provided that the spawners die. An overall maturation length and corresponding M-value for juveniles can thus be found by selecting those which best fit the observations over a period of years. This has been done for the period 1973-1980, which resulted in a overall spawning length of 13.8 cm and a M=0.68 (0.057 per month). This estimate is close to the smallest maturation length obtained by comparing age composition of expected spawners with the March catches. This is consistent with the view that the use of the March catches, as representative for the spawners, overestimates the maturation length according to the strength of later spawners (summer spawners) because this component may often consist of younger fish (Prokhorov 1965). The overall estimates of maturation length and M were therefore considered the most realistic estimates for use in assessment of long term yield (Hamre and Tjelmeland 1982).

Due to mass mortality of postspawners, the stock-recruitment relationship of capelin is a matter of great importance in determining the MSY. This relationship has been studied on the basis of estimated spawning indices of the yearclasses 1974 to 1978 and corresponding indices of recruitment measured as the abundance of the yearclasses of two-year-olds. The spawning stock indices are derived from the acoustic stock measurements separating mature and immature components by an overall maturation length of 13.8 cm. The overall estimate, M=0.68, is applied both for the juveniles and for the maturing part of the population. The calculated indices of stock and recruitment by yearclasses are plotted in Figure 2. These data were fitted to a Beverton and Holt recruitment function and the relevant parameters calculated. A function relating the recruitment to stock size was thus obtained, and implemented in the yield model.

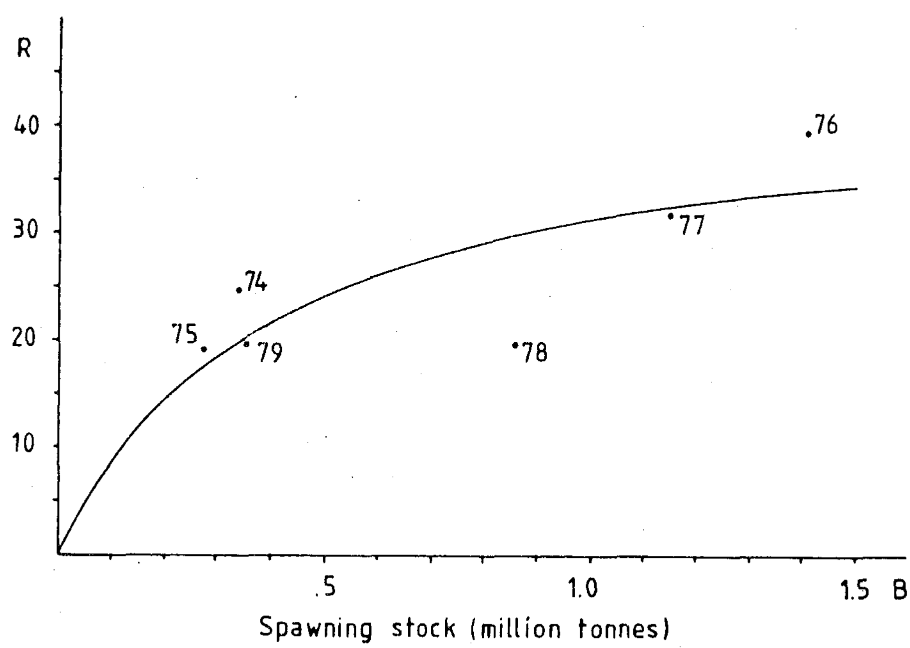

Figure 2. Stock-recruitment relationship of Barents Sea capelin. The solid line shows the function $R = \frac{44.5 \cdot B}{0.43 + B}$, where R = recruited individuals x 10^{10} and B = spawning stock biomass in mill. tonnes.

In addition to recruitment, the growth rate of capelin is of particular importance to the sustained yield because the length dependent maturity makes the mortality of spawners growth dependent.

The effects on the obtainable yield of capelin by a variable growth pattern is thus rather complex and a further gain in knowledge of these processes demands skilled field observation and modelling of the population dynamics. Another feature of growth characteristics of great importance to fishery management is knowledge of the relationship of growth to external factors, which may help to predict a possible change in the future growth pattern. These are areas of current research which will be discussed in a later session of this symposium (Gjøsæter 1984, Gjøsæter and Loeng 1984).

As to details of the growth function used in the capelin model, reference is made to the model documentation (Tjelmeland 1984). Augmented by a modelled fishing pattern, the model calculates yield and corresponding spawning stock as a function of the total fishing mortality F. Running the model until the equilibrium stock and catch are reached, the relevant data to construct the yield curve are obtained. Yield curves for two specific fishing pattern are shown in Figure 3. The figure also includes curves showing biomass output of M (biomass of capelin suffering natural death, excluding death of postspawners).

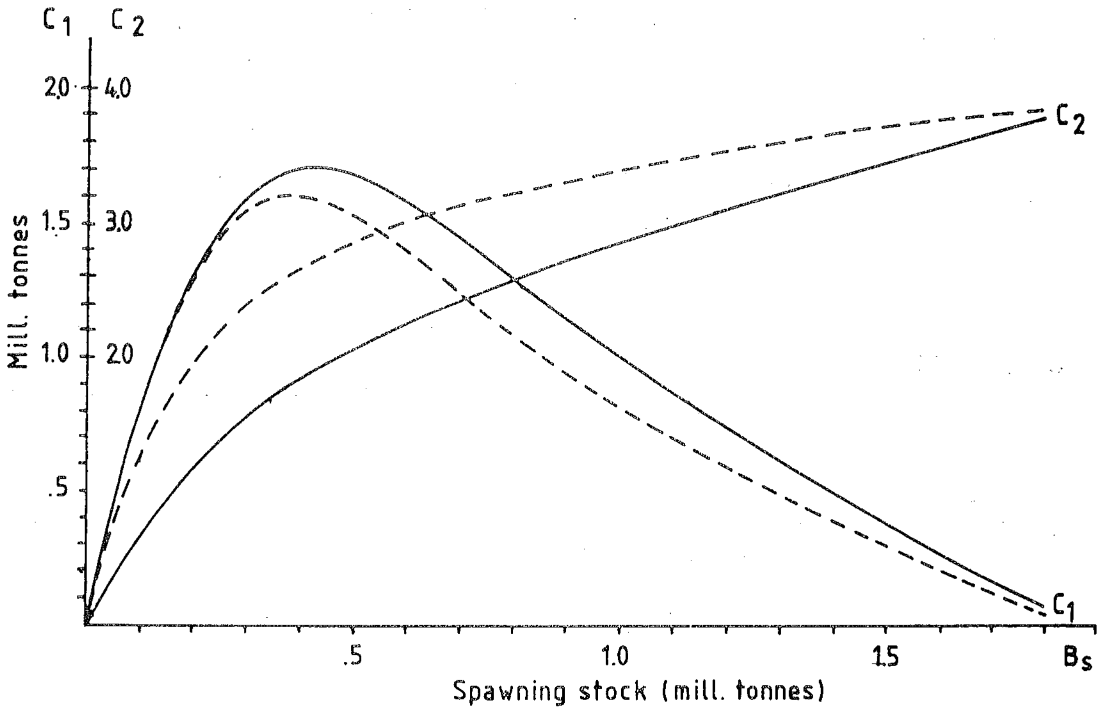

Figure 3. Sustainable yield (C_1) and M-output biomass (C_2) for Barents sea capelin at different levels of spawning stock (B_S). Broken lines apply to winter fishing only, solid lines autumn fishing only.

Figure 3 illustrates the estimates of sustained yield (C_1) and biomass output of M (C_2) by season as a function of the spawning stock. The two extreme cases are chosen for this illustration: (a) autumn fishery only (solid line) and (b) winter fishery only (broken line).

The yield curve (C_1) in the figure shows that the MSY is obtained by fishing the capelin in autumn and by an exploitation corresponding to a steady state of spawning stock of 450 000 tonnes. With similar growth and recruitment relationships as for the 6 yearclasses under study (Figure 2), this MSY amounts to 1.7 mill. tonnes. The MSY is reduced to 1.6 mill. tonnes if the whole catch is taken during the winter season (10% reduction), and is obtained by a constant spawning stock of 400 000 tonnes. It is noted that with a range of 300 000 to 500 000 tonnes of spawning stocks, the sustained obtainable yield is close to maximum for the two fishing patterns. This may justify the adopted TAC strategy for capelin which aim at a steady state of spawning stock of 500 000 tonnes.

The capelin is an important food resource for other exploited stocks in the Barents Sea. In a management context, it may therefore be of interest to know the effects of various fishing strategies on the capelin stock as a food supply to other animals. As illustrated by the M-output curves (C_2) it is seen that by managing an exclusive autumn fishery with a MSY strategy, some 2.0 mill. tonnes of capelin remains as food for other stocks, excluding the biomass of postspawners (450 000 tonnes). However, the importance of the stock as foodfish increases to some 2.5 mill. tonnes of capelin when the catch is taken during the winter only. One may therefore conclude that an increased autumn TAC of capelin at the cost of the winter catch will increase the obtainable yield slightly, but this strategy will substantially reduce the stock as food resource for other animals.

7. ALLOCATION OF TAC ON SEASONS

The allocation key of the yearly TAC on seasons is determined when the next year's allowable autumn catch is negotiated. The scientific advice on the autumn TAC is derived from a spawning stock prognosis one and a half years in advance and is subject to errors which may be corrected after the next year's survey. The assessment is therefore regarded as preliminary, and only used as a guideline for assessing the autumn TAC. As a safe-guarding measure, the 1980 autumn TAC was recommended to be set at a lower level than the subsequent winter catch. In later years, however, the practice has been to assess the autumn TAC as the half of the preliminary assessed TAC for the next regulation period. This allocation key is acceptable if the stock prognosis for the next year tallies, but the shortcomings arise when the autumn TAC is derived from a too optimistic stock prognosis, as happened in 1982. The 1983 USSR/Norwegian meeting of scientists in Hammerfest had a profound discussion of this problem, and proposed to return to the 1980 agreement to set autumn TAC below that of the subsequent winter. This would lower the risk of overfishing the young age-groups in years when the maturing stock is relatively small and reduce the negative effects of a autumn TAC derived from a too optimistic abundance estimate (Anon 1983). In spite of this advice, the USSR/Norwegian Fishery Commission increased the recommended autumn TAC for 1984 substantially, probably to compensate for the poor 1984 winter catch. This increased TAC will, however, reduce the next year's winter TAC correspondingly, resulting in a similar need for catch compensation in 1985. This may develop into a vicious circle, in which the autumn catches are increased at the expense of the winter catches. It should be noted that this sequence of events were experienced during the collapse of the Icelandic capelin stock in the early 1980's. The recent developments in the exploitation pattern of the Barents Sea capelin are therefore regarded with concern.

8. AREAS OF CURRENT RESEARCH

The development of the bio-acoustic stock abundance measurement techniques have had highest priority in the research activity on capelin since the early 1970's. Research on population behaviour, general biology and population dynamics has, however, developed gradually as relevant data and observation became available, mostly through the acoustic surveys. Apart from the acoustic surveys, the most important areas of current research, with direct reference to fishery management problems are:

1. Research on multispecies relationship. Research on overlap in distribution areas of herring and capelin in the Barents Sea. Grazing and food competition research. Predator - prey relationships to other stocks (cod, haddock, main mammal stocks).

2. Maturity and growth studies. Investigation of the maturity scale which may predict spawning time. Research on the inter-relationship between growth and maturity. Research on growth characteristics as basis for growth prognosis. Research on growth patterns (otolith studies) as basis for unit stock analysis.

3. Investigation of stock structure. Assessment of late spawners (summer spawners). Investigations in their biology and their relationship to the winter spawners.

4. Population modelling. Updating of parametres. Modelling the population dynamics of capelin by sexes. Modelling the multispecies relationship.

Research activities related to these topics should be given high priority in the current research program on the Barents Sea capelin stock.

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